INL/CON-05-00717
PREPRINT

Real Time Quantitative Radiological Monitoring Equipment For Environmental Assessment

Sharing Solutions for Emergencies and Hazardous Environments

John R. Giles
Lyle G. Roybal
Michael V. Carpenter

March 2006

Real Time Quantitative Radiological Monitoring Equipment for Environmental Assessment

John R. Giles, Lyle G. Roybal, Michael V. Carpenter

Idaho National Laboratory, P.O. Box 1625, Idaho Falls, ID USA 83415, MS 3940, John.Giles@inl.gov

Abstract – *The Idaho National Laboratory (INL) has developed a suite of systems that rapidly scan, analyze, and characterize radiological contamination in soil. These systems have been successfully deployed at several Department of Energy (DOE) laboratories and Cold War Legacy closure sites. Traditionally, these systems have been used during the characterization and remediation of radiologically contaminated soils and surfaces; however, subsequent to the terrorist attacks of September 11, 2001, the applications of these systems have expanded to include homeland security operations for first response, continuing assessment and verification of cleanup activities in the event of the detonation of a radiological dispersal device. The core system components are a detector, a spectral analyzer, and a global positioning system (GPS). The system is computer controlled by menu-driven, user-friendly custom software designed for a technician-level operator. A wide variety of detectors have been used including several configurations of sodium iodide (NaI) and high-purity germanium (HPGe) detectors, and a large area proportional counter designed for the detection of x-rays from actinides such as Am-241 and Pu-238. Systems have been deployed from several platforms including a small all-terrain vehicle (ATV), hand-pushed carts, a backpack mounted unit, and an excavator mounted unit used where personnel safety considerations are paramount. The INL has advanced this concept, and expanded the system functionality to create an integrated, field-deployed analytical system through the use of tailored analysis and operations software. Customized, site specific software is assembled from a supporting toolbox of algorithms that streamline the data acquisition, analysis and reporting process. These algorithms include region specific spectral stripping, automated energy calibration, background subtraction, activity calculations based on measured detector efficiencies, and on-line data quality checks and measures. These analyses are combined to provide real-time areal activity and coverage maps that are displayed to the operator as the survey progresses. The flexible functionality of the INL systems are well suited to multiple roles supporting homeland security needs.*

I. INTRODUCTION

The Idaho National Laboratory (INL) is a multi-program Department of Energy facility with significant expertise in the nuclear industry including power generation, decontamination and decommissioning of nuclear facilities, nuclear material safeguards and security, and nuclear measurements. The INL has been prominent in real-time radiation measurement technology since 1996. The Fernald Closure Project (FCP), near Cincinnati, Ohio, had developed crude data acquisition system to collect gamma-ray spectra using a NaI detector on a moving platform. The gamma-ray spectra were post-processed using a batch-mode analysis to compute radionuclide concentrations in soils. The radionuclide data were spatially located by matching clock times between spectral and GPS files. The INL automated this process using systems integration transforming this manual process into a turnkey, production-based system complete with automated spectral analysis, data archiving, data quality assurance/quality control, and data mapping capabilities. Turn-around times for areal coverage maps were improved from 4 days to 1 hour, and errors introduced by human factors were minimized and, in most cases eliminated. This real time measurement and data handling system has evolved to include a variety of radiation detectors including high-purity germanium (HPGe), large-area gas-filled proportional counters, and other scintillation detectors. Although the initial focus of the real time system development was to increase the efficiency of environmental characterization and remediation practices, these systems are ideally suited for homeland security applications including first response, initial event characterization, and event recovery efforts.

II. SYSTEM EVOLUTION AND CORE APPROACH

While the concept of real time measurements is not new, the INL has created custom systems that are tailored to specific environmental conditions. Systems developed to date are a product of a general effort by cleanup contractors to increase operational efficiency, while meeting stakeholder expectations and regulatory cleanup requirements. The recent trend in management of site characterization and remediation activities that fall under the purview of the U.S. Environmental Protection Agency (EPA) is termed the Triad. The EPA Triad approach integrates systematic planning, dynamic work plans, and on-site measurement technologies to accelerate the site characterization and remediation process. The obvious role of the real time measurement systems is a decision-making tool that efficiently provides quality data in a user-friendly format.

