Innovative Technology Summary Report

DOE/EM-0542

Spectral Gamma Probe

Characterization, Monitoring, and Sensor Technology Crosscutting Program and Subsurface Contaminants Focus Area

Prepared for
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Spectral Gamma Probe

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Characterization, Monitoring, and Sensor Technology Crosscutting Program and Subsurface Contaminants Focus Area

Demonstrated at
Savannah River Site
Aiken, South Carolina

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine whether a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://ost.em.doe.gov under "Publications."

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SECTION 1

SUMMARY

Technology Summary

Problem:

Past practices at several U.S. Department of Energy (DOE) sites have contaminated groundwater and soils with radionuclides. Development of cost-effective characterization and monitoring technologies for these contaminated sites is a high priority environmental restoration need within the DOE.

How It Works:

An innovative Spectral Gamma Probe designed for *in situ* detection of radionuclides was developed by the U.S. Army Corps of Engineers Waterways Experiment Station (WES) under the sponsorship of the U.S. Department of Energy. The enhanced Spectral Gamma Probe is intended for use as a site characterization tool at DOE waste sites containing radionuclides in the subsurface.

The enhanced Spectral Gamma Probe consists of a gamma radiation detection system that is driven into the subsurface using a Site Characterization and Analysis Penetrometer System (SCAPS) or other cone penetrometer truck. The sensor uses a NaI (sodium iodide) scintillation crystal to detect gamma radiation in the subsurface at the probe tip. Gamma rays emitted by the radioactive waste are collected and this energy spectrum is analyzed to identify radioactive constituents and their relative concentrations.

Figure 1. The DOE SCAPS cone penetrometer system at the Savannah River Site (SRS) during the evaluation of the spectral gamma probe at the R-reactor seepage basins.
Potential Markets:

The enhanced Spectral Gamma Probe was specifically designed for site characterization at DOE waste sites containing radionuclides in the subsurface.

Advantages over baseline:

In situ measurement of specific radionuclide concentrations can potentially result in significant reduction in the cost of characterization of hazardous waste sites with radioactive contamination. Currently sediment or soil samples are collected, taken to the laboratory, and counted with standard nuclear industry techniques. The Spectral Gamma Probe offers numerous advantages over the baseline primarily because the data are gathered *in situ*. Specific advantages include:

- Cost savings

  --For a demonstration at the Savannah River Site (SRS) R-Reactor Basins, the actual cost savings during collection of 180 measurements using the Spectral Gamma Probe system was $800,000.

  --Measurements with the gamma probe had a cost of $3,509 per sample compared with a cost of $7,961 for the baseline method.

  --Analysis shows that use of the Spectral Gamma Probe is more economical for site characterization where more than 30-35 samples are to be collected.

- Reduction in the generation of secondary waste during sample collection, analysis and disposal.

- Elimination of the need for transportation of hazardous radioactive samples to the laboratory for analysis.

- Reduction in the risk of human exposure during sample collection and analysis.

- Reduction in the turn-around time for sample analysis.

Demonstration Summary

The spectral Gamma Probe was evaluated at the R-Reactor Seepage Basins at the SRS in South Carolina during 1997 for its ability to provide quantitative measurements of gamma radiation *in situ* in the subsurface. The Spectral Gamma Probe was tested for its ability to measure cesium-137 (Cs-137) in the presence of other subsurface radioactive contaminants. A total of nine CPT pushes were conducted in seepage basins near the R-reactor. The data from these nine holes were from three different basins and were compared to laboratory measurements on core material collected from each of the same three basins.

The demonstration showed that Cs-137 activity measured with the spectral gamma probe was comparable to the laboratory measurements. In addition,

- Areas of gross radioactive contamination were easily detected in the field.

- Semi-quantitative results for Cs-137 could be determined directly in the field. Due to the analytical interference caused by large quantities of strontium, post-processing of the data was necessary for precise quantification of the Cs-137.

- Significant operational problems were not encountered during the evaluation.

- A decontamination system for the rod system designed by SRS Environmental Restoration for the demonstration performed well allowing workers to work with modified Level D protection.

- The actual cost savings for the collection of 180 measurements using the Spectral Gamma Probe system was $800,000. The per sample cost was reduced by approximately fifty percent.

The evaluation of the Spectral Gamma Probe was completed as part of the Characterization, Monitoring, and Sensor Technology Crosscutting Program for testing and evaluating sensors and tools for the cone penetrometer and was partially funded by the SRS Environmental Restoration Department (ANL, 1997a, 1997b). The technology evaluation was conducted by Argonne National Laboratory with support from the Savannah River Technology Center. The technology is currently available from the U.S. Army Corps of Engineers Waterways Experiment Station.

