SITE CHARACTERIZATION TECHNIQUES USED IN ENVIRONMENTAL REMEDIATION ACTIVITIES

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ABSTRACT

As a result of decades of nuclear energy research, weapons production, as well as ongoing operations, a significant amount of radioactive contamination has occurred throughout the United States Department of Energy (DOE) complex. DOE facility are in the process of assessing and potentially remediating various sites according to the regulations imposed by a Federal Facility Agreement and Consent order (FFA/CO) between DOE, the state in which the facility is located, and the U.S. Environmental Protection Agency (EPA). In support of these active site remediation efforts, the DOE has devoted considerable resources towards the development of innovative site characterization techniques that support environmental restoration activities. These resources and efforts have focused on various aspects of this complex problem. Research and technology development conducted at the Idaho National Engineering and Environmental Laboratory (INEEL) has resulted in the ability and state-of-the-art equipment required to obtain real-time, densely spaced, *in situ* characterization data (i.e. detection, speciation, and location) of various radionuclides and contaminants. The Remedial Action Monitoring System (RAMS), developed by the INEEL, consists of enhanced sensor technology, measurement modeling and interpretation techniques, and a suite of deployment platforms which can be interchanged to directly support remedial cleanup and site verification operations. *In situ* characterization techniques have advanced to the point where they are being actively deployed in support of remedial operations. The INEEL has deployed its system at various DOE and international sites. The deployment of *in situ* characterization systems during environmental restoration operations has shown that this approach results in several significant benefits versus conventional sampling techniques. A flexible characterization system permits rapid modification to satisfy physical site conditions, available site resources, and cleanup requirements. The rapid and precise collection of *in situ* measurements can reduce operational costs by reducing the volume of material requiring remediation. This approach can also reduce uncertainty by obtaining a "total-area field screen" versus a representative subset of hand-collected lab-analyzed samples. It can lower on-site health risks by reducing human exposure to contamination through reduction of hand samples during the field sampling process. And, *in situ measurements* can improve management decisions by providing real-time, densely spaced, repeatable, characterization data.

1. INTRODUCTION

As a result of decades of nuclear energy research, weapons production, as well as ongoing operations, a significant amount of radioactive contamination has occurred throughout the United States Department of Energy (DOE) complex. Recent estimates project the DOE environmental problems to involve more than 5700 separate groundwater plumes, more than 600 billion gallons of contaminated groundwater, over 200 million cubic meters of contaminated soils, and numerous landfills containing more than 3 million cubic meters of buried waste.

This DOE radioactive waste and associated contamination represents unique remediation challenges. Because approximately half of all DOE waste was disposed of before 1970, many of the landfills are commingled with various types of waste. As a result of these past disposal practices, much of the waste throughout the DOE complex is contaminated with both hazardous and radioactive materials. As such, this waste continues to pose a threat to surface and groundwater. The DOE sites where this waste is predominantly located are the Hanford Reservation, the Savannah River Site, the Idaho National Engineering and Environmental Laboratory (INEEL), the Los Alamos National Laboratory (LANL), the Oak Ridge National Laboratory (ORNL), the Nevada Test Site (NTS) and the Rocky Flats Plant (RFP). Figures 1 and 2 show early disposal practices at two DOE facilities, the Oak Ridge National Laboratory and the Idaho National Engineering and Environmental Laboratory, respectively.

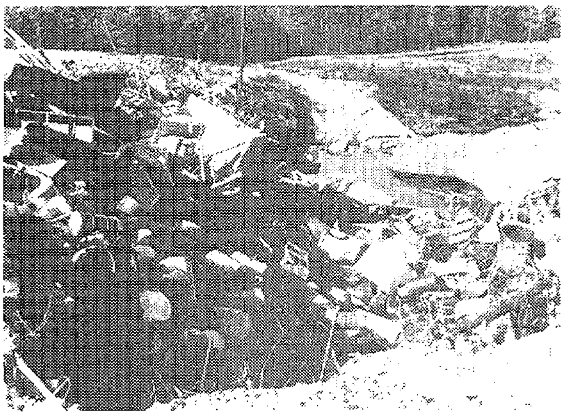

FIG. 1. Early waste disposal at the Oak Ridge National Laboratory.