The mobile, real-time measurement concept was initially utilized for precertification of remediated soil areas at the FCP prior to public release. Early versions of the system required several days of data matching, post-processing and analyses to generate survey area coverage maps. INL scientists and engineers integrated radiological and positional data acquisition with custom software to streamline the data collection and analysis, and post processing functions such that coverage maps depicting the areal distribution of radionuclides of the survey area were immediately available to field technicians and project management personnel.

The system software provides the "core" of the real time measurement systems. The software is written in LabVIEW™, which is an object-oriented, graphically-based software development environment similar in nature to visual C++, but specialized in data acquisition and analysis. The LabVIEW™ environment provides a number of tools that allow software engineers to efficiently generate sophisticated displays, communicate with hardware components.

Customized, site specific software created in LabVIEW™ is assembled from a supporting toolbox of algorithms that streamline the data acquisition, analysis and reporting process. These algorithms include region specific spectral stripping, automated energy calibration, background subtraction, activity calculations based on measured detector efficiencies, on-line data quality checks and measures, GPS data collection and coordinate conversion, and data integration. These analyses are combined to provide real-time areal activity and coverage maps that are displayed to the operator as the survey progresses.

III. REAL TIME SYSTEMS

NaI systems have been deployed from a variety of mobile platforms including all-terrain vehicles (ATVs) for covering large land areas; construction excavators for surveying trenches and areas that preclude personnel entry; hand-pushed, wheeled platforms for small and moderately sized areas that are inaccessible by larger, motorized vehicles; and backpack based systems designed for irregular terrain.

Factors, such as homeland security needs and evolving EPA regulatory insistence on real-time systems that support Triad drive design and function considerations for INL systems. These systems all share a similar basic operating system software. Depending on the requirements of the site and the detector used, modifications to the base system are made. A Global Positioning System (GPS) provides areal position information. The NaI spectrometer and multi-channel analyzer (MCA) hardware are computer controlled through either a parallel port or a universal serial bus (USB) connection. A typical deployment can be linked to a remote computer via a wireless network connection allowing physicists or managers to "watch" the data acquisition from outside the contamination zone.

III.A. Fernald Real Time In Situ Measurement Systems

The Feed Materials Processing Plant (later know as the Fernald Closure Project) was established in 1951 as an integrated facility for converting uranium ore concentrates to uranium compounds and metal products. Its primary missions were the production of uranium trioxide, uranium tetrafluoride, fabrication of target fuel elements, and the recovery of uranium and thorium from scrap and residue when economically feasible. As a result of historical operations and past waste disposal processes, soil in and around the Fernald site was contaminated with radionuclides including U-238, Th-232, and Ra-226.

Initial attempts to automate data acquisition, and quality parameters necessary to implement a real-time program are described in the Radiation Tracking system (RTRAK) Applicability Study.[1] Guidelines for use of real-time characterization systems and measurement strategies are described in "User Guidelines, Measurement Strategies, and Operational Factors for Deployment of In-situ Gamma Spectrometry at the Fernald Site."[2]

In 1996, the INL was tasked to design and implement an advanced NaI-based data acquisition and management system at the FCP site. The initial INL system was integrated into the Radiation Tracking System (RTRAK). The RTRAK system was a large tractor-based platform that was designed to characterize large, open, relatively flat areas. The RTRAK measurement system was consisted of a 4 in. by 4 in. by 16 in. NaI detector, spectral analyzer, a sub-meter accurate GPS unit, and an industrial, rack-mounted computer to control the system. In addition to the RTRAK, the FCP also implemented a smaller, hand-pushed platform that was used in areas where the RTRAK maneuverability was difficult. This system was called the Radiation Scanning System, or RSS, and was operated from a field-rugged, laptop computer. Later, a third mobile platform, the GATOR, was added using a small lawn tractor as the carriage, and the RTRAK system was retired. Figure 1 shows the GATOR performing a pre-certification survey of an excavated area at the FCP site.

Figure. 1. The FCP GATOR platform and front-mounted NaI detector.

All of the FCP deployment platforms share common hardware and software components. All platforms use the same NaI "log" detector, ORTEC multi-channel analyzers, and equivalent GPS equipment. Additionally, these systems share common operating software that differs only in initialization files that are read at system startup. These startup files are used to provide the detector specific efficiency curves and calculation constants as determined through system calibrations. This is an important feature in that it lessens the verification and validation burdens associated with placing software-driven systems into environmental processes that will become public records, and reduces the burdens of the configuration control aspects for these systems.