Contacts

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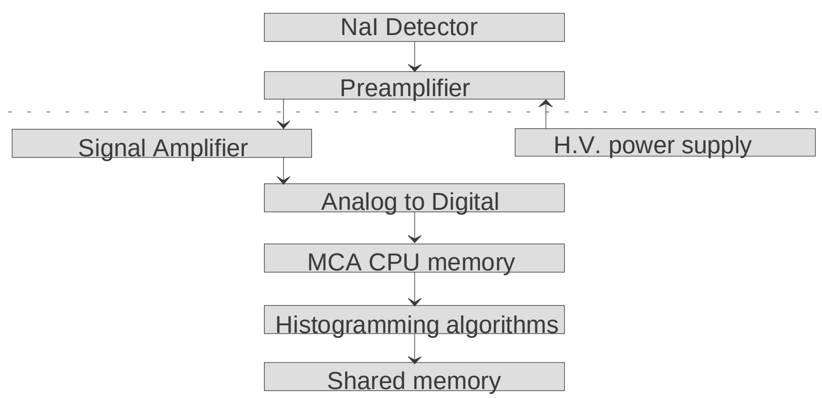
All published Innovative Technology Summary Reports are available on the OST Web site at http://em-50.em.doe.gov under "Publications." The Technology Management System, also available through the OST Web site, provides information about OST programs, technologies, and problems. The OST Reference number for the Enhanced Spectral Gamma probe is 2364.

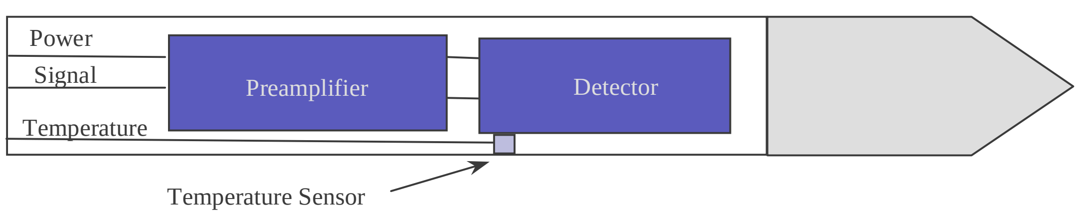
SECTION 2

TECHNOLOGY DESCRIPTION

Overall Process Definition

Demonstration Goals and Objectives: The goal of the demonstration at the SRS R Reactor Basins was to assess the capability of the spectral gamma probe to measure Cs-137 contamination in the subsurface. The data gathered with the gamma probe was compared with laboratory analyses from core material sent to off-site laboratories.





Technology Description:

Figure 2. Schematic Diagram of the Enhanced Spectral Gamma Probe

The spectral gamma system consists of sensor deployed in subsurface with the cone penetrometer rods and a data acquisition system at the surface (Figure 2). The downhole system consists of a sodium iodide (NaI) detector, containing a 1.0-inch by 3.0-inch cylindrical NaI crystal and photomultiplier tube; a temperature sensor; and a custom-designed preamplifier. It is necessary to monitor temperature because thermal changes in the detector can result in changes in spectra. The data acquisition system is equipped with industry-standard, rack-mounted nuclear instrument modules (NIMs) capable of data processing and storage. A spectroscopy amplifier splits the signal to the multichannel analyzer (MCA) buffer and to the ratemeter. The data acquisition system is a NIM-mounted 16-bit MCA buffer with an onboard 68010 central processing unit (CPU).

System Operation

The spectral gamma probe is deployed with a cone penetrometer truck. As the CPT rods are advanced into the ground, the probe transmits analog signals, which are recorded in the data acquisition system.

- Temperature and count rates are digitized on two channels of the truck's probe control data acquisition system. The results are viewed with a temperature correction/display program made available across a local area network (LAN) within the truck.

- The gamma probe detects radiation and provides count data in two different ways. A number for gross counts per second is provided in real time by the rate meter on the MCA. An automated data processor (ADP) collects counts by energy level and is used to differentiate radionuclides. The ADP provides real time data in the form of a graphical representation of the spectrum while count data are collected.

- Operational software was developed to allow improved identification and quantification of isotopes. This software creates a data display in real time while the push is in process. Raw spectral data are viewed in real time through the MCA software, but corrected data must be viewed through the program that does the correction. Once the probe is stationary, the software collects data over a selected time interval. The data are then corrected for temperature variation and are available for viewing in quasi-real time. Longer counting intervals increase the sensitivity of the system up to a certain limit. The maximum effective time and the sensitivity limit are functions of the system specifications and the local conditions of the test area.

- As the CPT rods are retracted, grout is injected effectively sealing the hole.

- The data reduction process for quantitative results is lengthy and requires a trained nuclear physicist to perform the calculation. An automated data reduction program is under development.