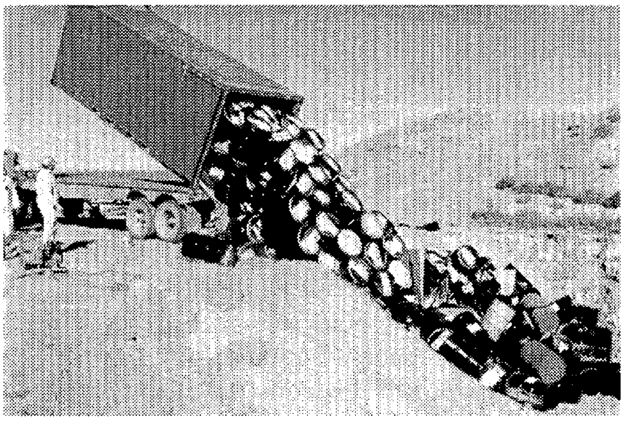

FIG. 2. Early waste disposal at the Idaho National Engineering and Environmental Laboratory.

1.1. Environmental restoration strategy

With the passage of new environmental laws and regulations, DOE waste disposal sites are now being evaluated and if necessary remediated. Each DOE facility must be remediated according to the regulations imposed by a Federal Facility Agreement and Consent order (FFA/CO) between DOE, the state in which the facility is located, and the U.S. Environmental Protection Agency (EPA).

Certain sites fall under the regulations of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Under this act, DOE conducts remedial investigations and feasibility studies. These remedial investigations characterize conditions at the site to identify the sources and extent of contamination. The feasibility study evaluates specific alternatives for cleaning up the site. Alternative remedial solutions are evaluated using specific CERCLA evaluation criteria. Finally, the selected remedial action is then documented in a Record of Decision which is subsequently implemented to achieve site restoration. Figure 3 illustrates the process to be followed to select an appropriate remediation solution for CERCLA sites.

1.2. Innovative site characterization techniques

In support of these active site remediation efforts, the DOE has devoted considerable resources on the development of innovative site characterization techniques that support environmental restoration activities. These resources and efforts have focused on various aspects of this complex problem.