The INL development of the FCP system software is the basis for all the spectral analysis systems presented herein. The FCP system software performs real-time spectral stripping, activity calculations, on-the-fly energy calibration checks and adjustments using 300-second virtual spectra to verify the location of natural K-40 and Tl-108 gamma ray lines at 1,460 keV and 2,614 keV respectively. Additionally, all measurement data is integrated with position data from the sub-meter GPS equipment. This is done while providing real-time feedback to the operator concerning areal coverage and quality assurance checks for alarms, potential conflicts in conditions that may cause the activity calculations to be in error, and hardware health monitoring functions.

An example of the real-time information available to the operator is provided in Figure 2. Here the operator is provided with a view if the spectrum as it is collected, and up to two areal coverage classed post plots that show the track of the survey vehicle while using a color-coded scheme to show up to three levels of activity. The color coded "trail" relates to cleanup criteria established for the FCP by local, state and federal regulators. The large X-Y post plots are displayed in the project specified coordinate system. Across the top of Figure 2, are a number of alarm flags that are used to warn the user of high activities, equipment failure or unusual conditions that may invalidate some of the assumptions used in calculating radionuclide activities.

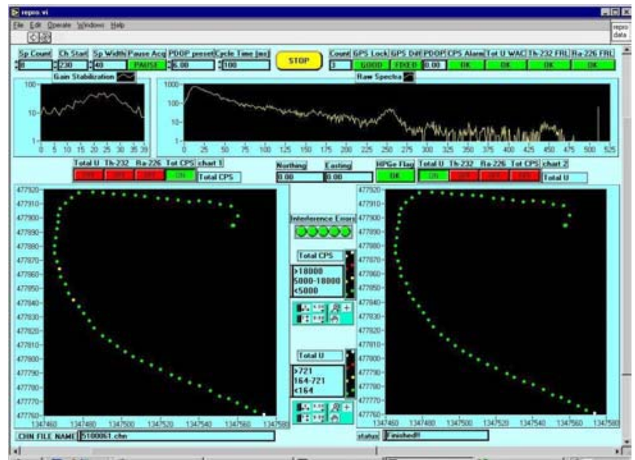

Figure 2. Example operator's screen.

The excavator mounted system (EMS) is also part of the FCP real-time suite of detector systems. It is a self-contained system that uses a standard excavator as the deployment platform. The EMS includes a self-righting vertical detector arm, which attaches to a detector mount and the same 4 in. by 4 in. by 16 in. NaI log detector used on the GATOR and RSS units. The detector arm is suspended from a horizontal platform that is coupled to the arm on the excavator and holds an on-board computer, a GPS receiver and antenna. The EMS is a remotely deployed system by design, and the EMS data acquisition and analysis functions are controlled from a laptop that is linked to the computer located on the end of the excavator by a wireless network connection.

The EMS is typically applied to non-standard survey situations that cannot be handled with the conventional manned platforms. These situations include surveys of pits, trenches, mounds, vertical surfaces, soft or wet ground, and other conditions that are unsafe for human entry. The EMS protects workers and reduces their potential exposure, thereby advancing the objectives of ALARA and worker health and safety. The EMS is capable of deploying a variety of detectors including NaI and HPGe gamma spectrometry systems. Figure 3 shows the EMS surveying a wet ditch area at the FCP where several buildings have been removed.

Real-time gamma measurements can be made in several modes including stationary measurements at a prescribed detector height or offset and mobile scanning measurements with the detector at a prescribed height and scan speed. As with the GATOR and RSS, all stationary or mobile measurements are position tagged using the onboard GPS hardware.

Figure 3. EMS NaI platform used to survey a trench at FCP.

III.B. Actinide X-ray In situ Scanning System - AXISS

The US Department of Energy (DOE) Mound Plant was established in late 1946 as a facility to support atomic weapons research and energy programs. It is located on 306 acres in the southwest portion of the city of Miamisburg, Ohio. Past waste disposal practices and unintentional releases have resulted in areas contaminated with Pu-238 that must be remediated before the site is released into the public domain. The INL, in conjunction with the Department of Homeland Security Environmental Measurements Laboratory, proposed using a large-area proportional counter (LAPC) designed to detect low-energy x-rays emitted by actinides such as Pu-238. Plutonium-238 emits a distinct x-ray triplet at 13, 17, and 20 keV; however, the penetrating power of these low-energy x-rays is very limited making this a surface or very near surface (i.e., 1 cm or shallower) detection device. This system design was based on previous detector characterization studies done by the Environmental Measurements Laboratory[3] where the LAPC was specifically designed to detect low-energy x-rays with excellent efficiency and resolution characteristics.