Advantages of CPT technologies include a significant reduction in secondary waste handling requirements. At the R-reactor seepage basin demonstration, the number of waste drums was reduced to one compared with seven generated during comparable drilling activities.

- The use of CPT and *in situ* measurement eliminates the requirement for sample collection, transportation and analysis.

- The use of the spectral gamma probe results in a significant reduction risk of human exposure during sample collection and analysis. A decontamination system for the rod system designed by SRS Environmental Restoration for the demonstration performed well, allowing workers to work using only modified Level D protection.

SECTION 3

PERFORMANCE

Demonstration Plan

The spectral gamma probe was evaluated at the R-Reactor Seepage Basins at the Savannah River Site, near Aiken, South Carolina. The probe was deployed in three of the six seepage basins that were constructed and operated between 1957 and 1964. In 1957, a fuel element failure in the reactor disassembly basin resulted in approximately 2,700 curies (Ci) of radioactivity being discharged into Basin 1, with overflow going to the other basins. By 1997, all of the basins had been backfilled and sprayed with asphalt. In late 1996, the basins and surrounding area were capped with additional soil and approximately 6 inches of asphalt paving.

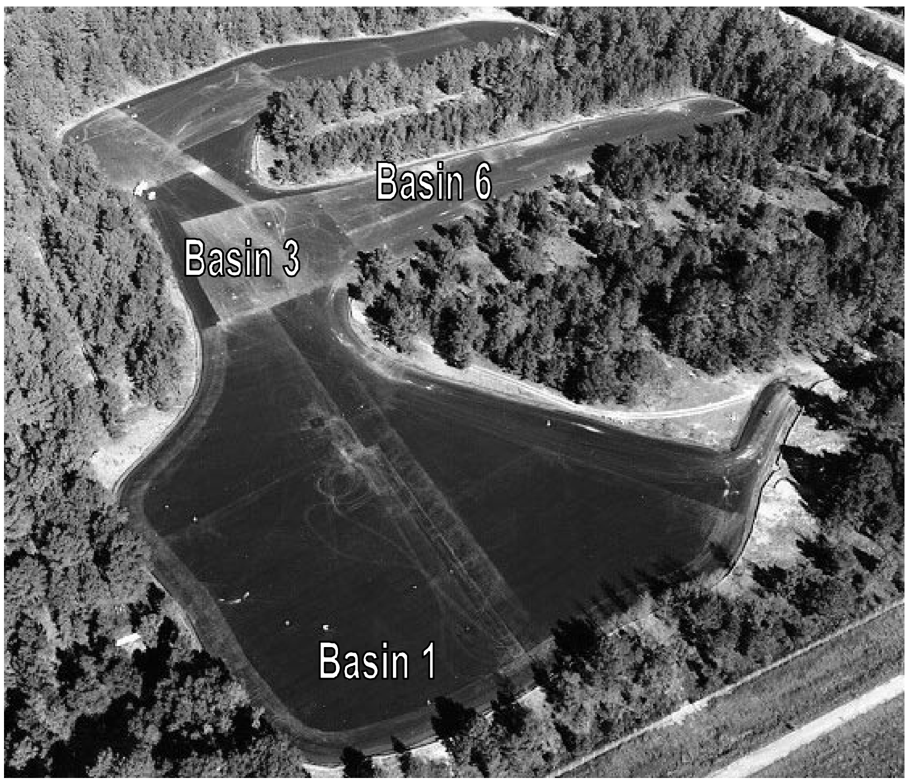


Figure 3. Aerial Photo of the R-Reactor Seepage Basins showing the approximate locations of sampling locations under the asphalt cover installed in 1996.

The technology evaluation of the spectral gamma probe was conducted at SRS from May through July 1997. The specific objective was to assess the capability of the spectral gamma probe to provide accurate measurements of Cs-137 contamination in the subsurface. A detailed work plan documents the evaluation activities (ANL, 1997b).

- The spectral gamma results were compared with the laboratory analytical results from soil samples collected in 1995 obtained by using a hand auger. Two-foot increments of soil were composited, and the analyses were performed on the composited sample; thus, the measured contamination was an average of that found within the 2-foot soil sample. This procedure eliminates variations present at a scale of less than two feet.

- In each of three basins (Basin 1, Basin 3, Basin 6), three gamma probe pushes were clustered around a hand-augered sample collection location.

- The gamma probe was calibrated by placing 1-µCi Cs-137 and Co-60 sources on the probe and counting for approximately 20 minutes. The laboratory-determined radius of influence for the gamma probe was 8 inches.

- During a push, counts were taken at 1-foot intervals in background zones and at 3-inch to 6-inch intervals as the zones of expected contamination were reached. Allotted counting times varied from 10 minutes to 45-60 minutes.

