



Technology Overview

Real-Time Measurement of Radionuclides in Soil: Technology and Case Studies



February 2006

Prepared by
The Interstate Technology & Regulatory Council
Radionuclides Team

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EXECUTIVE SUMMARY

In recent years, new options for measuring contaminant levels in real time at radioactively contaminated sites have emerged. In addition to improved technologies and the accumulation of field experience, the overall management and planning philosophy has evolved to the point that it can now be integrated with the technological improvements. As a consequence, paradigm-shifting alternative approaches that offer significant reductions in costs, dependable accelerations in schedule, and major improvements in reliability are now available. While these real-time radiological characterization techniques were developed to assist with site cleanups under environmental regulations, these technologies would be equally applicable to radiological characterization activities in the aftermath of a radiological dispersion device (improvised nuclear device or “dirty bomb”).

Real-time measurement systems allow radionuclides in both surface and subsurface soil to be measured more rapidly than they can be with traditional sampling approaches. The basic technologies for these real-time systems are two different types of solid-crystal gamma detectors: sodium iodide and germanium. Understanding the advantages and limitations of each is an important consideration when planning a real-time survey. When these instruments are combined with new location technologies, the ability of real-time measurement systems to present data in an immediately useful format is greatly enhanced. Some of the new positioning technologies provide accuracy down to a sub-centimeter level and can allow for three dimensional location control during excavation. As a further enhancement, the detectors and location devices have been mounted on various platforms to make data acquisition convenient to the specific needs at different sites. These platforms range from hand-pushed carts to tractors to excavators and even to direct-push samplers for characterizing subsurface soils.

The real rewards of technical advances in field instrumentation come when the technologies realize synergies with data collection methodologies and decision frameworks. Two different but complementary tools, the Triad approach and Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), provide these methodologies and frameworks. Triad is an approach to data collection and decision-making that rests on three legs: systematic planning, dynamic work plans and real time measurement. MARSSIM provides detailed guidance on planning, implementing, and evaluating environmental and facility radiological surveys. These surveys are specific to radiological contamination and are aimed at demonstrating compliance with regulations during the final status survey after remediation has been completed. Both MARSSIM and Triad address the management of uncertainty in the decision-making process. These similarities allow both Triad and MARSSIM to be used with real-time measurement techniques to develop protocols for efficient site characterization and closure

Real-time measurement systems can support the various phases of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) process: preliminary assessment, remedial investigation/feasibility study, and remedial action. Combined with more traditional discrete sample collection, real-time measurement systems can provide critical support for a number of key activities in the CERCLA remedial decision-making process particularly the management of uncertainty. Other issues that frequently complicate characterization and remediation activities include large areas, the presence of other

contaminants, the presence of buried contamination, inadequate prior characterization, and the presence of hotspots.

Real-time gamma data collected in support of soil remediation must meet the data quality and documentation requirements of the appropriate regulatory program, typically CERCLA or Nuclear Regulatory Commission decommissioning. Quality assurance and quality control (QA/QC) for real-time measurement systems focus on different sources of uncertainty than traditional sampling methods. Uncertainty due to limited coverage and spatial variability is reduced, but inferential and analytical measurement uncertainty become more important than with discrete sampling. Since real-time measurement systems do not have well-established performance parameters, it is important to carefully set up a QA/QC program that fits the radiological constituents being measured, the performance capabilities of the measurement system, and the site characteristics. Important factors to consider include essential performance requirements (such as energy of gamma rays, identity of surrogate or progeny nuclides, identity of interfering gamma rays), conditions and contexts of soils (including soil moisture, topography, and measurement geometry), and contaminant distribution (deviation from uniform distribution, lateral inhomogeneities, etc.).

A few regulatory and stakeholder issues have emerged from the limited number of deployments of real-time measurement systems. Real-time measurements have become widely accepted for characterization and remedial phases at most sites; however, the use of these technologies has generally not been allowed for final certification purposes. While the physical sampling and statistical analyses performed for non-radionuclides have well-established protocols that are familiar to most regulators and stakeholders, the protocols and data presentations for real-time radiological surveys are not. Communicating to stakeholders the results from these surveys and the associated risks will require explanations different than those used for traditional sampling techniques.

Real-time radiological data collection techniques have now been used at several sites so that the collected experiences can be evaluated for future users. Case studies document the applications of the detectors on various platforms, on various terrains, measuring different contaminants in combination with dynamic work plans. These case studies confirm that cost savings can be realized by utilizing real-time survey methods in characterization, remediation, and verification phases of the cleanup process.

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REAL-TIME MEASUREMENT OF RADIONUCLIDES IN SOIL: TECHNOLOGY AND CASE STUDIES

1. INTRODUCTION

The ITRC Radionuclides Team developed this technology overview to educate regulators, contractors, site owners, stakeholders, and others involved in site cleanup decisions about the benefits of a streamlined data collection approach that has proven effective at radionuclide contaminated sites and may prove effective at other types of sites as well. This team is primarily made up of state regulators and stakeholders associated with the cleanup of U.S. Department of Energy (DOE) sites contaminated with radioactive materials. Other members include representatives from the U.S. Environmental Protection Agency (EPA), DOE, other federal agencies and contractors. Members of the Radionuclides Team have previously been involved in, or are knowledgeable of, the successful deployment of real-time radionuclide characterization technologies. These experiences led the team to generate this document, which describes the available technologies including benefits and limitations, processes for utilizing the technologies, and relevant site-specific experiences in implementing these technologies. The team's primary goal is to facilitate the exchange of information and experiences among states and DOE sites with regard to improving the cleanup of the contaminated sites.

Real-time radionuclide characterization technologies can bring about significant cost savings and can accelerate schedules, but they do not reduce the need for hands-on technical expertise. The technical understanding and the decision frameworks for this approach are changed from those in a traditional model, but they are not necessarily simpler. In fact, the changes brought about by using real-time measurement systems are too complex for a document of this type to cover completely. It should also be noted that while real-time radiological characterization techniques were developed to assist with site cleanups under environmental regulations, these technologies would be equally applicable to radiological characterization activities in the aftermath of a radiological dispersion device (improvised nuclear device or "dirty bomb"). Thus, this document is not a comprehensive review of the technology base or the decision and planning framework, but rather a useful review to provide the reader with a broad basic understanding of real-time radiological site characterization as it is currently implemented.

1.1 An Introduction to Real-Time Measurement Systems

A site characterization uses data to determine whether unacceptable risk exists at a given site and to determine the nature and extent of the contamination leading to this risk. Data are also collected to determine the design parameters for engineered cleanup solutions, to guide the remediation process, and for verification that the site has been remediated to meet the cleanup standards. In each stage of the characterization and remediation process, information is collected to address specific objectives formally stated as data quality objectives (DQOs). DQOs are qualitative and quantitative statements, such as how many samples are needed and from where they should be taken, that originate from a formalized, seven-step DQO process and are developed to ensure that data are of known, documented, and legally defensible quality with regard to the objectives and decisions for which they will be used.

Data collection and analysis is often a lengthy, iterative process. Environmental samples are taken, sent to laboratories for analysis, and then decisions are made as to whether additional sampling is needed. This process can be costly and time consuming. Real-time data collection, in which data is available almost immediately, can significantly reduce investigation and decision-making costs by relying on field methods for rapid, onsite sample analysis and real-time decision support. This means that decisions can be made in the field to continue or modify an investigation as it progresses, rather than delaying key decisions while awaiting results from a remote laboratory. Additionally, real-time data collection allows data gaps to be identified and filled while the field team is still mobilized. Real-time data collection can also improve remedial actions, such as soil removals, in which excavation is guided by sampling results to determine the extent of contamination. The type, timing, quality, and quantity of data can be optimized to achieve the DQOs.

Improvements in technology and computing capacity have increased the quality of real-time measurement techniques. It is now possible to rapidly screen or scan for a large number of potential contaminants at increasingly lower detection limits. Advances in the speed and capacity of small-scale computers have allowed huge data sets to be handled easily in the field. These advances, combined with recent dramatic improvements in location control and mapping technologies using global positioning systems (GPS) and geographic information systems (GIS), greatly enhance the capabilities of real-time data collection. Various combinations of these technologies provide powerful tools for expediting site closure.