A typical spectrum collected with the AXISS system is shown in Figure 4. This is a ten second (true time) spectrum taken in scanning mode over one of the contaminated areas at the MCP. The x-ray triplet from Pu-238 is clearly evident as demonstrated by the 10% full-width-half-maximum energy resolution. This spectrum represents a calculated activity of about 2.5 nCi/g Pu-238 contamination in soil. Field measurements have shown minimum detectable concentrations for Pu-238 of 30 pCi/g for a 300-second count, and 166 pCi/g for a 10-second count, which are commensurate with the MCP remedial action goals of 55 pCi/g and 165 pCi/g for the average and hot spot criteria, respectively.

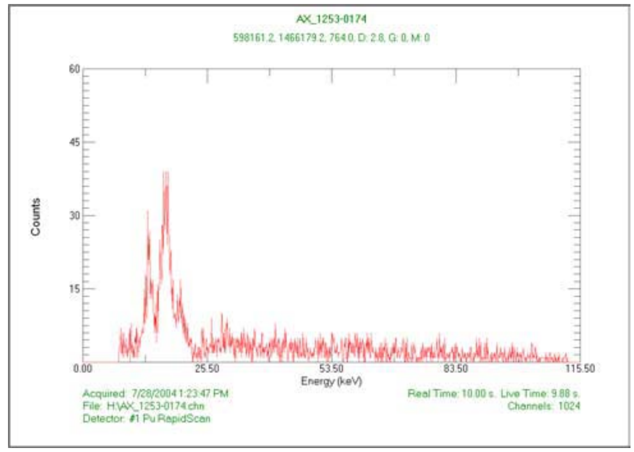

Figure 4. Plutonium-238 x-ray spectrum collected in scan mode over Pu-238 contaminated soil.

The operating software used for the AXISS is very similar to that used for the NaI systems in use at the FCP site. Radionuclide and position data is available as it is collected for remedial decision-making. The AXISS possesses protocol for routine system operation including daily source checks, energy calibration, efficiency calibration, and background measurements.

The AXISS has been deployed from both a three-wheeled cart and single-wheel cart platform. Figure 5 shows the single-wheel version being used at the MCP. Because the AXISS is designed for mobile scanning, it provides the ability to rapidly cover 100% of the desired survey area. Figure 6 shows a color contour plot of Pu-238 activity in the Building-38 excavation area at the MCP. Note the general trends of higher activity levels in the southeast and northwest corners of the excavation, and several small "hot spots" caused primarily by individual particles of material.


Figure 5. INL AXISS system deployed at the MCP Building-38 excavation site in Miamisburg, Ohio.

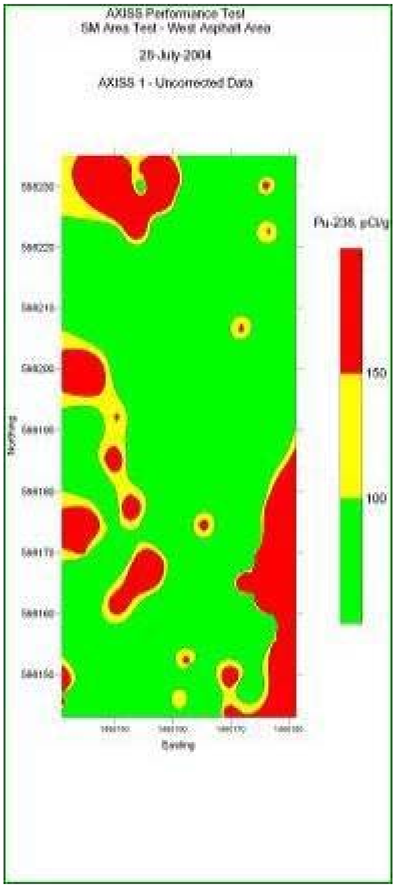

Figure 6. Contour plot depicting Pu-238 contamination in soil at the MCP Building-38 excavation site.

III.C. Backpack Sodium Iodide System - BaSIS

The Backpack Sodium Iodide System (BaSIS) was developed by the INL for initial use at the MCP. The BaSIS uses software and analysis techniques common to the FCP real-time and AXISS platforms. The BaSIS system was designed for sites with terrain that precludes the use of a mechanized platform, but is safe for personnel entry. The basic system is comprised of a sub-meter GPS receiver, a handheld gamma-ray detector, and a high-bright, sunlight readable display that communicates with a small onboard computer using wireless network technology. The configuration allows personnel to view the survey in real-time from a remote location if desired. Figure 7 shows the BaSIS system being used for a survey of a hillside at the MCP.