- One push at each basin was begun as shallow as 1-2 foot below the ground surface to obtain a complete profile, to obtain background data for the basin, and to ensure that no contaminated fill was present. Each push started at least 2-feet above the expected zone of contamination. The ratemeter was monitored for gross counts per second as an indication of overall radioactivity.

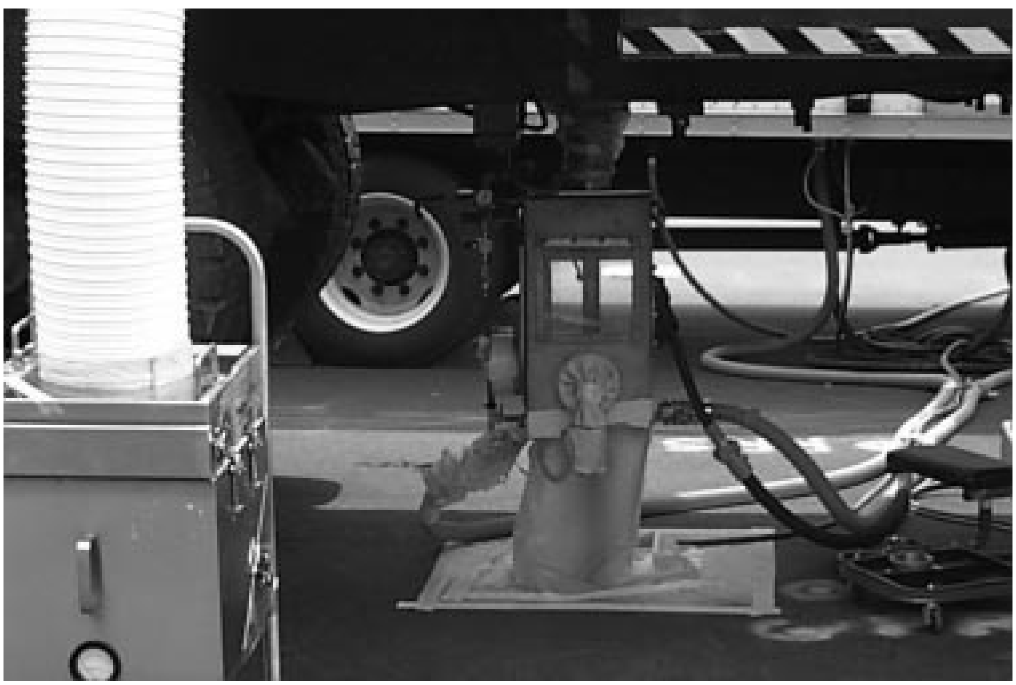


Figure 4. Glove box decontamination system designed for the SCAPS truck.

- A decontamination system was built to ensure that radioactivity adhering to the sample rods was not brought into the truck. A decontamination chamber was built, attached below the truck, and was used to clean the CPT rods. Removal of the soil particles from the rods was accomplished by a plastic blast system that is similar to sandblasting with small plastic beads.

Results

The *in situ* measurements made with the spectral gamma probe were found to be comparable to the laboratory measurements on the core samples. The results from the evaluation are provided in detail in ANL 1997a (see Appendix A). Figure 5 compares the field results with the laboratory measurements made on core collected from Basin 6. The bounding corners of the shaded box in Figure 5 are the laboratory measurements on soil samples composited over a 2-foot interval. The data from the three pushes with the spectral gamma probe are plotted for comparison. Similar results were obtained at Basins 1 and 3.