To take advantage of these technological improvements, however, changes must be made to the way in which decisions are made and information is gathered. The Triad approach (EPA 2001 and ITRC 2003) and the *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)* approach (EPA 2000) provide guidance for making the highest quality remedial decisions. The Triad approach to decision making for hazardous waste sites offers a technically defensible methodology that leverages innovative characterization tools and strategies for managing decision uncertainty. The “Triad” refers to three primary components: systematic planning, dynamic work strategies, and real-time measurement systems. In addition to using real-time measurement techniques, both Triad and MARSSIM effectively use more traditional analytical measurement methods. Many state and federal agencies are adopting these streamlined approaches to data collection and management, reflecting a growing trend toward using smarter, faster, and better technologies and work strategies.

1.2 Origin and Purpose of This Technology Overview

This document originated as a result of the convergence of a number of factors, which include the following:

- the advancement of measurement, positioning, and computational tools allowing high quality data to be collected, analyzed, and visualized quickly
- a national need to characterize and remediate very large and complex radiologically contaminated sites in a more cost-effective manner than traditional techniques allow
- developing experience at a growing number of sites where real-time measurement technologies have been deployed to characterize and remediate sites with varying and increasing degrees of regulatory acceptance

- site managers' desire to deploy suites of real-time technologies that integrate and expedite remediation and closure activities because of the recognized cost and schedule savings
- regulatory agencies' desire to more fully understand how these technologies can be used defensibly to reduce uncertainty in decision-making and to confidently confirm the cleanup of large tracts of radiologically contaminated properties
- the development of the Triad approach and MARSSIM (Multi-Agency Radiation Survey and Site Investigation Manual) approaches, which incorporate real-time technologies to survey contaminated sites
- a need for improved real-time measurement instrumentation identified during the ITRC long-term stewardship survey (ITRC 2004)

The document will provide the reader with a basic understanding of real-time radiological site characterization, including these topics:

- real-time field instruments for radiological characterization in surface soil
- radiological data collection methodologies
- decision support roles for real-time measurement systems
- integration of real-time with MARSSIM and the Triad approach
- case studies of actual site experiences implementing these technologies
- benefits and limitations of instrumentation
- location acquisition and mapping integration with data collection
- available processes for maximizing effectiveness of data being collected
- issues relating to regulatory and stakeholder acceptance

1.3 Document Organization

This document first addresses the various technologies that have been combined to create real-time radiological data collection systems and then describes the framework within which the technologies operate (data collection approaches, decision-making, quality control, and regulatory considerations). Next, it presents real world case studies and, finally, offers conclusions about the use of real-time technologies. The appendices include acronym definitions, a glossary of terms, and detailed information on the technologies discussed, as well as additional case studies. Individual sections of the report are described below.

Section 2 describes radiological detection technologies, along with the various platforms to which they have been attached. This section also addresses how real-time data quality is established and describes components of quality assurance and quality control programs for real-time technologies. Discussion of the framework for applying these detection technologies begins in Section 3. This section describes the Triad approach process, which integrates real-time measurements with systematic planning and dynamic work plans, and key aspects of MARSSIM, which offers consistent guidance to planning, conducting, evaluating, and documenting radiological cleanup. Triad and MARSSIM are both conceptual data collection tools and thus have a natural linkage to this document, which focuses on real-time data measurement and collection tools. There is a strong emphasis on MARSSIM guidance since it specifically addresses radiological contamination, but since many sites have both radiological and chemical

contamination on surfaces and in the subsurface, Triad, an overarching approach for deploying real-time instrumentation for site characterization, is also discussed. Various other aspects of MARSSIM and Triad are also presented in greater detail in Appendices C, D, E and F.

The use of real-time data for decision making is discussed in Sections 4 and 5. Section 4 contains a discussion of how the use of real-time measurement technologies fits into the overall remedial decision-making process and how the data from these technologies are used to address uncertainty in that decision making. Section 5 provides an overview of how decision-making uncertainty can be managed, and how cost-effective data collection programs can be developed. Though traditional discrete sampling has a role to play, the spatial uncertainty of radioactive contamination typical of many sites creates by far the largest uncertainty in decision making. Thus, uncertainty is almost impossible to address adequately in a cost-effective manner when using the traditional approach. It is here that real-time measurements can provide a significant benefit to the total data collection program by balancing the amount of discrete sampling and laboratory analysis with real-time field measurements so as to optimize the cost versus uncertainty trade-off.

Section 6 provides help with the critical but challenging requirements of quality control and quality assurance, which are crucial (in both the collection and analysis of data) to “smart” approaches such as Triad and MARSSIM. Since these smart approaches are newer they have not had the same level of quality assurance and quality control (QA/QC) procedure and protocol development as the traditional discrete sampling approach, and consequently users of real-time approaches are burdened with establishing data quality levels and QA/QC programs that assure data quality criteria are met. Section 7 considers issues related to regulatory and stakeholder acceptance of real-time measurement technologies used for characterization and verification.

Section 8 contains five case studies of the application of real-time measurement technologies in the field; additional case studies are provided in Appendix G. Finally, Section 9 draws together observations and conclusions from the document as a whole. References cited in this document are included in Section 10.

2. REAL-TIME FIELD INSTRUMENTS FOR RADIOLOGICAL CHARACTERIZATION IN SOIL

Real-time systems allow characterization to be carried out in the field more rapidly than traditional approaches. Investigations can thus proceed unhindered as timely information is acquired. Recent improvements in detection, location, and mapping technologies have greatly improved the accuracy, mobility, and usability of real-time measurement technologies for addressing radiological soil contamination. The following sections describe field detectors used for radiological contamination (Section 2.1), location control and mapping technology (Section 2.2) and the real-time systems used (Section 2.3). The descriptions are based on information in *The Use of Real-Time Instrumentation to Achieve Site Closure* (DOE 2003).

2.1 Field Detectors for Radiological Contamination

The selection of appropriate instruments for direct field measurements can be a critical factor in meeting the data quality objectives for a site. The choice of instruments may be based on site conditions and the capability of the instrument to detect radionuclides of concern at minimum detectable concentrations that can account for a site's action levels or cleanup levels. Radiation detectors are categorized into four classes: 1) scintillation, 2) solid-state, 3) gas-filled (e.g., ionization, proportional, and Geiger-Mueller), and 4) passive integrating detectors. Appendix H of MARSSIM provides detailed descriptions of various field instruments currently being used. This document will focus on two types of detectors most commonly used at radiologically contaminated sites—sodium iodide (NaI), a scintillation type detector, and high-purity germanium (HPGe), a solid-state type detector.

Field instruments commonly used for detecting radiological contaminants rely on the detection of gamma-ray emissions from the radionuclides of interest. If the decay chain is in secular equilibrium (i.e., the radioactivity of the parent contaminant, over time, becomes equal to that of the progeny within the series), then detection of emissions of one or more decay progeny that are in secular equilibrium with the primary radionuclides are used. Assumptions about secular equilibrium can be confirmed either by a review of the process history of the source materials and the period of time that in-growth of the progeny has known to have passed through or through a definitive spectroscopic measurement that confirms that the parents and progeny are at the same activity level.

Field gamma-ray detectors typically employ one of two types of solid crystals that interact with gamma rays to produce a detectable signal: sodium iodide scintillators and high-purity germanium semiconductor-type detectors. NaI crystals are generally easier and less expensive to grow to large sizes than HPGe crystals. This large size is an advantage, since larger crystals convert more gamma rays to detector counts. NaI scintillators have good efficiency for the conversion of gamma rays; however, their low resolution makes spectrometric measurements of mixtures difficult.

HPGe detectors, conversely, are typically smaller but yield much higher resolution of gamma rays than NaI detectors. Therefore, HPGe detectors are favored when definitive spectroscopic measurements are required. One drawback of their field use, however, is that HPGe detectors require cooling with liquid nitrogen while NaI detectors require no detector cooling. Both HPGe and NaI detectors are described in greater detail below.

