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THE DEPLOYMENT OF AN INNOVATIVE REAL-TIME RADIOLOGICAL SOIL CHARACTERIZATION SYSTEM

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ABSTRACT

Fluor Fernald Inc., in conjunction with partners from Argonne National Laboratory, the Department of Energy's Environmental Measurements Laboratory, and Idaho National Engineering and Environmental Laboratory, has developed a program for characterizing radiological contaminants in soil in real time. The soil characterization system in use at the Fernald Environmental Management Project (FEMP) for over three years combines gamma ray spectrometry equipment with other technologies to produce a system that can scan large areas of ground and produce color coded maps which display quantitative information regarding isotopic contamination patterns. Software running on a battery powered lap-top computer, is used to control acquisition of gamma spectral data, to link the spectral information with precise detector position measurements from Global Positioning System (GPS) satellites, and to control transmission of data to a central station or van via a wireless Ethernet link where Surfer® 6 mapping software is used to produce maps showing the position and amount of each target analyte. Either sodium iodide (NaI) gamma ray detectors mounted on three different vehicles for mobile measurements or stationary tripod-mounted hyper-pure germanium (HPGe) detectors can be used in this system to radiologically characterize soil. The operational and performance characteristics, as well as the strengths and limitations of each of these units, will be described. The isotopic information generated by this system can be made available to remediation project mangers within an hour after the completion of a scan to aid in determination of excavation footprints, segregation of contaminated soil and verification of contamination removal. The immediate availability of radiological characterization data made possible by this real-time scanning system has allowed Fluor Fernald to accelerate remediation schedules and reduce costs by avoiding excavation delays and expensive and time consuming laboratory analyses. Obtaining actual radiological characterization data from a much greater percentage of the soil under characterization than would be possible with the collection of physical samples has also resulted in more effective remediation of the site. The regulatory climate under which these real-time measurements are performed is briefly discussed.

INTRODUCTION

The United States Department of Energy (DOE) is faced with the huge task of remediating millions of cubic yards of contaminated soil at many sites throughout its nuclear weapons manufacturing complex. The Fernald Environmental Management Project (FEMP), located twenty miles northwest of Cincinnati, is one of these DOE sites currently undergoing remediation. Fluor Fernald Inc. has contracted with the DOE to remediate approximately 2.6 million cubic yards of soil spread over 1200 acres. The primary contaminants of concern include uranium, thorium and radium. Cost effective and timely means of identifying and characterizing contaminated soils are essential to meet remediation schedules and budgets. The selected remedy for the FEMP requires that most contaminated soil be excavated and placed in an engineered on-site disposal facility (OSDF). If material exceeds the waste acceptance criteria

(WAC) of 1030 parts per million (ppm) total uranium for the OSDF, it must be shipped to an approved off-site disposal facility.

To address this problem, Fluor Fernald, in conjunction with partners from Argonne National Laboratory, DOE's Environmental Measurements Laboratory, and Idaho National Engineering and Environmental Laboratory, has developed and implemented a program for characterizing radiological contaminants in soil in real time. This real-time soil characterization system has been in use at the FEMP for over three years. It involves in-situ gamma spectroscopy equipment to perform spectral measurements, Global Positioning System (GPS) equipment to determine the coordinates of each measurement, data display software to enable field technicians to view position and activity measurements immediately on a computer displayed map of the scan area, and wireless Ethernet equipment to transmit results in real-time for generation of hard copy reports and color coded maps. Real-time processing of the data includes acquisition of gamma spectral and position data, analysis of spectra to obtain net counts per second and isotopic activities from selected spectral regions of interest and conversion from wet weight to dry weight radionuclide concentrations on the basis of in-situ soil moisture measurements. This system can scan large areas of land and can generate summary reports and maps which display quantitative information regarding isotopic contamination patterns within an hour after completing the scan.

The purpose of this presentation is to provide an overview of the real-time soil characterization program at Fernald. The specific equipment used at Fernald (both hardware and software) and some key programmatic elements will be described to guide others wishing to start this type of program. Specific equipment is mentioned purely to serve as a starting point in the preparation to establish such a program. Alternative hardware and software products with similar capabilities are available from other vendors. While the regulatory environment at each site will be different, serious consideration should be given to quality assurance and data defensibility during the setup of an in-situ measurements program.