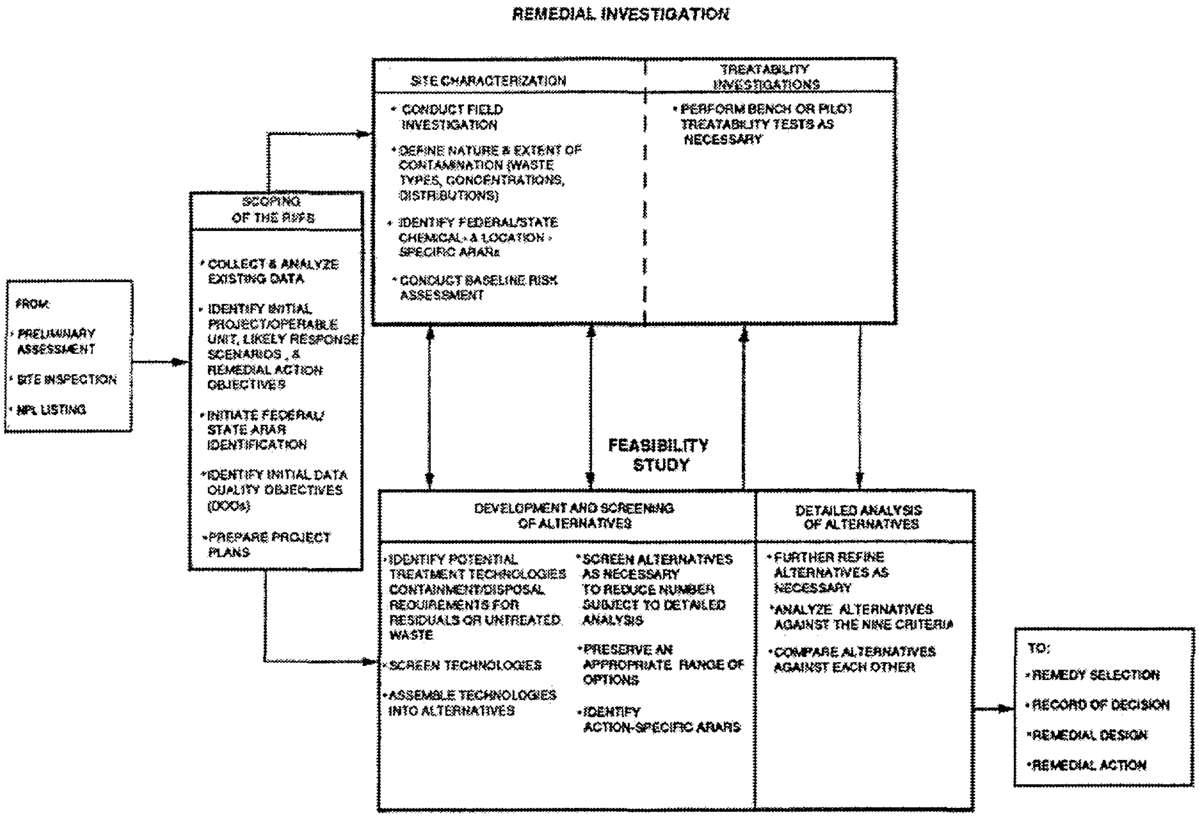

FIG. 3. USEPA CERCLA Remedial Investigation/Feasibility Study process [1].

INEEL research and associated technology development has resulted in the ability and state of the art equipment required to obtain real time, densely spaced, *in situ* characterization data (i.e. detection, speciation, and location) of various radionuclides and contaminants. The Remedial Action Monitoring System (RAMS) [2], developed by the INEEL, consists of enhanced sensor technology, measurement modeling and interpretation techniques, and a suite of deployment platforms which can be interchanged to directly support remedial cleanup and site verification operations. The RAMS is an *in situ* radioactive and hazardous waste monitoring and data management system that is applied during radioactive and hazardous waste cleanup operations. The RAMS consists of three major components:

— deployment platforms,
— characterization sensors, and
— the data management system.

The integration of these subsystems is flexible to produce an optimal *in situ* measurement and data management system to satisfy site specific applications where immediate, high quality field characterization information is required.

1.3. INEEL deployment platforms

Several deployment platforms have been developed and used by the INEEL to support the collection of *in situ* radiological measurements. The applicability of these platforms is dependent on site specific conditions.

1.3.1. Excavator mounted system

The Excavator Mounted System (EMS) is a specialized platform to which a variety of radiation sensors can be attached and used to investigate areas of contamination by methodically scanning the surface during data collection (see Figure 4). The system is used primarily in uneven terrain, for discreet delineation between clean and contaminated soil, mapping the lateral extent of contamination, and where layers of soil are excavated in controlled "lifts". The platform possesses automated functions that enhance data quality by maintaining constant vertical platform position during scanning operation. This is accomplished by using mechanical dampeners on each of the platform's axis of travel. A terrain following system maintains a constant, vertical sensor offset from the surface under investigation. The EMS is normally deployed from the arm of most commercially available tracked excavators.

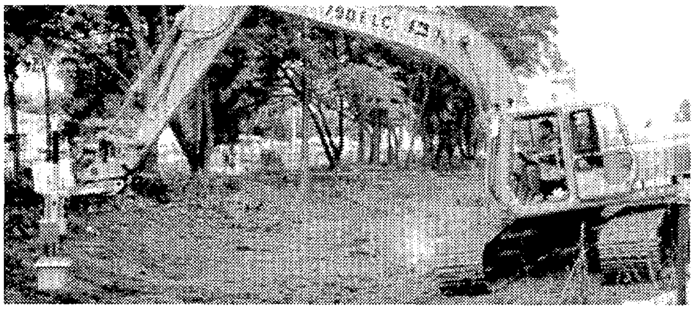

FIG. 4. INEEL excavator mounted system (EMS) in situ characterization at DOE Mound.

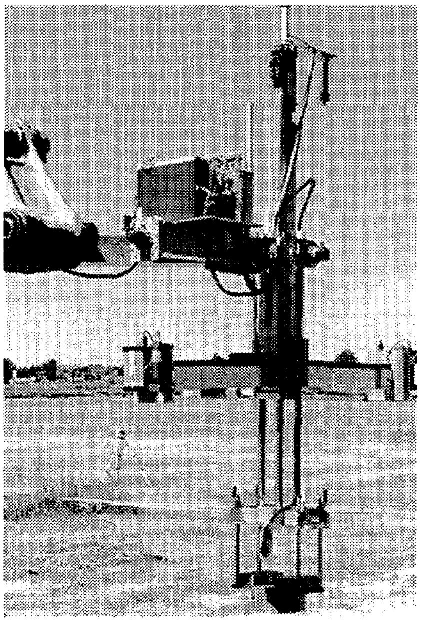

FIG. 5. INEEL excavator mounted system (EMS).