While an NaI detector is generally used in a scanning mode to cover large areas quickly, an HPGe detector is generally used to make high-quality stationary measurements, thus NaI and HPGe detectors are complementary in characterizing radiologically contaminated soils. NaI detectors are generally more sensitive owing to their larger energy resolution (about 50 KeV); HPGe detectors typically have a resolution of 2 KeV for the same gamma ray. Although an NaI detector yields a bigger response, it has difficulty resolving bands within a peak; an HPGe detector may have a smaller overall response, but it resolves the peaks which NaI detectors cannot. The superior resolution of the HPGe detector leads to more definitive measurements with these systems when compared with NaI and contributes to the complementary nature of the two systems.

2.1.1 NaI Detectors

NaI detectors are a type of scintillation detector: when a gamma ray enters the detector crystal, electronic interactions inside the crystal can cause light to be emitted. The amount of light emitted is proportional to the energy of the gamma ray absorbed. These light flashes are detected by a photo multiplier tube (PMT) coupled to the detector. To shift the frequency of the emitted light to the range detectable by most PMTs, an activator, usually 0.1% thallium, is doped into the crystal. Thus, the detector is more properly referred to as NaI(Tl).

The PMT converts light flashes to electrical charges, which in turn are measured by a pulse height analyzer. The intensity of the resultant voltage pulse is proportional to the energy of the gamma-ray photon that initiated the sequence. A device called a “multichannel pulse height analyzer” (MCA) performs the function of determining the number of pulses of a given height detected in a given time. A computer which produces a gamma-ray spectrum processes the digital output of the MCA; a total gross count output is also available.

In order for a gamma ray to be detected, it must excite an electron in the crystal from the valence band to the conduction band. A relatively high-energy gap for NaI contributes to the relatively poor resolution of this type of detector when compared with, for example, the HPGe detector. The practical significance of poor energy resolution is the production of gamma-ray spectra that have poor peak resolution, characterized by broad peaks that overlap in many cases.

NaI detector crystals come in many different sizes and shapes, which also affect the performance of the detector. In general, the larger the crystal, the more gamma rays from a given source will be converted to detector counts. The thickness of the crystal also affects the efficiency of the absorption of gamma rays of various energies. For instance, high-energy gamma rays may pass completely through a thin crystal, a property exploited in thin NaI detectors like the Field Instrument for Detecting Low Energy Radiation (FIDLER). This unit detects low-energy gamma rays at high efficiency, while most high-energy gammas pass through the crystal and go undetected. The detection of radionuclides with appropriate low-energy gammas is enhanced by the reduction of background noise from high-energy gammas.

Conversely, thick detector crystals are often useful for the detection of uranium, radium, and thorium isotopes that have prominent high-energy gamma rays. Through the selection of widely spaced gamma rays, these systems can resolve the progeny of uranium-238 (U-238), radium-226 (Ra-226), and thorium-232 (Th-232) used in their detection. However, mutually interfering gamma rays may be present and must be accounted for in the calibration process.

NaI detectors are preferred for performing scanning surveys¹ for several reasons: they are sensitive, rugged, inexpensive, and they require no detector cooling. The modest resolution of the NaI gamma-ray spectrum is generally not detrimental to the objectives of such surveys, which are concerned with identifying elevated areas of radioactivity. A simple measurement of gross activity may be sufficient in these cases. In fact, gamma walkover surveys of gross activity

¹Scanning surveys are initial site surveys that identify areas of elevated radionuclide concentrations and map general patterns of contaminant distribution.

performed with handheld gamma detectors have become routine at radiologically contaminated sites.

2.1.2 HPGe Detectors

HPGe detectors operate with the use of semiconductor crystals as opposed to the scintillation crystals used in NaI detectors. Interactions of gamma rays with the semiconductor crystal produce electron-hole pairs within the crystal, which generate an electrical charge. An appropriate bias voltage must be applied across the detector to collect the produced charges. As previously mentioned, a characteristic of HPGe (semiconductor) detectors is a high degree of energy resolution, typically on the order of 1 to 3 KeV. However, susceptibility to thermal signal degradation must be controlled by maintaining the detector electronics at liquid nitrogen temperatures.

The signal processing train for an HPGe detector is analogous to that of the NaI. Instead of a PMT, a pre-amplifier/amplifier directly converts the electron-hole pairs produced by the detector to inputs to the MCA. Due to the high-energy resolution of the system, a far greater number of MCA channels are used for an HPGe detector than for a NaI detector.

2.2 Location Control and Mapping Technologies

A number of different technologies are available for providing real-time location information during a mobile scan with a real-time measurement system. These range from differentially corrected GPS, to civil survey-grade systems, to tracking laser-based systems, to laser broadcasting systems. Costs and complexity vary significantly and are primarily dependent on the level of accuracy desired. A differentially corrected GPS provides positional control with an error of approximately two meters horizontally and tens of meters vertically. Civil-survey grade systems, whether GPS or laser-based, can provide accuracy to less than a centimeter in all three dimensions, but at significantly greater costs. The primary value of laser-based systems is that they provide three-dimensional location control for excavation work and that they operate even when GPS satellites are not available (e.g., inside or adjacent to buildings).

Recording gross activity data electronically together with location control information provides several important benefits compared with traditional scans or surveys in which the results are monitored but not electronically recorded. The following benefits are often realized:

- *Enhanced QA/QC of data sets.* The logging and mapping of scanned data after its collection allows the completeness of coverage to be evaluated, as well as potential problems with instruments to be flagged and evaluated.
- *Enhanced documentation.* The logging and mapping of scanned data after its collection provide a record of what was done and visual evidence of anomalies (or lack of anomalies) that can be entered into the closure documentation for a site.
- *Enhanced data analysis.* The logging of scanned data allows for post-data collection analysis, including aggregating data through moving window averages to further reduce counting errors, identifying suspect areas that might require additional discrete sample collection, and

determining and delineating excavation footprints on the basis of these data. In general, practical detection limits are lower via post-data collection analysis of data sets than they would be otherwise.

2.3 Real-time Measurement Systems/Platforms in Use

Several technology systems are currently available that combine a GPS, a GIS, and gamma-ray spectrometer(s) to map surface radiological contamination. These systems have been successfully deployed on contaminated federal government properties. In most cases, the systems consist of off-the-shelf components that have been configured to meet site-specific requirements. Generally, these systems map the position and concentrations of gamma-ray emitting radionuclides. The gamma-ray spectrometer measures the intensity of gamma rays that are characteristic of contaminants in the near surface as the system is moved over the surface. Simultaneously, a GPS system measures the location of each measurement. The raw spectral information and location data is telemetered to a central computer located in a support van where spectra are analyzed and converted to concentration (activity) information. GIS software on the central computer is used to prepare color-coded maps of radionuclide concentrations in the surface and near-surface soils of the study area. This approach allows contaminant distributions to be measured in a study area and maps to be prepared within the same day. The available maps, in turn, allow decisions on further remedial action to be made while field teams are deployed or while closure verification processes are in progress. The following sections describe some of the real-time radiation survey systems currently in use.

2.3.1 The Integrated Technology Suite

The Integrated Technology Suite (ITS) that was deployed at the Fernald Closure Project was a real-time field analytical information system that combined gamma-ray spectrometry for NaI and HPGe detector systems with GPS and GIS (DOE 2003). The ITS employed a large 4x4x16 in NaI detector in each of its mobile platforms. These platforms included the Radiation Tracking System (RTRAK), based on an agricultural tractor; the Gator, based on an all-terrain vehicle; the hand-pushed Radiation Scanning System (RSS); and the excavator-mounted excavation monitoring system (EMS). The mobile NaI systems continuously collected 4 s spectra as they moved at a speed of 1 mph over the study area. At this pace, they covered approximately an acre per hour in 3 m wide swaths. The various platforms were suitable to different terrain. The RTRAK is best suited to large open areas with firm ground, while the Gator and RSS can be used in more confined and sloped areas. The EMS was designed specifically for use in support of deep excavations and in contamination areas where its reach-in capability can be exploited. The high sensitivity of the large NaI detector allowed these mobile systems to perform full coverage surveys for the purpose of identifying areas of elevated radionuclide concentrations and to map general patterns of contaminant distribution.

The various mobile NaI platforms, RTRAK, Gator, RSS, and EMS, are described in greater detail below.