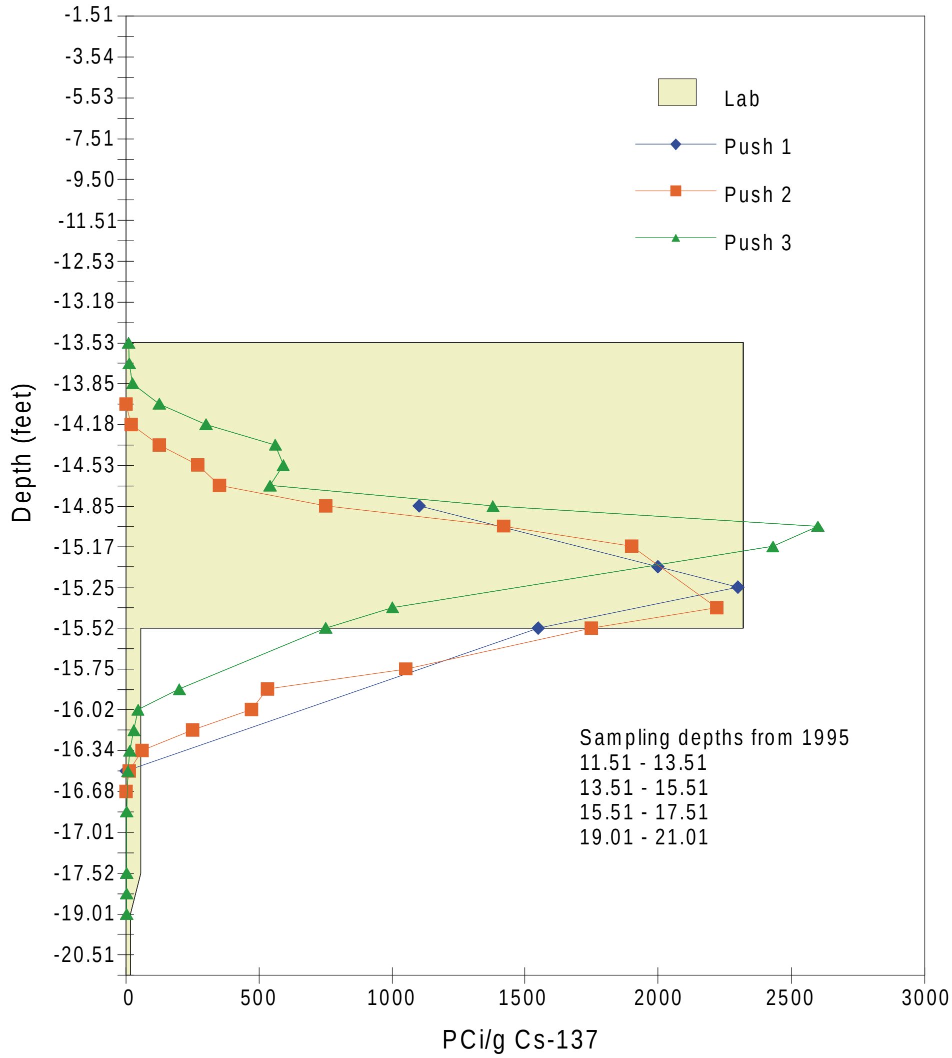


Figure 5. Field measurements of Cs-137 levels from Basin 6 (after ANL, 1997a).

In summary, the results of the ANL evaluation are:

- The spectral gamma probe provides a more detailed profile of the contamination than the baseline methods. The sampling interval for the gamma probe varied from 3-inch to 1-foot intervals. At these sampling intervals, the probe was stopped for counting. The laboratory analyses were done on sediment samples that were composited over a 2-foot interval. The peaks of activity determined by the probe generally fell within the peaks of activity as measured by the laboratory analysis (Figure 5). The gamma probe was also able to detect areas of activity not identified by the grosser sampling method used for the laboratory analysis.

- The lower limit of detection (LLD) for Cs-137 appears to be approximately 5 pCi/g. Weaker gamma emitters will have higher LLD. The density and moisture content of the soil also affect the detection limit. In Basin 3, the Cs-137 level was calculated at 1 pCi/g. This value corresponds with laboratory data of 0.0487-6.32 pCi/g. Additional testing will be required to define the LLD for Cs-137 and other radioisotopes.

- Some areas in Basin 1 and Basin 3 were contaminated to the extent that they exceed the dynamic range of the sensor, which was designed for detection of low-level activities. In addition, the gross count rate was extremely high due to the high levels of strontium and other beta emitters.

- Total counts per second included lower-energy activity resulting from high levels of strontium and other beta sources in Basin 1 and Basin 3. The ADP was set to filter out the lower-energy counts. This discrimination generally resulted in fewer gross counts per second from the ADP than from the ratemeter as observed in the field.

- The decision was made not to use an ECPT cone to measure tip and sleeve pressure to avoid problems with contamination. ECPT data might have aided in the interpretation of the results in that there were indications that the soil was not as uniform as had been assumed. The lack of soil density data complicated the interpretation of the gamma data.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

Baseline Technology

The baseline method for measurement of radionuclides in contaminated sediments requires collection of samples that must be transported to a laboratory and analyzed with standard nuclear industry counting techniques. The advantage of the baseline approach is that it provides a high degree of precision and accuracy; however, it is extremely costly and presents numerous risks associated with collection, transport, and analysis of highly radioactive samples.

Since the distribution of contamination is not homogenous at most waste sites, a large number of samples is typically required to accurately delineate the extent of contamination. Due to the high cost per sample using the baseline method, budgetary constraints will limit the number of samples collected and analyzed. In many cases this may result in inadequate site characterization and that can lead to the design and implementation of suboptimal remedial systems.

Other Competing Technologies

No other technologies are currently available that can be used for *in situ* measurement of radionuclides. Other more costly gamma radiation sensors are available, but have not been adapted for use with the cone penetrometer.