EQUIPMENT

Several different kinds of "off-the-shelf" equipment have been combined to create an integrated real-time soil characterization program. Gamma spectrometry equipment provides radionuclide measurements. GPS equipment identifies the location of these measurements. Data transfer from the field is accomplished with wireless Ethernet equipment. Computer software is used to control and link together the processes of data acquisition, data reduction, quality checking of data, summary report generation, and contaminant mapping. By minimizing manual data manipulation, the soil characterization process is greatly expedited. Soil characterization decisions can be made in the field, without having to wait for the collection and laboratory analysis of physical samples. The controlling software is called LabView™, which is a graphically based software development environment, developed by National Instruments Inc. for controlling laboratory instruments. The LabView™ environment provides the software engineer with the ability to generate sophisticated displays, communicate with hardware modules using common protocols, create instrument operational sequences, and perform various file handling functions. LabView™ uses "virtual instruments" (VIs), which are the equivalent of program subroutines in conventional computer language, to acquire GPS position data, collect and analyze gamma ray spectra, transfer data to a local area network for retrievable storage, and provide lap-top computer displays for feedback to field technicians in real-time.

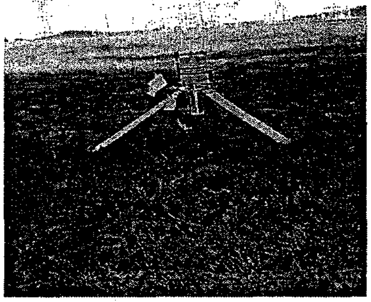
High Purity Germanium Detectors (HPGe)

One facet of the real-time measurements program at the FEMP involves high-resolution gamma spectrometry measurements with HPGe detectors. The detectors used at Fernald are EG&G ORTEC GAMMA-X® detectors in a PopTop™ configuration. They are low background n-type HPGe detectors with a 5-liter liquid nitrogen dewar and a thin beryllium window, giving them a useful energy range of 3 Kev to 10 Mev. Typical detector characteristics and routine measurement parameters are listed in Table I. Figure 1 contains pictures of all the Fluor Fernald in-situ measurement systems including an HPGe detector. DART multichannel pulse height analyzers (MCA), which are manufactured by EG&G ORTEC, are used to collect 8192 channel spectra with a typical gain of 0.375 Kev per channel. After spectral acquisition, LabView™ initiates transfer of the data from the MCA to a lap-top computer where conventional gamma spectral analysis is performed. This includes location of peak centroids, integration of net peak areas, nuclide identification, calculation of radionuclide concentrations in the soil, correction of results for moisture content of the soil, and generation of a report that lists analysis results on a dry weight basis. Two gamma analysis software packages are available at the FEMP to perform these functions: either GammaVision™, an EG&G ORTEC product, or EGAS™, supplied by an independent subcontractor. Multiple HPGe detectors can be set up at different locations and operated independently, or they can be controlled from a remote central location such as a field operations center housed in a van. During these operations, the LabView™ software is used to insert GPS position and soil moisture measurements into the sample description in the gamma spectrometry files, and to create electronic field worksheets, which serve as logs describing the data collection activities. Upon completion of data acquisition by each HPGe detector, the data are transferred via wireless Ethernet transmissions to the field operations center for data quality review, report generation and mapping, and transfer to archival storage.

TABLE I
DETECTOR CHARACTERISTICS AND OPERATING CONDITIONS

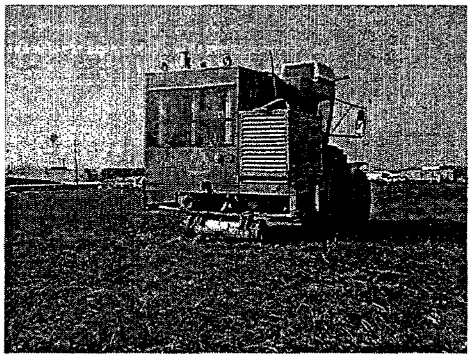
Performance Characteristic	HPGe Detectors	Sodium Iodide Detectors
Detector Height / Field of View	100 cm / 113 m^2	31 cm / 4.5 m^2 static 31 cm / 8.8 m^2 mobile
	31 cm / 19.6 m^2	
	15 cm / 3.1 m^2	
High Voltage	- 3000 to –4000 volts	+600 to +800 volts
Count Time	5 to 15 minutes	4 seconds
Vehicle Speed	N/A	1 mile per hour
Efficiency	70% to 80% relative	10:1 relative to 3"x3" NaI
Resolution	2.2 to 2.4 Kev @ 1332 Kev	7% to 8% @662 Kev
Minimum Detectable Concentration	Total U 5.5 ppm	Total U 63 ppm*
	Th-232 0.12 pCi/g	Th-232 0.91 pCi/g*
	Ra-226 0.14 pCi/g	Ra-226 1.1 pCi/g*