2.3.1.1 RTRAK

The RTRAK employs a John Deere farm tractor as its mobile platform. It requires two operators, a driver, and a detector systems operator. A 4x4x16 in NaI detector is mounted at the rear of the tractor at a height of one foot above ground inside a protective PVC tube. The detector system electronics and MCA are located inside the air-conditioned cab of the tractor. The system computer, which is also located in the cab, controls data acquisition and collects raw spectral data from the MCA, along with location data from the on-board GPS receiver. The tractor is driven at a speed of 1 mph, while raw spectra are collected every 4 s. Each spectrum is tagged with location data from the GPS system. Study areas are scanned in back-and-forth passes as in mowing a lawn and, with a detector field-of-view radius of 1.2 m, a single 4 s scan covers an area of 8.8 m². Allowing a typical overlap of 0.4 m for adjacent passes and roughly 4 m² end-to-end overlap for consecutive scans, an acre of land requires roughly 1000 readings of 4 s duration, or about 1 hour, to cover. Raw spectra are sent via a wireless Ethernet connection to the main ITS computer mounted in a panel van, which is located near the study area. Raw spectra are analyzed on the ITS computer in a process which yields the concentrations of the isotopes of interest for each 4 s measurement. Quality checks are performed on the data before it is further used in a GIS application on the ITS computer, which generates color-coded concentration maps of the study area. Maps are generally available within 24 hours of data collection.



Figure 2-1. The RTRAK system

2.3.1.2 Gator System

The Gator is named for the John Deere all-terrain vehicle that serves as the mobile platform for the system. It uses the same NaI detector, system computer, and GPS systems as the RTRAK. The Gator cab is not sealed or air conditioned, and the NaI detector is mounted in front of the vehicle at a height of one foot above ground. Study areas are scanned in the same manner as for the RTRAK. Detector field of view and area coverage rates are the same as for RTRAK. Likewise, data acquisition, transmission, review, and mapping are all done in the same manner as for the RTRAK. Given its lighter weight and all-terrain capabilities, the Gator is used in areas with more difficult terrain than can be surveyed with the RTRAK. A differential GPS system mounted on the Gator was developed to perform accurate topographical mapping of excavation areas. The Gator is driven over excavated areas while recording precise, three-dimensional GPS coordinates. This data is used to determine excavation progress and accurate soil removal volumes on a daily basis.



Figure 2-2. The Gator system

2.3.1.3 RSS

The RSS is the smallest, lightest, and most maneuverable of the mobile NaI systems. It employs a converted three-wheeled jogging stroller as a detector platform. The large NaI detector, mounted in the center of the platform at a height of one foot above ground, is identical to those used in the RTRAK and Gator. The system MCA, GPS receiver, and computer are also mounted on the platform. A single person can operate the RSS. Data are collected in consecutive 4 s scans, transmitted, analyzed, and mapped just as with the other mobile platforms. Coverage rate is the same as for the other platforms, assuming the absence of impediments. Impediments may be present, since the system is intended for use in areas that are not accessible to the larger platforms, including areas with trees or man-made structures.



Figure 2-3. Radiation scanning system

2.3.1.4 EMS

The EMS is the most recent ITS platform developed. It employs a standard John Deere excavator to deploy both NaI and HPGe detector systems in either mobile or static measurement mode. Detector systems, including MCAs, are mounted on a self-righting, vertical, mast attached to the system platform, which, in turn, is mounted on the arm of the excavator. While the system operates in basically the same manner as the mobile NaI systems described above, it is configured somewhat differently. Data acquisition using the EMS is controlled from the main ITS computer in the support van, which also receives, analyzes, and maps data. The system



Figure 2-4. Excavation monitoring

also employs a computer which is mounted on the system platform on the excavator arm and receives signals from the detector MCAs, GPS receiver, lateral proximity sensors, and ground position sensor, all of which are mounted on the system platform or detector mast. Data is sent via wireless Ethernet to the main computer in the support van. The EMS employs a third computer located in the cab of the excavator. This computer presents the outputs from the proximity and ground sensors on an operator viewable display to assist in maneuvering the EMS platform at the end of the excavator arm. The display also presents a real-time coverage map showing a trace of the movement of the detectors so that the operator can assure full coverage. The EMS was developed for use in deep excavations and in trenches, which are not suitable to either mobile surveys or even tripod-mounted static measurements with the other ITS systems. The reach-in abilities of the system also permit measurements to be taken remotely in areas of high contamination. The EMS employs a differential GPS, which allows accurate position

measurements in three dimensions. In this way the depth of each measurement, in addition to its x-y location, can be accurately recorded.

2.3.2 HPGe Systems

HPGe systems are commercially available self-contained detector systems that are deployed either on a conventional tripod or on the arm of an excavator using the recently developed EMS. These detectors produce high-resolution gamma ray spectra, which reduces gamma ray interference and thus allows the accurate determination of multiple gamma-ray-emitting radionuclides in a single measurement. These systems require a counting time on the order of several min. The actual counting time will vary depending on the MDC required.

The tripod- and EMS-mounted HPGe detector systems are used to investigate areas of elevated radiation identified by the mobile NaI systems. They may also be used to characterize areas directly on a smaller scale than is possible with the mobile NaI systems. Static measurements are typically made on a grid pattern over areas of interest. The field of view of an uncollimated detector (one in which the entering radiation is made narrower, or parallel, by an elongated, restrictive aperture) can be adjusted by changing the height of detector over the measurement surface. Alternatively, a collimator may be attached to limit the field of view. The available systems, tripod-mounted HPGe and EMS-mounted HPGe, are described below.

2.3.2.1 Tripod-Mounted HPGe

The HPGe detection systems used at Fernald as part of the ITS include the NOMAD Plus line of tripod mounted systems available from EG&G/ORTEC. These are self-contained detector, controller, MCA, and data analysis systems, which produce a direct report of isotopic concentrations. The systems are calibrated by the manufacturer for the measurement of radionuclide concentrations in surface soil in flat terrain. Measurements are taken at various detector heights to control the size of the field of view; detector collimators are not currently used. Detector heights of 1 m, 31 cm (1 ft) and 15 cm (6 in) have fields of view of 113 m², 20 m², and 3.1 m², respectively. Static measurements are collected for count times of either 5 min or 15 min for various applications at Fernald. The minimal detectable concentrations for selected radionuclides are on the order of 2 pCi/g for U-238, 0.15 pCi/g for Ra-226, and 0.10 pCi/g for Th-232 using a 15 min count time. Tripod-mounted HPGe systems are used at Fernald not only to confirm and delineate areas of elevated radionuclide levels as identified in mobile NaI scans, but also for direct characterization of soils in some cases using multiple adjacent measurements. In areas that have been remediated or are otherwise deemed ready for a final status survey, discrete HPGe measurements over a grid may be used to compare soil levels to release criteria to determine if an area is ready for final certification.

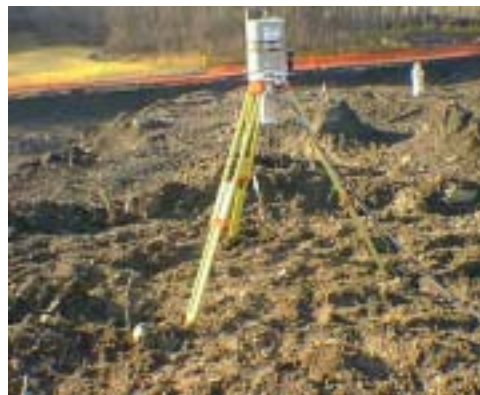


Figure 2-5. Tripod-mounted HPGe detector

2.3.2.2 EMS-Mounted HPGe

The excavator-based EMS was designed to deploy the same HPGe detector systems that are deployed on tripods in conventional applications at Fernald. A custom built detector mount attaches the HPGe detector to the EMS mast, including the Dewar, which contains liquid nitrogen required for detector cooling. Detector signals are fed to an MCA located in the EMS computer box mounted on the platform from which the detector is suspended. Raw spectral data from the MCA are fed to the system computer in the computer box, which then sends them to the main EMS computer in the support van via a wireless Ethernet connection. Raw spectra are analyzed with commercially available software loaded on the main computer. A log file is compiled for each measurement, which includes spectral information, GPS data, time, date, and other pertinent measurement information. Isotopic concentration data is then mapped using GIS software. In addition, all data is archived in the site's master database at the end of each day. Except for some spectral analysis operations, data from HPGe and NaI measurements, described above, are collected similarly using the EMS.