Alternative Innovative Approach

An alternative innovative approach to the baseline sample collection and analysis would be to use CPT or drill rigs to retrieve samples to the surface for immediate analysis with field analytical techniques. This approach would present additional hazards to site personnel, would require waste handling, and would not allow continuous measurement. The advantage of this approach would be to reduce the counting times for some low-level compared with the *in situ* method.

Technology Applicability

Other Potential Applications

This technology can be used anywhere to characterize underground gamma radioactivities assuming that the subsurface is conducive to CPT exploration and characterization.

The parameters that were considered for the present application are the same as those to be considered for other applications, and include the level of background radiation as well as the ability to penetrate the soil with CPT.

Scale-Up Requirements

The use at the R-Reactor Basins at SRS required only relatively shallow measurements. Pushing to greater depth (e.g., > 40m) or pushing in sites with challenging geology may require use of a heavier CPT truck and/or the use of the sonic head. The gamma probe does not offer any scaling opportunities for increasing the volume of soil to be assayed or the speed of measurement.

Future Technology Selection Considerations

The sensor used a sodium iodide (NaI) scintillation crystal, which has relatively high detection efficiency but has relatively poor energy resolution. The selection of higher resolution detectors, i.e., high purity germanium detectors, should be considered (See Section 7). A germanium sensor has not yet been used in downhole applications because it must be cooled to liquid nitrogen temperatures.

Patents/Commercialization/Sponsor

The Spectral Gamma Probe was developed under U.S. Department of Energy funding at the U.S. Army Corps of Engineers Waterways Experiment Station. Argonne National Laboratory, the Special Technologies Laboratory, and the Savannah River Technology Center made contributions leading to the success of the program.

SECTION 5

COST

Introduction

This cost evaluation of a field demonstration of the spectral gamma probe was prepared in 1997 for this report by MSE of Butte, MT. The analysis uses actual costs generated during the evaluation and demonstration of the technology conducted at the DOE Savannah River Site as part of the Characterization, Monitoring and Sensor Technology Program's cone penetrometer evaluation program. The evaluation of the probe was funded by the DOE Office of Science and Technology and the SRS Environmental Restoration Department.

Methodology

The baseline technology used for this comparison is the collection of soil and sediment samples sent to an offsite laboratory for analysis. Two laboratories that currently provide radionuclide analysis include General Engineering Laboratories and Roy F. Weston, Inc.

Basic assumptions for the cost analysis of the spectral gamma probe technology include:

- The baseline technology and the gamma probe will be evaluated for 180 events (the number of events completed during the actual demonstration);
- An event is defined as collecting spectral gamma data at a selected depth during one cone penetrometer push for the gamma probe or one core sample for the baseline;
- Capital costs are not associated with the baseline, i.e., analysis of the samples will be provided as a service by a contract laboratory.

Cost Analysis

Capital and Annual Operating Cost Analysis

Spectral gamma probe analysis costs include the capital cost and the operating cost associated with the purchase and operation of the gamma probe and operation of a CPT by a vendor. Cost information developed during the demonstration of the gamma probe technology was combined with cost data from past experience to produce a more realistic scenario. Tables 1 and 2 summarize the costs for the two approaches.

- Capital Cost
  – Capital costs are not associated with the baseline because analysis of samples is typically available from commercial vendors as a service on a cost per sample basis.
  – Capital costs for the spectral gamma probe include procuring the CPT truck, probe, decontamination equipment, and miscellaneous items.
- Sample Collection
  – A drill rig or other type of mechanical extraction was not used during collection of the baseline samples due to risk of personnel exposure and the complexity of decontamination of equipment. The samples were collected with a hand auger.
  – The gamma probe requires a CPT system and labor to perform sample analysis.

- Operational Costs

  – Since the gamma probe does not bring sediment to the surface, the amount of waste generated by the CPT and operational costs associated the protection and safety of personnel when extracting, transporting, and analyzing a core sample with were significantly reduced.

  – Through the three-month trial at the Savannah River Site, one drum was sufficient to handle the decontamination waste. If the baseline had been used, seven drums of radioactive waste would have been generated.

  – Costs for analytical testing are the most significant cost in the baseline.

Table 1. Capital cost for the gamma probe system.

Capital Cost	
	Gamma Probe
Probe	$30,000
Decontamination	$151,600
Miscellaneous	$6,000
Total	**$187,600**

Table 2. Operating cost for baseline and gamma probe technology.

Operating Cost (based on 180 sampling events)		
	Gamma Probe	Baseline
Labor	$144,000	$648,000
Rig Rental	$300,000	$0
Personal Protective Equipment	$0	$135,000
Transportation	$0	$45,180
Analytical Tests	$0	$594,000
Returned Waste Handling	$0	$10,800
Total (based 180 events)	**$444,000**	**$1,432,980**

Effect of Event Quantity on Cost

Figure 6 is a plot that shows project cost per event as a function of the number of events. The number of events was varied from 0 to 200. The graph depicts more clearly depicts a comparison between the average costs of the baseline to the spectral gamma probe. The spreadsheet model was generated using demonstration data in addition to input from SRS personnel based on past experience with the traditional baseline method.