With a characterization sensor attached to the base of the sensor mount plate, the platform scans a surface, acquiring data and logging the exact position of each data point. This sequence can be repeated for successive vertical excavations. Information collected is converted real time into contamination maps. Site managers use these maps when making critical decisions regarding the next step in the remediation process.

This system has been implemented by Lockheed Martin Idaho Technologies Co. (LMITCO) at DOE sites in the States of Idaho, Ohio, and South Carolina. At the INEEL, RAMS has been used to map caesium-137 contaminated soils. In Ohio, RAMS was used on two separate remediations. First, an abandoned buried tank was retrieved as well as the surrounding thorium-232 and actinium-227 contaminated soil [3]. Second, RAMS was used to map plutonium-238 hotspots in a canal bed (see Figure 5). Finally, at the DOE Savannah River site, RAMS was used to characterize a caesium-137 soil site during its remediation [4]. Most recently the EMS was deployed at various sites within the United Kingdom to map potentially contaminated soils.

1.3.2. Surface area mapper (SAM)

INEEL's Surface Area Mapper (SAM) is a wheeled sensor platform that is easily deployed for broad area, surface, radiation characterization (see Figure 6). The SAM platform is designed such that radiation sensors are positioned above an open "window" at the base of the platform allowing high-energy particles to pass unimpeded into the open face of the sensor.

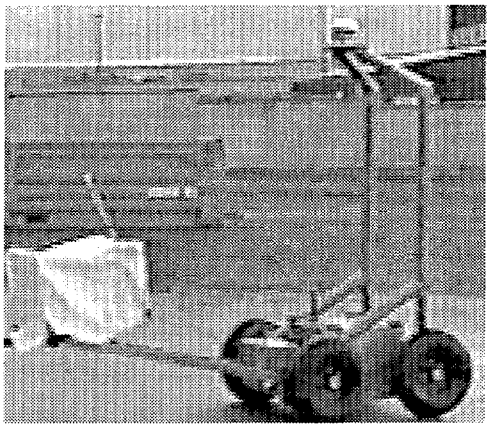

FIG. 6. INEEL's Surface Area Mapper (SAM).

1.4. Characterization sensors [5]

SAM is integrated with an automatic global positioning system (GPS), enabling the precise location and instant display of *in situ* data at a remote workstation. SAM workstation monitors the ongoing data collection process, displaying processed information on a monitor for easy viewing by decision makers. SAM can be used to collect precise characterization data even in more difficult terrain. Its configuration allows access to moderate variations in ground surface topography. And since it is fitted with a wide push bar, two people can easily maneuver it.

INEEL's RAMS makes use of both "enhanced" commercially available characterization sensors, as well as "INEEL-developed" characterization sensors. Table I lists potentially applicable sensors versus contaminants of interest. Of these, the INEEL has extensively modeled three sensors, useful for the detection of low level gamma and alpha radiation[5]. These sensors are a Plastic Scintillator for detecting moderate to strong gamma emitting radioactive contaminants, a Germanium-Spectrometer for speciation of radioactive contaminants, and a six-crystal array Calcium Fluoride (CaF_2) detector for detection of the L X ray component of primarily alpha emitting radionuclides such as ^{238}Pu.

1.4.1. Plastic scintillator detector (PSD)

The RAMS gross count detector consists of a 30 ×30 × 3.81 cm (12" × 12" × 1.5") plastic scintillator with an adjustable discriminator with the pulses above a discriminator level stored in a scaler. Gross counts are scaled and transmitted at 1second intervals. The detector and pulse processing circuitry are mounted as an integral assembly in an enclosed aluminum case. Shielding of 5-cm (2") thick by 10-cm (4") high lead bricks surround the plastic scintillator along its four sides. The top of the detector is unshielded. The sensitive front face of the scintillator is about 4.4 cm. (1.7") above the bottom of the lead brick shield.