The initial configuration of the BaSIS at the MCP was designed to accommodate either a 3-in. by 5-in. NaI detector, or a Field Instrument to Detect Low Energy Radiation (FIDLER) detector, which is a thin-crystal NaI detector used for the measurement of low-energy gamma and x-rays with energies between 10 keV and 100 keV. The 3-in. by 5-in NaI detector was used to detect Th-232 (using the 2,614 keV gamma-ray from Tl-208), and the

Figure 7. BaSIS survey of hillside at MCP using FIDLER detector.

FIDLER was used to detect Pu-238 and as a gross counting instrument. Subsequent deployment of the BaSIS at the INL involved the use of the 3-in. by 5-in NaI detector for measurement of Cs-137 in soil to support site remediation activities.

The BaSIS is configured to use two different spectral striping methods to calculate activity. It can use a classical "region-of-interest" methodology where background channels are use to define a straight-line continuum that is subtracted from the signal to calculate the net count rate in a spectral region, or the software can use an energy corrected background striping method where a stored background spectrum is subtracted channel-by-channel before a region-of-interest strip is applied. Spectra, including the background spectrum, are independently energy calibrated in real-time using a proprietary algorithm involving naturally occurring K-40 and Tl-208 gamma rays. This independent energy calibration accounts for gain shifts in the system caused by ambient temperature fluctuations.

The BaSIS can be operated in either a scanning mode, or in a stationary "point-and-shoot" mode. In scan mode, the system provides the user with real-time activity calculations every five seconds. In this mode, the area can be surveyed at a relatively rapid pace to provide personnel with information regarding radiological conditions. Subsequent to the rapid scan, stationary measurements can be made at select locations to verify the results of the survey. Figure 8 shows the results of a scanning survey and stationary measurements at a soil contamination site at the INL. All radionuclide activity data are position tagged using sub-meter GPS equipment. The radiological and position information are displayed for the operator in real time, and a data file created that can be used to make activity maps that support on-site decision-making.

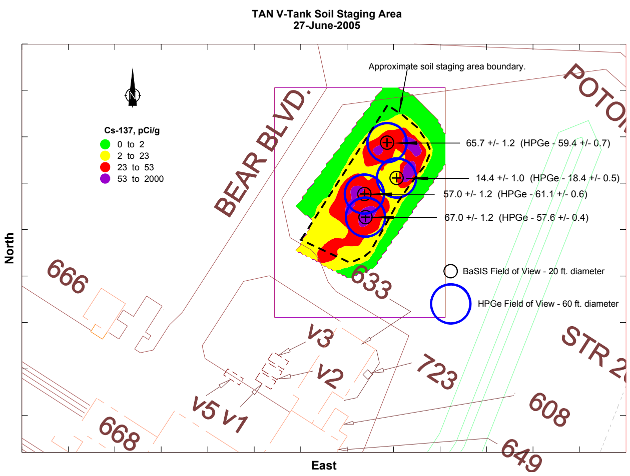

Figure 8. BaSIS survey map of Cs-137 contamination in soils at INL site.

V. CONCLUSIONS

Real-time measurement systems have been developed by the Idaho National Laboratory to address the need for rapid, accurate and comprehensive characterization of radiological contamination in the field to support environmental remediation activities.

After September 11, 2001, emphasis on traditional cleanup technologies became a companion with technologies that can serve in additional roles to support US Department of Homeland Security (DHS) objectives. The INL is endeavoring to constantly improve and adapt current systems and processes to provide better technology to expedite environmental remediation challenges, and to embrace the new roles that serve homeland security missions.

REFERENCES

1. U.S. Department of Energy, “RTRAK Applicability Study,” 20701-RP-0003, Rev. 2, DOE, Fernald Environmental Management Project, Fernald, OH, January 1999.
2. U.S. Department of Energy, “User Guidelines, Measurement Strategies, and Operational Factors for Deployment of In situ Gamma Spectrometry at the Fernald Site,” 20701-RP-0006, Rev. 1, DOE, Fernald Environmental Management Project, Fernald, OH, January 1999.
3. K. M. MILLER, “Large-Area Proportional Counter for In Situ Transuranic Measurements”, Transactions of the American Nuclear Society, 70(1), pp. 47-48 (1994).