Based on Figure 6, the spectral gamma probe is a more cost effective tool than the baseline technology if the number of sampling events exceeds 35-40 events. Spectral gamma allows extensive collection of data at a successively lower per sample cost until the difference in cost below baseline is approximately $4000/event.

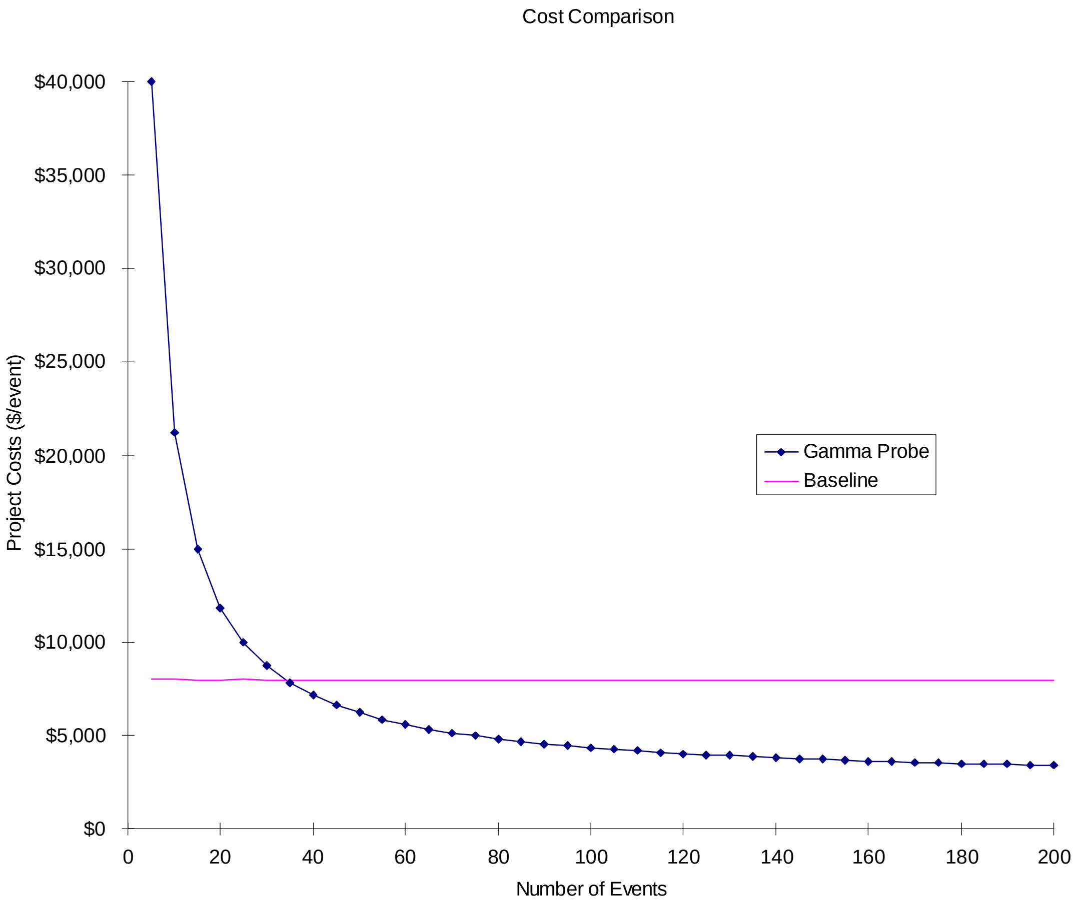


Figure 6. Graph showing total project cost divided by the number of events as a function of the number of events relative to a baseline cost of $7,961 per sample.

Cost Conclusions

The gamma probe has a nominal cost of $3,509 per sampling event evaluated at an operating rate of 180 events. The baseline system has a nominal cost of $7,961 per sampling event evaluated at the same processing rate. Therefore, the gamma probe system has a cost advantage of $4,452 per event. In nominal dollars, the gamma probe system would cost $631,600 to own and operate, and the baseline would cost $1,432,980. Therefore, the cost savings of a spectral gamma probe system would be $801,380 for the specified 180 events.

SECTION 6

REGULATORY AND POLICY ISSUES

Regulatory Considerations

No special permits are required for the operation of a cone penetrometer. Permitting for characterization of a site with the Spectral Gamma Probe should be less stringent than those required for drilling and sample collection since investigation derived wastes are significantly minimized.