This arrangement moderately restricts the viewing angle of the detector and provides some protection from background gamma rays. This entire assembly weighs about 105 kg (230lbs.).

TABLE I. POTENTIALLY APPLICABLE SENSORS/DETECTORS FOR VARIOUS CONTAMINANTS OF CONCERN.

Radionuclide	**Potential Sensor/Detector**
^{137}Cs, ^{108m}Ag, ^{232}Th, ^{60}Co	Plastic Scintillator, Ge semiconductor, NaI Scintillator
^{90}Sr, ^{90}Y	Xenon proportional counter, Plastic Scintillator
^{14}C, ^{99}Tc	No in situ techniques
^{241}Am	Plastic Scintillator, Ge semiconductor, NaI Scintillator
^{238}Pu, ^{239}Pu, ^{244}Cm, ^{233}U	Calcium fluoride detectors
^{238}U	Xenon proportional counter, Ge semiconductor
^{235}U	Plastic Scintillator, Ge semiconductor, NaI Scintillator

The field of view is approximately 120 cm × 120 cm (4 ft. × 4 ft) at the normal 15-cm (6") height above the soil surface. Any pulse above the lower level discriminator registers a count, therefore, the plastic scintillator detector's large size allows it to gather data quickly as it scans the ground. However, because of its poor energy resolution, this detector cannot differentiate among radionuclides.

1.4.2. Gamma ray spectrometer

In situ gamma ray spectrometer measurements or grab samples are routinely used to determine radionuclide compositions. The RAMS gamma ray spectrometer assembly incorporates a High Purity Germanium (HPGe) semiconductor detector in an all-attitude dewar. The HPGe detector is an n-type Ge detector 5.0 cm diameter and 2.0 cm thick. The detector is shielded by a bismuth shield/collimator, and is recessed 7.9 cm from the front of the collimator. The shield/collimator wall thickness is 4.44 cm (1.75") and attenuates 662 keV gamma radiation by a factor of 20. This configuration restricts the viewing angle of the detector to a defined solid angle provides some protection from background gamma rays. When shielded the detector has a field of view of about 60 cm diameter with the bottom of the collimator 15 cm (6") above the ground. The complete detector assembly with detector/ electronics, shield/collimator and support frame weighs approximately 50 kg (110 lbs). The spectrometer electronics consist of a Canberra Industries portable multi-channel analyzer (MCA). The MCA is equipped with the INEEL-designed dual-energy, low power pulser and processing electronics. Acquisition control, data transmission and storage uses software written by the INEEL.

1.4.3. Calcium fluoride detector

The RAMS Calcium Fluoride detector consists of a six-detector rectangular 2x3 array. The detector thickness is 0.152 cm. Which supports good counting efficiency for the Pu L X rays and at the same time, minimizes the efficiency for the higher energy 60-keV x rays and γ rays. The detector array is used in the scanning mode with a scanning rate of less than 15 cm/s for *in situ* measurements. The energies of the pulses from the L X rays and 60-keV γ rays emitted from a ^{241}Am source from each detector are aligned by adjusting the high voltage on each photomultiplier tube so that the gains are matched. This combined signal is fed into two single-channel analyzers (SCA) and counters that record the L X ray emitted by the Pu isotopes and the 59-keV γ rays emitted by ^{241}Am, respectively.

INEEL's approach is to couple the most appropriate characterization sensor(s) with the most appropriate deployment platform. INEEL has been the provider as well as the integrator of a variety of characterization sensors. Therefore, additional commercial and developmental characterization sensors can easily be integrated with the previously describe deployment platforms and the following data management system.

1.4.4. Real time data management system (RTMS)

The INEEL Real time Data Management System (RTMS) is a computer based program application that integrates hardware, software, sensor output, positioning information, and data analysis functions [6]. The RTMS is independent of any one hardware or sensor system and can be programmed to interact with the autonomous attributes of virtually any hardware and sensor combination. The RTMS can, therefore, be integrated with a site's existing monitoring hardware and sensors, thus utilizing available assets. For example, the RTMS is being utilized for site characterization at the DOE Fernald site [6].