* Values in table are based on a single 4-second RTRAK measurement.



HPGe Detector

Radiation Tracking System - RTRAK



GATOR

Radiation Scanning System - RSS

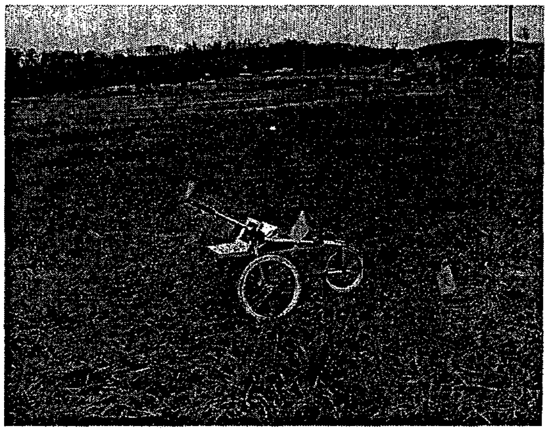


Figure 1: Fluor Fernald In-Situ Measurement Systems

The primary contaminants of concern at the Fernald site are total uranium (i.e. U-238), Th-232 and Ra-226. The characteristic gamma energies used to quantify these isotopes are shown in Table II. This system is flexible enough to provide accurate concentrations for any isotope with one or more prominent gamma emissions. The gamma analysis software reports an error-weighted average result when more than one of the characteristic peaks for a given radionuclide is identified.

TABLE II
GAMMA RAYS USED DURING IN-SITU SOIL MEASUREMENTS TO QUANTIFY U-238, Th-232 and Ra-226

Analyte Radionuclide	HPGe Detectors			Sodium Iodide Detectors		
	Radionuclide of Emission	Gamma Energy Kev	Gamma Abundance %	Radionuclide of Emission	Gamma Energy Kev	Gamma Abundance %
U-238 or Total U	Th-234	63.2	3.9	Pa-234m	1001	0.845
	Th-234	92.6	5.41			
	Pa-234m	1001	0.845			
Th-232	Ac-228	338.4	11.7	Tl-208	2614.4	35.86*
	Tl-208	583.1	30.6*			
	Ac-228	911.1	29.0			
Ra-226	Pb-214	351.9	35.0	Bi-214	1764.5	15.8
	Bi-214	609.3	43.0			
	Bi-214	1120.4	17.0			

* Includes a 0.359 branching for the decay of Bi-212

Mobile Sodium Iodide Detectors (NaI)
Another facet of the Fernald real-time measurements program involves low-resolution gamma spectrometry with 4-inch by 4-inch by 16-inch sodium iodide detectors hermetically sealed in aluminum housings. These detectors, manufactured by Alpha Spectrum Inc. and Bicron Inc, are coupled to a 3.5-inch diameter photomultiplier tube. They are surrounded with packing foam and encased in a PVC or aluminum enclosure for insulation and shock protection. Typical measurement conditions and detector characteristics are shown in Table I beside those of HPGe detectors. Whereas HPGe measurements at Fernald are stationary, NaI measurements are normally performed from moving vehicles. At the present time, NaI systems, including detector, multichannel analyzer, GPS equipment and lap-top computer are mounted on three different vehicles. The first is a full-sized John Deere farm tractor with the detector mounted on the back of the tractor, and the computer and signal processing electronic modules located in the enclosed air-conditioned cab. This provides a more stable operating environment for the MCA and computer. The second NaI scanning vehicle is a six-wheeled diesel-powered John Deere Gator, a smaller, lighter, more maneuverable open-cab utility vehicle. The NaI detector is suspended from the front of the vehicle, with the electronics mounted on the vehicle bed behind the driver's seat. The third mobile NaI platform is a three-wheeled jogging stroller that must be manually pushed by an operator. The first system is called the Radiation Tracking System (RTRAK); the second system is called the GATOR, and the third is called the Radiation Scanning System (RSS). These NaI scanning systems are shown in Figure 1. In contrast to the RTRAK, the latter two vehicles lack air conditioning. On the RTRAK and GATOR, the long NaI crystal axis is