2.3.3 Site Characterization and Analysis Penetrometer System (SCAPS)

The U.S. Army Engineering Research and Development Center has designed technologies that have led to the development of the SCAPS Research and Development Program. The SCAPS platform consists of a 20 ton truck equipped with vertical hydraulic rams that are used to force a cone penetrometer into the ground at a speed of 2 cm/sec to depths of approximately 50 m in nominally consolidated fine-grained soils when using a 100 m umbilical cable (25 m when using 50 m umbilical cables). During a vertical push, data is continuously collected and recorded with 2 cm spatial resolution.

The truck consists of two separate enclosed compartments: the data acquisition/processing room and the hydraulic ram/rod handling room. SCAPS multi-sensor penetrometer probes are equipped to simultaneously measure tip and sleeve resistances to determine soil stratigraphy, layer boundaries, and soil type, as well as to collect contaminant specific sensor data to determine the presence of pollutants in each soil strata. The SCAPS data acquisition room contains a real-time data acquisition and processing computer system, electronic signal processing equipment, and a networked post-processing computer system for 3-dimensional visualization of soil stratigraphy and contaminant plumes. Figure 2-6 shows a typical SCAPS truck configuration.

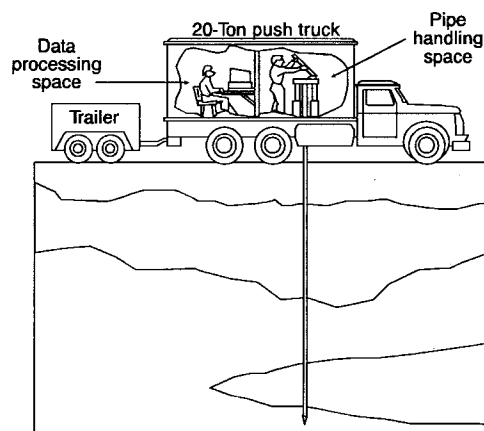


Figure 2-6. SCAPS truck

A trailer-mounted grout pumping system accompanies the SCAPS truck. This system is attached to a specially designed grouting system that has been incorporated into the SCAPS probe to facilitate backfilling the hole with grout as the penetrometer push rods and probe are retracted. This feature prevents subsurface cross-layer contamination. The SCAPS truck is also equipped

with a specially designed steam-cleaning system mounted beneath the truck rod handling room that removes soil and contaminants that may adhere to the push rods and probe during retraction. Contaminated effluent is collected for proper disposal. The SCAPS Enhanced Spectral Gamma Sensor (shown in Figure 2-7 below) detects gamma-emitting radionuclides in soil, groundwater, and mixed tank wastes in situ.

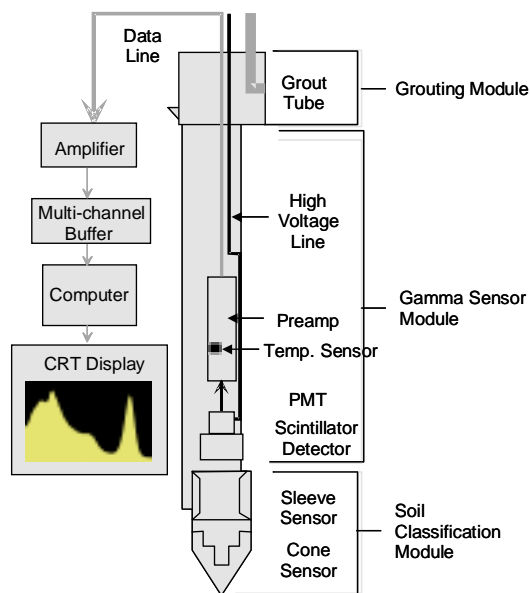


Figure 2-7. Enhanced spectral gamma sensor

2.3.4 Canberra In Situ Object Counting System (ISOCS)

The ISOCS, developed by Canberra, Inc., is a portable, in situ, germanium-based (HPGe) spectroscopy system. The ISOCS obtains data from a distance, operating like a camera, thus minimizing personnel exposure during data collection. The sensor head is remotely located and is operated from a personal computer. The computer controls the analyzer and the software, which provides detailed information on radiation sources. The results can be processed while images and data are being collected and directly reported onsite. The ability to provide quantitative information in real-time reduces the costly delays encountered with offsite analysis. The ISOCS is well suited for characterization of either flat surfaces (e.g., walls and ceilings) or individual objects. This system can identify the type and amount of radioactive source in hotspots, and its remote operation reduces the potential exposure of personnel to high radiation environments.

The ISOCS has been deployed for characterizing both decontamination and decommissioning (D&D) and soil remediation projects on DOE sites nationwide. The system is available with a broad energy capability so that a wide array of gamma emitting nuclides can be detected, including transuranics (e.g., americium-241) as well as the more typical fission and activation products (e.g., cesium-137, cobalt-60).

2.3.5 Global Positioning Radiometric Scanner (GPRS)/ORTEC[®] ISO-CART[®]

There are two in situ radiological measurement systems in use at the Idaho National Laboratory (INL): the INL GPRS manufactured by TSA, Inc. and the ORTEC^{®2} ISO-CART[®]. These systems have been used to support a variety of activities at the INL including routine and emergency environmental monitoring, and environmental actions conducted under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). These are commercially available, stand-alone systems that can be used for identifying radiological contamination in surface soils:

- The INL GPRS is a mobile field survey system designed to rapidly characterize the areal extent of gamma-emitting radionuclide contamination of surficial soils. The GPRS consists of two large-area plastic scintillation detectors mounted to the front of a Humvee all-terrain vehicle that is equipped with GPS navigation instruments. The detector height is fixed at a height of 1 m. At this height, the detector has an approximate field of view radius of 7.6 m. The GPRS uses an on-board computer to integrate the radiological data (counts per second) with the GPS data to provide information regarding the spatial distribution of gamma-emitting contamination.
- The ORTEC[®] ISO-CART[®] system used at the INL is a field-based gamma spectroscopy system that identifies and measures gamma-emitting radionuclide concentrations in surface soils. The system is comprised of a coaxial germanium detector, an ORTEC[®] DIGI-DART[®] (portable, digital spectrometer), a field-rugged notebook computer, and a deployment platform (tripod, wheeled cart, etc.). The detector is typically set at a height of 1 m above the ground, which provides an effective field of view of approximately 20 m. Count times typically range from 5 to 15 min and depend upon the desired detection limit, measurement accuracy, and actual contaminant concentrations. The system uses the M1 software developed by the DOE Environmental Measurements Laboratory (EML). This software uses internal efficiency calibration factors, attenuation corrections, and angular flux corrections to calculate and report the individual radionuclide specific activities (pCi/g) and associated uncertainties.

2.3.6 UltraSonic Ranging and Data System (USRADS[®])

The USRADS[®] technology consists of two functional units: first, a field survey technician equipped with a gamma ray probe and an alpha/beta probe, an ultrasonic transmitter, and a radio transmitter and second, a mobile field station that receives the radio and ultrasonic transmissions from the field surveyor and records the information in a personal computer. The radiometric instruments are mounted on a boom that the survey technician swings in an arc as he systematically transverses the land area being surveyed. USRADS[®] locates the survey technician to within 6 inches once each second using the time of flight of ultrasonic pulses from the transmitter on his backpack to transducers mounted on tripods throughout the survey area. These travel times are reported to the field computer via radio frequency (RF) transmissions.

² References herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government, any agency thereof, or any company affiliated with the INL.

Simultaneously, the radio transmitter on the survey technician’s backpack also sends one radiometric instrument reading each second to the field computer. Approximately 3,600 simultaneous position and radiometric instrument readings are recorded each hour, producing an accurate, high-density representation of the distribution of radioactivity referred to as a “survey track”.