The RTMS performs the integration of 3-dimensional positioning, real time data display, processing, transfer, and archiving of *in situ* data collected during remediation activities at the site. The system consolidates and automates many costly *in situ* measurement-related functions formerly performed separately and manually. RTMS is designed to enhance both large area as well as smaller more detailed and discreet hot-spot field screening functions.

The RTMS provides real time, on-site value to site managers and remediation operators in three primary areas.

— Health and safety of workers and remediation personnel,
— Segregation of contaminated and clean materials, and
— Verification of remediation operations.

2. IN SITU FIELD APPLICATIONS

In situ characterization techniques have advanced to the point where they are considered a valuable asset to remediation operations. The INEEL is actively deploying its systems in the field during remedial operations. This integration not only supports the remedial managers but it assists in furthering the development of these techniques. Two implementation examples include a RAMS deployment at the INEEL Waste Area Group 5 (WAG-5) site, and the DOE Mound Ohio-Erie canal remediation.

The INEEL WAG-5 operation involved the characterization of a ^{137}Cs contaminated area which was the result of a 1961 accident. Approximately 82,000 *in situ* measurements were obtained during this operation. This information was used to generate distribution maps of the ^{137}Cs contamination (see Figure 8). This information is being used to determine appropriate remediation plans. For example, this characterization could potentially reduce the volume of contaminated soils requiring treatment by up to 50 %.

The second example, which illustrates the value of *in situ* characterization, involves the DOE Mound site. Figure 9 presents a side-by-side comparison showing contoured ^{238}Pu data from