perpendicular to the direction of travel, while on the RSS the long crystal axis is parallel to the direction of travel. The detectors on all of the NaI vehicles are mounted 31 cm above the ground surface, and use DART MCAs for acquisition of 512 channel spectra and on-board data storage. The gain is set at 5.8 Kev per channel for all of the NaI systems. A combination of one mile per hour vehicle speed and four second spectral acquisition time was found to be a reasonable compromise between the need for detection of small area hot spots and the need to count longer to achieve lower detection limits. Spectra are collected one after another as the vehicle moves back and forth across the area to be characterized. Each spectrum is stamped with the position coordinates furnished by GPS satellites as well as the time it was acquired. In real time, colored spots that represent position and activity measurements are painted on a computer-generated map so that the operator can monitor the coverage of the scan area and the activity levels being detected. At the end of a run, the data stored in the scanning vehicle are downloaded to the field operations center by wireless Ethernet transmission, where data quality checks are performed, reports are generated and color coded maps showing quantitative contaminant distribution patterns are plotted. Two to four acres per eight hour shift can be characterized in this manner, and summary reports and maps can be furnished to project management within an hour after completion of a scan. Because of the short count times and the lower resolution of NaI detectors, the usual gamma spectrometry peak search and nuclide identification routines are not used. Fixed energy spectral regions-of-interest (ROIs) for the analyte signal and the background are integrated to obtain the net counts per second for each of the isotopes of concern.

Global Positioning System Equipment (GPS)
A static position measurement technique is needed for typical HPGe measurements, whereas dynamic position measurements are required for the mobile NaI detectors. With the GPS equipment in use at Fernald, position measurements with sub-meter accuracy are routinely performed for both static and mobile soil characterization work. To obtain this degree of position accuracy, differential GPS (DGPS) signals as well as GPS signals must be received from satellites. The DGPS signals are used to make corrections to the coarse GPS position measurements. GPS equipment from two suppliers is used at Fernald. Trimble Navigation Ltd. manufactures the GPS Pathfinder Pro XRS unit, and the Swathstar III is manufactured by Satloc Inc. Both manufacturers incorporate a 12-channel GPS receiver and a DGPS receiver in a single unit with one antenna to receive both signals. This allows the differential corrections to be made in real time. These units also generate a GPS data quality indicator code so that a data reviewer can identify when the satellite signals were inadequate.

Although the occurrence of errors is not very common, GPS users must be aware of factors that can adversely effect the accuracy of GPS position measurements. While GPS signals are available twenty-four hours per day, there are certain time periods when satellite telemetry is poorer because of the relative positions of the receiver and the satellites. False position readings can result when GPS signals reflect from trees, fences, buildings, vehicles or water surfaces near the job site. Dense tree canopies nearby hills, and tall buildings can also block GPS signals.

SOIL REMEDIATION ACTIVITIES AT THE FEMP

HPGe detectors have the following uses in the Fernald soil remediation program:

- Defining nature and extent of contamination.
- Refining of general excavation boundaries.

- Delineation of above WAC and "hot spot" boundaries.
- Verification of contaminant removal.
- Demonstration that Final Remediation Levels have been attained.

HPGe detector uses reflect their ability to accurately quantify a variety of isotopes, their superior energy resolution which minimizes isotopic interferences, their ability to average results over a large area, thereby minimizing the effects of heterogeneity, and their ability to focus on small areas, if needed, by lowering the detector height. However, HPGe detectors do have certain limitations. Radon disequilibrium in soil affects Ra-226 measurements because radon daughter gamma emissions are used to quantify this isotope. Seasonal and daily temperature and humidity variations can have a negative effect on detector and MCA performance. Sources of "shine" may cause misleading results because of gamma rays impinging from outside the normal or expected detector field of view. HPGe measurements should not be made in wet or rainy conditions because of the shielding effect that moisture has on the gamma rays emitted from soil particles.