2.3.7 Laser-Assisted Ranging and Data System (LARADS) and Global Positioning Environmental Radiological Surveyor System (GPERS-II)

The Environmental Restoration Contractor (ERC) at Hanford uses two in situ radiological measurement instrumentation systems: LARADS and the GPERS-II. Each is an integration of commercial off-the-shelf detectors, radiological count rate meter(s), position measurement equipment (laser or GPS), and computerized graphics software tools. These systems can provide a real-time visual display of the concentrations and locations of radiological contamination at the work site to guide cleanup and display the final site condition. Each system can use a variety of detectors and can be operated in either a scanning or static count mode, and each enables the operator to document scanning measurements, stationary radiological measurements, and sample locations of surfaces with the radiological readings and exact coordinates, within less than 2 cm (0.8 in), automatically logged in real time. Each can operate on its own, but if needed the two can work together in a combination that supports most in situ radiological measurement needs for the ERC. Figure 2.8 shows a GPERS-II and Figure 2.9 shows an LARADS system.



Figure 2-8. GPERS-II system



Figure 2-9. LARADS cart

The LARADS and GPERS-II systems can be operated using either a backpack-walking stick or a four-wheeled cart with detectors mounted according to the site needs (including size of site, type of terrain, nature of vegetation—sagebrush, trees, etc.). A cart is safer to use on steep slopes than a backpack. The LARADS supports in situ radiological measurement on surfaces inside or outside facilities. The laser position measurement feature is well suited for in situ measurements of interior surfaces (such as walls, floors, ceilings, etc.) where a GPS signal may not be available. The GPERS-II is an outdoors application since it uses a GPS and the associated GPS satellite network. As a backpack, GPS-based system, it is more suitable for surveys of wooded or other outdoor sites where a laser pathway may be interrupted. Figure 2.8 above shows a GPERS-

It with a backpack, walking stick (detector), and a GPS, while Figure 2.9 shows an LARADS cart being safely lowered down a slope with the laser positional tracking system in foreground.

Walking stick surveys for gamma contaminants generally maintain a shielded 2-in diameter by 2 in shielded NaI detector within 8 in of the surface. Cart surveys for gamma contaminants use a shielded NaI detector mounted 8 in from the surface with a 5 ft diameter field of view. For beta surveys (e.g. for Strontium-90), however, two shielded HP210T beta detectors are mounted on the cart, the cart is positioned, the detectors are lowered to within 0.5 in of the surface, and a static count is taken. The window of one of the beta detectors is shielded to exclude the beta and collect only the gamma while the other collects both beta and gamma. The difference is used to determine the beta concentrations at Sr-90-contaminated sites.

3. DATA COLLECTION APPROACHES

The real-time data collection technologies described in the previous section are significant site assessment advances in and of themselves, but the consequences of their availability goes beyond simply improving the same characterization functions under the previously established conventional approach to site remediation. Rather, these new technologies improve data collection strategies and, as a direct consequence, also improve the decisions that are ultimately made with the data—these technologies significantly enhance and redefine existing remedial approaches. To understand this improved approach, it is first necessary to examine how data collection is addressed to best use recent advances in real-time data collection technologies.

Data collection described in this section addresses two applicable approaches: the Triad Approach (EPA 2001, ITRC 2003) and MARSSIM (EPA 2000). EPA's Triad approach combines real-time data with systematic project planning and dynamic work plan strategies for the specific purpose of cutting costs and speeding remediation. MARSSIM was developed by the EPA, the Department of Defense (DOD), DOE, and the U.S. Nuclear Regulatory Commission (NRC) to produce a consistent guidance for radiological cleanup. The following sections briefly describe the two approaches. Additional details regarding Triad and MARSSIM are presented in Appendices C, D, and E. Appendix C contains information on systematic planning and dynamic work strategies, the two other elements which, when combined with real-time measurements, form the Triad approach. Appendix D contains information on three areas important to MARSSIM: key concepts, the graded approach, and the role of field measurements. Appendix E provides a summary of the general components of a possible protocol that could be used on a large and complex site; this protocol combines the Triad and MARSSIM approaches into dynamic work strategies.

3.1 The Triad Approach

Over the past two decades, there have been continued attempts to introduce improved strategies to accelerate the site characterization and remediation processes. EPA now encourages the use of the Triad approach. It is one of the "smarter solutions", offering more effective, less costly approaches to site cleanup and focusing on overall decision quality as the overarching goal of project quality assurance.

3.1.1 Overview of the Triad Approach

The Triad approach combines systematic project planning, dynamic work plan strategies, and the use of real-time data. These components are used interactively to improve decision quality in the remediation process and to expedite site characterization and cleanup. The Triad approach focuses on managing the uncertainty associated with decision making as part of the environmental remediation process. As part of systematic project planning, the Triad approach encourages systematically defining the important issues related to project uncertainty and developing strategies to reduce the uncertainty to acceptable levels. Planners focus on the lack of confidence that exists within the process and the possible sources of uncertainty. While traditional programs focus solely on the errors and uncertainties in analytical measurements, the Triad approach realistically incorporates uncertainties that arise from many aspects of the project: the integrity of historical data, modeling, sampling uncertainties, analytical errors, the representativeness of area covered and more.

Also critical to systematic planning are the development and use of conceptual site models. Conceptual site models capture what is known about the state of a site, particularly the information that pertains to potential decisions. A complete conceptual model is instrumental in identifying data gaps that contribute to the majority of the uncertainty associated with site decision making. This, in turn, supports the development of data collection strategies that target those data gaps.

Under the Triad approach, dynamic work strategies are built into project work plans, which are written in a flexible mode to guide the project to adapt in real-time. The work plans recognize that during the course of data collection, particularly when real-time measurement systems are used, project teams can adjust or modify work to accommodate those results. This may mean modifying the locations and/or frequency of sampling, adjusting analytical techniques, or changing the course of excavation work during remediation. The object is to ensure that the resulting effort, whether it is data collection or remediation, remains as targeted on the original goals as possible and that work can be adjusted to remain focused on those goals when site conditions turn out to be different than those assumed in the site conceptual model. Dynamic work strategies assume that timely information is available upon which to base modifications to what is being implemented. This underscores the importance of the third leg of the Triad approach: real-time data collection. Real-time measurement technologies gather and share data quickly enough to support real-time decision-making.

3.1.2 Data Quality Indicators (DQIs) for Radiological Measurements Using the Triad Approach

DQIs are properties within a measurement process that describe the quality and reliability of the measurement in terms that are useful to the observer. These properties can be compared to the DQOs used for specific, individual measurements to evaluate the suitability of prospective methods. In the case of radiological measurements, DQIs can be affected by the instruments response due to factors such as temperature/weather, source range, response time, etc. Care must be taken to consider all benefits and shortcomings of each instrument. Accuracy must be measured against set standards established for each instrument type. Other factors in DQIs include bias, precision, detection limits, completeness, and comparability.

Application of the Triad approach to radiologically contaminated sites is based on the recognition that overall decision uncertainty with respect to achieving soil cleanup levels is generally dominated by uncertainty due to the small number of samples collected³. Traditional sampling program designs have been criticized for considering sampling error separately from analytical error (if at all) while over emphasizing the latter. Under the Triad approach, it became apparent that resources would be most effectively used by increasing the number of samples collected to reduce sampling error, while using relatively inexpensive field analysis methods or in situ measurements with perhaps greater uncertainty than laboratory analyses. While individual sample measurement (analytical) error might be greater under this approach, this error is more than compensated for by a reduction in sampling error through the collection of a greater number of samples (measurements). Further benefits are accrued from a reduction in overall characterization time using real-time or short-time analyses in the field.

DQIs of in situ gamma measurements within this Triad context are the basis for many of the benefits attributable to using the Triad approach at radiologically contaminated sites. A detailed discussion of these—measurement accuracy, precision, representativeness, inferences, comparability, and sensitivity—is provided in Appendix D.

3.1.3 Benefits of the Triad Approach

The Triad approach offers several benefits over traditional programs. These benefits include the following:

- Real-time data are often less costly per measurement than traditional laboratory analyses. Significant cost savings can be obtained during characterization, assuming that real-time data meet the data quality needs of a project and contribute to reducing uncertainty in decision making. This was demonstrated by the Integrated Technology Suite (ITS) systems at Fernald.
- Real-time data and dynamic work strategies allow for work to adapt or adjust to information as it is produced, resulting in more efficient data collection programs and remedial efforts. In the case of remediation work, the cost savings from these adjustments can be significant. Specifically, these strategies allow continuous excavation operations, waste stream minimization, and precise excavation at soil remediation sites.
- Real-time data combined with dynamic work strategies can significantly shorten the characterization, remediation, and closure cycle for sites. Given the ability to generate real-time data in the field, characterization, remediation, and site closure could possibly be combined into one field deployment.
- Real-time data can produce a better overall remediation product than a traditional program because work can be adjusted to account for unexpected findings.