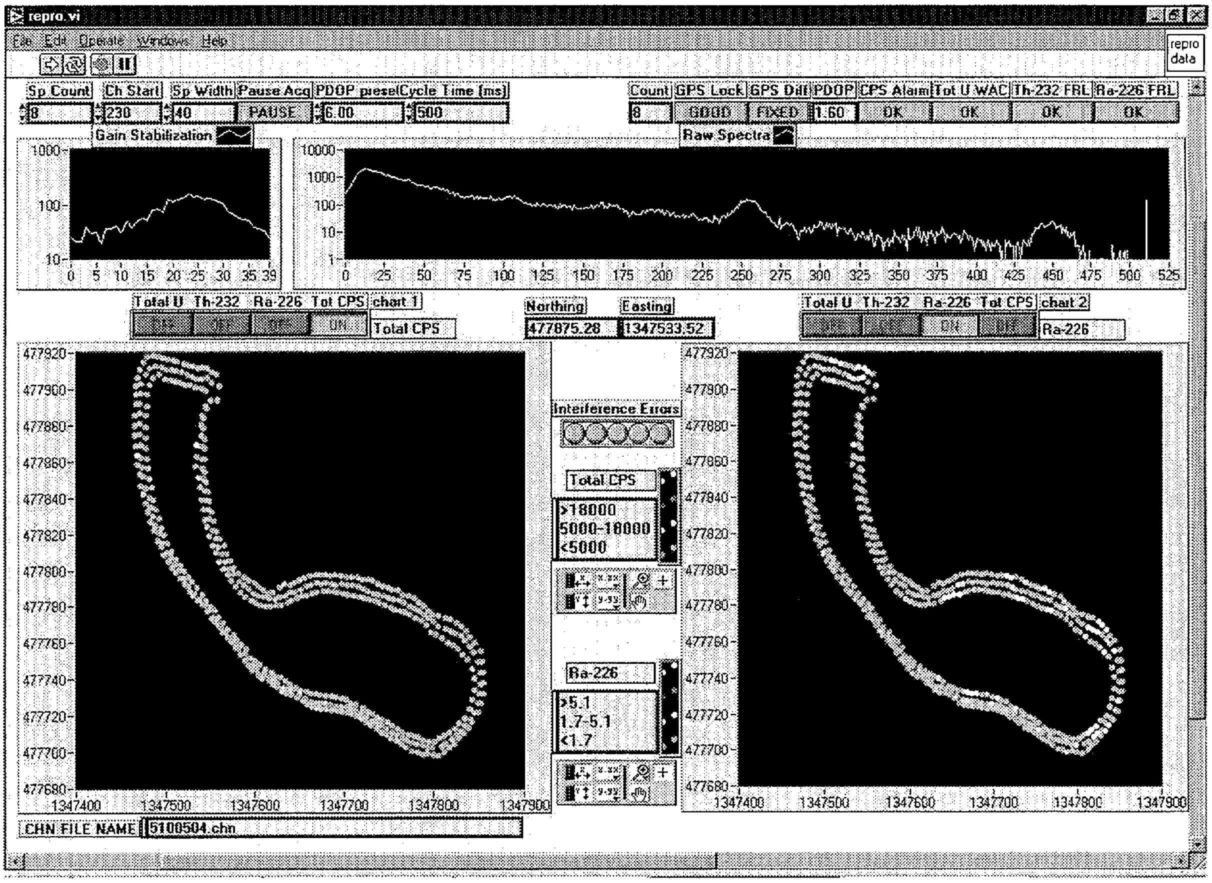

FIG. 7. The RTMS integrated display screen used to manage the data flow process.

A) 30 hand collected samples, which took over 2 hours to collect; and B) 21,916 *in situ* measurements collected at the same location in only 91 minutes. The color gradation in both plots represent activity level as a function of the count rate. Hand collected sample points in panel (A) are superimposed on the panel (B) plot. The area of investigation involved approximately 672m^2.

3. INTERNET RESOURCES

The INEEL has had over 25 years of experience in the modeling and application of *in situ* measurements. Over this time period, a significant amount of information has been generated. An important reference for this information is now located on the internet and is available to interested parties. The INEEL Gamma Ray Spectrometry Center has recently established an internet Homepage to better disseminate its information as well as provide easy links to other related sites. This site provides online reference material such as the Gamma Ray Spectrum Catalogue, Scintillation Spectrometry, 2nd Edition; and the Gamma Ray Spectrum Catalogue, Ge and Si Detector Spectra, 4th Edition. The site also provides links to numerous resource sites for nuclear data, reference materials, professional societies, and other related links. The INEEL Gamma Ray Spectrometry Center homepage is located at *www.id.inel.gov/gamma/*

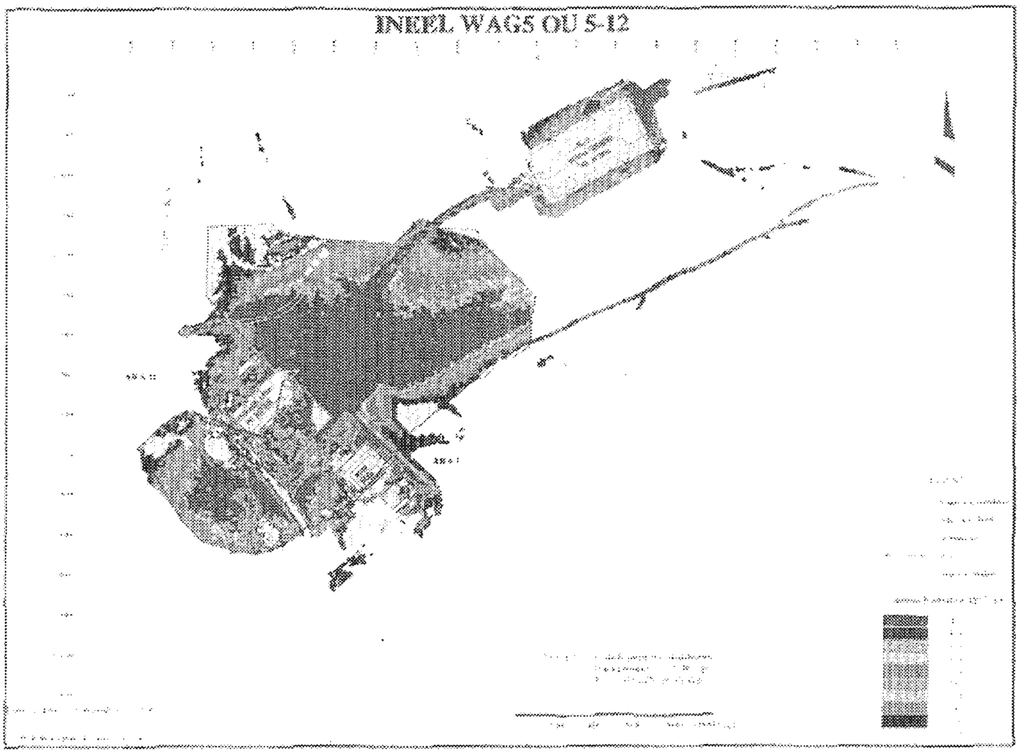

FIG. 8. INEEL WAG 5-12 137Cs distribution map.