Vehicle mounted NaI detectors have the following uses in the soil remediation program at Fernald:

- Scanning large flat areas for general contamination patterns.
- Defining general excavation boundaries.
- Identifying large or small areas of WAC exceedance.
- Identifying hot spots above FRL.
- 100% coverage scans of excavation areas after removal of lifts.

The mobile NaI vehicles are able to provide rapid, 100% coverage of large areas. The accuracy, precision and detection limits are sufficient to determine the general patterns of contamination with respect to total uranium, Th-232 and Ra-226. The data output is amenable to mapping and spatial averaging. The latter attribute makes the NaI detectors very useful for determining the average concentration of soil contaminants. These properties make the NaI systems ideal as front-end survey tools to help focus HPGe and physical sampling activities on those areas of most importance.

Both HPGe and NaI systems perform in-situ gamma spectrometry. However, at times, circumstances are more favorable for using one system rather than the other. Also, certain remediation operations require measurements which can best be performed by one or the other of the two real-time systems. HPGe and NaI systems complement one another. The two types of systems are most powerful when used in tandem to perform soil characterization. The mobile NaI systems have the ability to rapidly survey large areas, while HPGe detectors provide more definitive characterization of areas of interest once they have been identified.

REGULATORY CLIMATE

The Fernald Environmental Management Project is a superfund site. By legal agreement, both the United States and the state of Ohio Environmental Protection Agencies have oversight responsibilities for the cleanup of the site. Before in-situ gamma spectrometry techniques could be incorporated into the routine program for soil characterization and excavation, two things had to be accomplished. First, since in-situ measurements are not widely used in superfund site remediation, the regulators had to be convinced of the accuracy and appropriateness of the technique for the Fernald cleanup. Second, a quality assurance program comparable to a rigorous laboratory QA program had to be developed to provide documentary evidence of the quality of in-situ measurements and the defensibility of the data. To accomplish the first objective, a Real-Time Work Group comprised of regulators, DOE, and Fluor Fernald personnel was formed to provide a forum to discuss technical issues related to the use of in-situ detectors. The calibration of both HPGe and NaI detectors was discussed in great detail in several Work Group sessions. Under the direction of the Work Group, an extensive comparison study of in-situ and laboratory measurements was devised and implemented. This study went a long way toward satisfying regulator's concerns regarding the accuracy of in-situ measurements. Partly as a result of the open exchange of information in the Real-Time Work Group, the regulatory agencies have approved the application of in-situ techniques to the remediation of Fernald soils. Because of their superior resolution and their demonstrated accuracy and comparability to laboratory measurements, HPGe detectors have been approved for all uses, except for analyses intended to certify that final remediation levels have been attained in a given area. The comparability study also helped to decide upon operational guidelines and programmatic controls that would help to ensure the accuracy of in-situ measurement results. For example, the comparability study showed that it was necessary to deploy a second HPGe detector nearby the site where routine characterization measurements were being performed to monitor the variation of radon daughter concentrations throughout the day. To produce in-situ results comparable to laboratory analyses, a correction algorithm based on the radon monitor readings, had to be applied to the raw Ra-226 results. A different radon correction algorithm was necessary for HPGe and NaI detectors.

The quality assurance program of the Real Time Instrumentation Measurements Program was designed to contain all the elements that have become standard in laboratory quality assurance programs. It contains requirements for assignment of clear lines of responsibility, personnel training, implementation of written procedures, documentation of work performed, quality checks of analysis results, proper storage of records and independent audits. It also delineates requirements for periodic instrument calibrations, frequent instrument performance checks and analysis of in-situ analogues of "quality control samples." Instruments must be calibrated annually. The response of instruments to radioactive check sources is measured daily when instruments are in use, and the results are trended on control charts. Daily HPGe measurements at a well characterized fixed field quality control station, are performed, and plotted on control charts. This analogue of a laboratory control sample also provides valuable information about the influence of environmental factors on HPGe measurements.

With the approval of the regulators overseeing the cleanup of Fernald, in-situ measurements systems have been in routine use for over three years. The availability of radiological information almost immediately after the completion of in-situ measurements has expedited the clean up over 490 acres of the Fernald site to date, which is well ahead of the projected schedule. Over the course of the cleanup, it is projected that the use of in-situ technologies will result in a saving of over thirty million dollars.