The Triad Approach is an example of one of the enhanced strategies that has become available due to the past three decades' scientific, field, regulatory, and public participation experience. The foregoing discussion provides a brief overview; more detailed information and internet resources are provided in Appendix C.

³ This applies to other media in varying degrees as well.

3.2 The MARSSIM Approach

While the Triad approach is an overall strategy for achieving cost-effective site remediation and could apply to any site, MARSSIM, described in the section below, includes guidance focused specifically on radiological contamination. It is similar to Triad in that it recognizes the benefits of flexibility and incorporates a performance-based approach, systematic planning, and the DQOs process. The following section briefly outlines MARSSIM, with additional information on key concepts such as derived concentration guideline levels (DCGLs), the gray region, the graded approach, and the role of field measurements presented in Appendix D.

3.2.1 Overview of MARSSIM

MARSSIM is a guidance document that was collaboratively developed by four federal agencies: DOD, DOE, EPA, and NRC. MARSSIM provides an approach for planning, conducting, evaluating, and documenting building surface and surface soil final status radiological surveys for the demonstration of compliance with dose or risk-based regulations or standards. In addition to the participation of the federal agencies, an extensive peer review of the guidance was conducted by EPA's Science Advisory Board, whose members were drawn from major universities, state regulatory agencies, national laboratories, and consulting firms. The discussion of MARSSIM included in this section is either paraphrased or drawn directly from Revision 1 of the MARSSIM document (EPA 2000).

The purpose of MARSSIM is to provide a standardized and consistent approach for planning, conducting, evaluating, and documenting environmental radiological surveys, with a specific focus on the final status surveys (e.g., to demonstrate closure) that are conducted to demonstrate compliance with cleanup regulations. This approach is scientifically rigorous and is flexible enough to be applied across a wide range of sites. MARSSIM was developed for the investigation, cleanup, and closure of thousands of federal facilities where radioactive materials were produced, processed, used, and stored. The facilities range in size from single room labs to production facilities encompassing many square miles.

The scope of MARSSIM is currently limited to surface soil and building surfaces because many sites have extensive soil and building surface contamination problems. In addition, computer models used to calculate radiological dose and risk primarily address exposure arising from contaminated soil and building surfaces and cleanup criteria are often established for surfaces. MARSSIM does not address subsurface material, other media (i.e., construction materials, groundwater, surface water, and sediments), utilities, or nonradiological contaminants. There are no restrictions built into MARSSIM, however, that would prohibit the principles from being applied to situations falling outside its explicit scope. MARSSIM also does not provide guidance for developing cleanup standards or translating them into DCGLs.

3.2.2 MARSSIM Perspective on the Role of Field Measurements

The term “measurement” is carefully defined in MARSSIM to mean “1) the act of using a detector to determine the level or quantity of radioactivity on a surface or in a sample of material removed from a media being evaluated, or 2) the quantity obtained by the act of measuring” (EPA 2000). MARSSIM encourages the use of field methods as part of a site's measurement program. Direct measurement and scanning methods are examples of methods that are used in

the field. Frequently, however, sites possess a number of contaminants that may display heterogeneous patterns of distribution. Thus, instrumentation and characterization techniques must be capable of assessing the levels of contamination over large areas and also capable of determining whether smaller elevated areas exist. For these reasons, it is unlikely that a single instrument can meet all of the site's measurement requirements. When field methods cannot detect radiation levels below the DCGLs, discrete samples and laboratory methods are required.

3.2.3 MARSSIM Approach to Characterization, Cleanup, and Closure

MARSSIM's concept of a data life cycle—a process that describes the flow of data and manages the uncertainty so as to support sound decision making—encompasses the processes of survey planning, survey implementation, and assessment of survey results prior to making a decision. The first step in the data life cycle, survey planning, is developed using the DQO process. While the term DQO has long been familiar to analytical chemists in relation to mandatory objectives of analytical precision and accuracy, it has a broader meaning as it is used in MARSSIM. The DQO process is a series of planning steps, based on the scientific method, for establishing criteria for data quality and developing survey designs (EPA 1987a, b, 1994). The DQO process focuses on the decisions that are required to achieve closure of final status survey units and ultimately establishes the type, timing, quality, and quantity of data required to make decisions.

Technical defensibility, a product of the scientific method when it is properly applied, is a crucial component of the decision-making process. MARSSIM extends the application of the scientific method via the DQO process to the closure of radiologically affected sites. The DQO process provides systematic procedures for establishing the survey design criteria, including when and where to perform measurements, the level of decision errors for the survey, and how many measurements to perform. The DQO process uses a graded approach that defines data quality requirements according to the type of survey being designed, the risk of making a decision error based on the data collected, and the consequences of making such an error. Key elements of the DQO process include clear statements describing the nature of the problem, the decision to be made, identification of the inputs to the decision, determination of spatial boundaries within which the decision criteria will apply, and the use of a decision rule or statement that can be answered by the collected data within the specified limits on the decision error.

This brief consideration of MARSSIM has been included to provide a perspective on a planning, implementation, evaluation, and documentation approach for environmental radiological surveys within which real-time measurement technologies can play an important role. A more detailed consideration of MARSSIM, as well as related internet resources are provided in Appendix D. Also included in Appendix D is a summary of the general components of a possible protocol that combines the Triad and MARSSIM approaches into dynamic work strategies. This protocol could be used on a large and complex site for fulfilling the remaining characterization and site closure needs.

3.3 Integration of the Triad Approach and MARSSIM

The Triad approach and MARSSIM were developed separately to address different areas of concern; however, they share common origins in the need for better evaluated, more flexible solutions to the traditional slow and expensive approach to site cleanup. Both necessarily

incorporate flexibility into their application, and both recognize the value and encourage the use of real-time measurement systems and field-deployable analytical techniques where appropriate. These two tools can be complementary, since remediation of a radiologically contaminated site could use the Triad approach as its overall strategy, while at the same time using MARSSIM to develop efficient survey designs and a standardized basis for making accurate remediation decisions. Integrating the Triad approach and MARSSIM can be of benefit to field managers. An example of the integration of the Triad approach and MARSSIM is presented in Appendix D.

4. REAL-TIME MEASUREMENT TECHNOLOGIES USED IN SITE CHARACTERIZATION, REMEDIATION, AND CLOSURE

Real-time technologies fit into the overall remedial decision-making process and are used to address uncertainty in that process. The following section elaborates on the decision support role provided by real-time measurement systems during various phases of the cleanup process and details commonly encountered problems in use of these systems. This discussion primarily focuses on the CERCLA decision-making process applicable at many sites; however, the principles outlined here can be used under other regulatory frameworks as well.

4.1 Decision Support Roles for Real-Time Measurement Systems

The decision that must often be made at a given site is whether or not a specific area (final-status survey unit, remediation unit, etc.) meets cleanup criteria. If a real-time measurement system is to play a role in this decision, it must provide information about the presence or absence of contamination above the criteria. Invariably, the real-time system is combined with some form of traditional discrete sampling and laboratory analysis to provide a basis for decisions. The exact nature of this mix will depend on the specific requirements of the data collection combined with the capabilities of the available real-time measurement systems.

Real-time measurements are most effective in these settings:

- when a dynamic work strategy, such as is used by the Triad approach, is in operation
- when the real-time data collection and analysis focus on reducing the uncertainty associated with the decision to be made
- when data collection is staged in a manner that emphasizes real-time measurements at first, followed by more traditional sampling and laboratory analysis as a follow-up
- when verification and validation sampling and analysis data collection for the real-time measurement technology are an integral part of the overall data collection program
- during excavation to direct work in a manner that allows continuous progress and verification simultaneously

The dynamic work strategies mentioned above are developed as part of the work plan that allows for the benefits offered by real-time measurements, described previously: a response can be adjusted or adapted in real-time to the results of real-time measurements. For example, on the basis of real-time results, a decision might be made to collect a discrete sample and send it for more traditional laboratory analysis. Real-time measurement systems, combined with this

traditional discrete sample data collection, can provide critical support for a number of key activities in the CERCLA process.