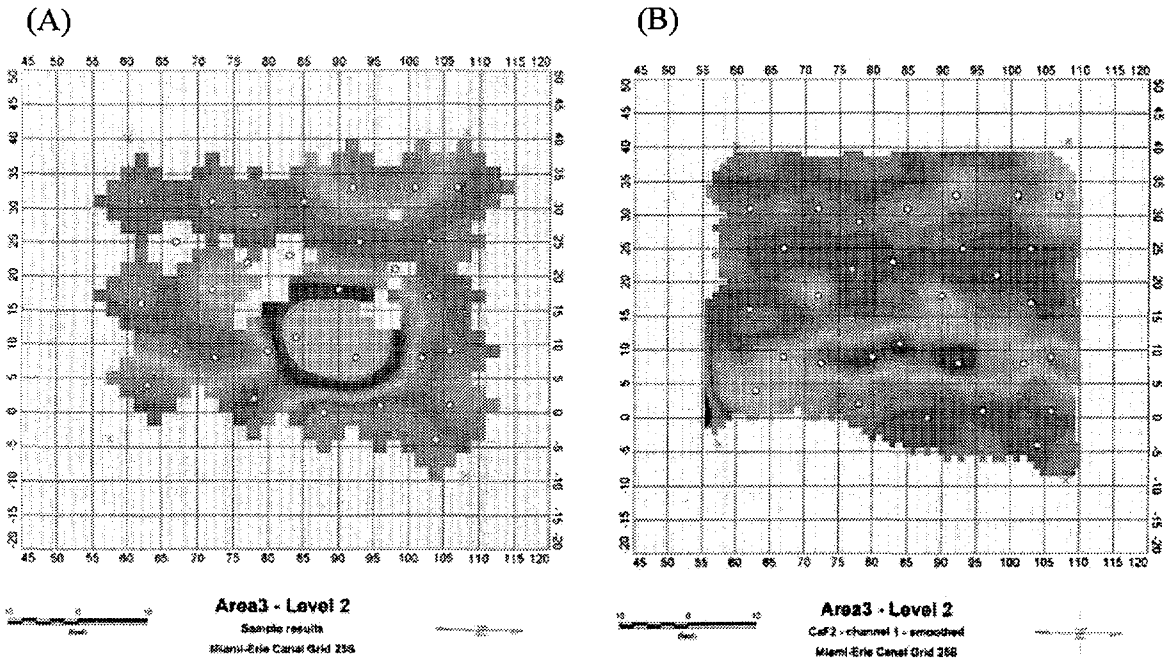

FIG. 9. Contoured 238Pu data from A) 30 hand collected samples and B) 21,916 in situ measurements.

4. SUMMARY

Innovative remediation technologies offer tremendous opportunities for cost savings, risk reductions, and operational efficiency. Implementation of *in situ* characterization systems during environmental restoration operations has shown that this approach results in several significant benefits versus conventional sampling techniques. For example, a flexible characterization system permits rapid modification to satisfy physical site conditions, available site resources, and cleanup requirements. As such, the rapid and precise collection of *in situ* measurements can:

— **reduce operational costs** by reducing the volume of material being remediated (i.e. more effectively delineating clean from contaminated material),

— **reduce uncertainty** by obtaining a "total-area field screen" versus a representative subset of hand-collected lab-analyzed samples,

— **lower on-site health risks** by reducing human exposure to contamination through reduction, and in some cases, elimination of hand samples during the field sampling process, and

— **improve management decisions** by providing real-time, densely spaced, repeatable, characterization data.

The INEEL promotes the development of innovative deployment, characterization, and interpretation techniques. Through on-going research, regulatory acceptance is being pursued to ensure that advanced techniques are available, for DOE and other customers, to achieve remediation goals and schedules. Regulator awareness and acceptance is being accomplished by integrating research into active environmental and waste management operations.

5. ACKNOWLEDGEMENTS

This paper presents a programmatic discussion and summary of INEEL work. The author wishes to acknowledge the technical achievements of the various authors identified in the references.

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