Safety, Risks, Benefits, and Community Reaction

All regulatory requirements for use of the Spectral Gamma Probe should be similar or less stringent than those required for the baseline because the method reduces the risk of exposure of workers to hazardous conditions and eliminates the need for collection, shipment, and analysis of samples.

Worker Safety

A significant benefit of the Spectral Gamma Probe system is that it significantly reduces the risk of exposure to hazardous materials by workers because direct push methods are used.

- The hazards associated with the collection and analysis of samples are eliminated.
- The hazards associated with the containment, disposal, and treatment of secondary waste are significantly reduced.
- Crew exposure is minimized because rods are cleaned before they are drawn into the truck.
- Data are collected in a more rapid manner thereby reducing the length of worker's exposure to hazardous materials.

Community Safety

The use of this technology eliminates risk of exposure associated with shipping and analysis of highly radioactive samples.

Environmental Impact

The use of the Spectral Gamma Probe should reduce the environmental impact.

- Drill cuttings or secondary waste is virtually eliminated.
- The penetrometer holes are smaller diameter and can be sealed during retraction of the rods.
- The spectral gamma system can be easily decontaminated with only a small volume of material.

Socioeconomic Impacts and Community Perception

The use of the Spectral Gamma Probe should not have any socioeconomic impacts. Community reaction should be positive due to the use of an environmentally friendly technology.

SECTION 7

LESSONS LEARNED

Implementation Considerations

The use of the spectral gamma probe is currently limited to sites where a cone penetrometer can penetrate the subsurface to the desired depth. Its use will be restricted where contamination is located deep in the subsurface (>50m) and in challenging geologic environments (successes are generally limited to clayey and sandy sediments). Sites that have radioactivity levels that span wide ranges could present problems for quantitative analyses. The present system used at SRS was optimized to measure very low levels of contamination as required by the performance specification for that problem. Measurements made where high radiation levels were present resulted in significant gain shifts in need of significant post-measurement corrections.

Technology Limitations and Needs for Future Development

The NaI detector used in the present spectral gamma probe has a relatively high detection efficiency but has a relatively poor energy resolution and its light output varies with temperature. As a result, it is difficult to resolve gamma-ray peaks when signal-to-background ratios are relatively low. Higher resolution is currently available achievable with a high purity germanium (HPGe) detector, but it cannot be used for downhole applications because it must be cooled to liquid nitrogen temperatures.

Selections to improve future gamma probe sensors might include electronic components that do not undergo gain shifts with either temperature or counting rate and a higher resolution, room-temperature detector. The electronic circuitry is currently available, while a promising candidate for the detector is currently under development. It contains xenon at high pressure (~ 40 atm), operates as an ion chamber, has a detection efficiency slightly less than NaI, but has ~ 5 times better energy resolution. The higher energy resolution is important not only from the viewpoint of separating closely spaced gamma-ray peaks, but also for enhancing signal-to-noise ratios because it includes less background in that calculation. Consequently, even though the detection efficiency of the high-pressure xenon detector (HPXe) is a little less than that for NaI, its higher resolution more than compensates for the loss. The result is that the detection level is lowered and the system performance is raised. Note that the resolution of the HPXe detector does not approach that of HPGe, which is on the order of 0.1%, but it operates at room temperature--a critical factor for downhole measurements.

APPENDIX A

REFERENCES

Argonne National Laboratory, 1997a. Spectral Gamma Probe Evaluation Report, U. S. Army Engineer Waterways Experiment Station, Argonne National Laboratory Internal Report, Argonne, Illinois, December.

Argonne National Laboratory, 1997b. Gamma Probe Evaluation Work Plan, Waterways Experiment Station, Argonne National Laboratory Internal Report, Argonne, Illinois, April.

Morgan, J. C., J. W. Adams, and J. H. Ballard, 1997. Field Demonstration of the SCAPS Cone Penetrometer Gamma Probe for Rad-Waste Detection.

APPENDIX B

ACRONYMS AND ABBREVIATIONS

ADP	automated data processor
ATM	atmospheric pressure
bgs	below ground surface
cps	counts per seconds
CPT	cone penetrometer truck
CPU	central processing unit
Ci	curie
Co-60	Cobalt-60
DOE	U. S. Department of Energy
ECPT	electronic cone penetrometer test
HPXe	high pressure xenon detector
HPGe	high purity germanium (HPGe)
LAN	local area network
LLD	lower limit of detection
MCA	multichannel analyzer
MDL	minimum detection level
µCi	microcurie
NaI	sodium iodide
NIM	nuclear instrument module
pCi	picocurie
SRS	Savannah River Site
SCAPS	Site Characterization and Analysis Penetrometer System
WES	U. S. Army Corps of Engineers Waterways Experiment Station