4.1.1 CERLCA Decision Making

While there are many specific decision points encountered when implementing CERCLA, most turn on a simple question: does a particular area contain contamination at levels that are unacceptable from a human or ecological health risk perspective? During the preliminary assessment (PA), the answer to this question determines whether a complete remedial investigation/feasibility study (RI/FS) is required. During the RI, the answer dictates whether any site remediation is necessary. During the remedial action (RA) design and implementation, the answer decides whether or not particular parcels of land or groundwater units are remediated. Post-remediation, the answer determines whether closure has been attained.

The nature and extent of contamination at hazardous waste sites are never known with complete certainty. Because of this inherent uncertainty, decisions that need to be made during the course of a CERCLA project also have associated uncertainties. Either of the two types of errors can be made when answering the fundamental question about the presence or absence of contamination above some acceptable level: Type I⁴, which occurs when an area is declared clean, though in reality it still has contamination above the cleanup criteria, and Type II, which occurs when an area that really is clean is declared still contaminated. The first error results in residual contamination left behind that poses unacceptable risks. The second error results in unnecessary remediation and associated costs. The probability of making these mistakes is a measure of the uncertainty associated with the CERCLA decisions that must be made thus the lower the probability, the less the decision-making uncertainty. This notion of uncertainty is consistent with the EPA's approach to decision making. It is also consistent with MARSSIM's approach to uncertainty in the final-status survey process.

4.1.2 Preliminary Site Assessments/Site Investigations

The principal goal of a preliminary site assessment/site investigation (PSA/SI) work is to identify whether concerns are warranted about risks from environmental contamination at a site. While PSA work focuses on historical document review, interviews, and other anecdotal information regarding site use, limited, selective data collection during an SI can also assist in supporting the findings of the review. Real-time measurements are well suited for this type of work, particularly those that can quickly identify the presence of classes of contaminants that may be at levels of concern (e.g., gross gamma activity for gamma-emitting radionuclides). During a preliminary SI, real-time techniques serve two purposes: 1) identifying the presence of potential contaminants of concern (COCs) for selected areas of a site (allowing for effective biased sampling using more traditional laboratory analyses to identify and quantify the individual contaminants of concern that may be elevated) and 2) providing a rapid means for assessing the potential extent of problems that have been identified.

One of the possible outcomes of a PSA is the determination that all or portions of a site are not of concern. This is effectively a closure decision and represents an example of how information

⁴ Type I and Type II errors are discussed in detail in Appendix D.

other than discrete sample results from traditional laboratory analyses is used to support closure decision making. In MARSSIM parlance, this is equivalent to concluding there are no impacts to a site or portions of a site (i.e., areas have no reasonable potential for residual contamination).

4.1.3 Remedial Investigations

Site characterization work is conducted during a RI. At this stage of the process, sufficient evidence from a PA or SI exists to indicate that a site has been adversely affected by contamination. The questions in RIs are: what is the nature and extent of these impacts and what risks are posed? RI work also generates information that can serve as the basis for an FS and may be the basis for a remedial design.

Data generated by an RI are used to clearly identify COCs and the levels at which they are present. Because of this data need and the potential for litigation for some CERCLA sites, traditional sampling and laboratory analyses with definitive contamination identification capabilities and controlled measurement error constitute the backbone of the RI data collection effort. Real-time data collection can supplement more traditional RI data collection activities by assisting in determining where biased RI sampling should take place. Real-time data collection can also be effective in determining the likely spatial extent of impacts from contamination. This information is crucial for evaluating remedies in an FS and provides a key input to remedial design work.

4.1.4 Remediation Support

Real-time measurement systems become critical in remediation support. By this time in the CERCLA process, COCs have been identified and cleanup criteria derived. This provides definitive performance standards that can be used for selecting and evaluating potentially applicable real-time systems. The use of real-time measurement systems can facilitate the implementation of improved remediation strategies, such as precise excavation and in situ segregation of soils for disposal purposes. EPA CERCLA guidance recommends that estimates of risk based on direct exposure rate measurements of penetrating radiation may be used as a real-time method for indicating that remedial objectives are being met during the conduct of the response action. The use of exposure rate measurements during the conduct of the response actions may not decrease the need for a final status survey (EPA 1999).

These strategies can result in a remediation program that reduces costs while providing a better remediation project (i.e., lower probabilities of missed contamination). Real-time measurement systems can also be used to fill specific needs associated with particular sites. One example of such a specific need is segregating soils that exceed waste acceptance criteria at the waste stream destination. Additionally, real-time measurement enables site personnel to quickly verify concentrations, thus allowing high-cost remediation equipment and crews to remain productive. This offers a tremendous cost-saving advantage over a traditional approach, in which equipment and staff would be idle while awaiting laboratory results.

4.1.5 Closure Support

Nothing within MARSSIM or current EPA guidance precludes the use of real-time measurement systems for supporting closure or final-status survey decision making. Real-time measurement systems are particularly appropriate for demonstrating compliance with hot spot or elevated area requirements. The prerequisites for real-time measurement use for closure are assuring that performance requirements are met and that adequate QA/QC is in place to demonstrate that performance requirements are being satisfied. The ability to provide nearly 100% coverage of the remediation area generally reduces the risk of Type I error.

4.2 Commonly Encountered Issues

For radioactively contaminated sites, a number of common issues frequently complicate characterization and remediation. The availability of real-time measurement technologies can present alternative approaches to address at least some of these issues. This section discusses a number of common issues that may arise in the context of potential real-time measurement technology applications during actual site investigations and describes suggested approaches for addressing these issues.

4.2.1 Large Areas

For federal facilities, the sheer size of potentially affected areas can challenge the design and implementation of affordable characterization and/or closure data collection programs, particularly when the baseline consists of traditional, static work plans based on discrete sample collection and laboratory analysis. A common challenge when dealing with large areas lies in the determination of average conditions. While average conditions can be estimated even for large areas with relatively sparse data collection efforts, the primary concern is the identification individual sub-areas that have been impacted by contamination. Uniform coverage of large areas with standard gridded sampling programs often leads either to very large costs or very large grid spacing between sampling locations (i.e., higher Type I error chance). The availability of real-time measurement systems within the Triad approach and/or MARSSIM context provides technically defensible alternatives that can produce superior characterization results at much lower costs.

The availability of real-time data collection technologies provides additional opportunities for addressing contamination concerns in large areas more cost-effectively than traditional techniques. Walkover-based gamma scans, wheeled gamma scanning techniques (such as mobile NaI systems) or the NaI flyover technologies employed by DOE's Remote Sensing Laboratory can provide complete characterization coverage for large areas at relatively minimal costs. For example, a gross gamma walkover survey combined with a GPS and data logger can cover an acre for a few hundred dollars, representing per measurement costs on the order of a few pennies.

The real-time nature of these systems means that when potential anomalies are encountered, data collection can be modified or adapted to resolve anomalies. For example, if a walkover gross activity NaI system identifies a potential anomaly, a surface sample can be taken. Alternatively, if mobile gamma spectroscopy using one of the mobile NaI systems identifies a potential anomaly, a longer, stationary reading can be collected over that location to a lower detection sensitivity to eliminate the possibility of a false positive.

The following are key steps in selecting an appropriate approach to address large areas:

- determining whether the characteristics of the likely contamination lend themselves to real-time in situ detection
- matching detection sensitivities, the sizes of areas that would be of concern, and the overall size of the area requiring characterization with the appropriate scanning approach (walkover versus drive over versus flyover, as well as appropriate instrumentation)
- developing the optimal mix of approaches and decision-making logic within a dynamic work strategy e.g., if a flyover measurement indicates a given condition, then a follow-on measurement by in situ gamma spectroscopy will be required.

4.2.2 Radiological and Chemical Contamination

Many sites include collocated chemical and radiological contamination in media. The presence of collocated radiological and chemical waste usually presents special challenges from a waste disposal perspective (i.e., separating low-level radiologically contaminated media from mixed-waste streams or waste that has only chemical contamination). Waste stream profile characteristics can have significant cost and logistical implications for an overall remediation program. Bounding these implications requires understanding the characteristics of potential waste streams, such as contaminated soils, before remediation begins.

For situations where it can be assured that the radionuclide contamination footprint envelops the chemical contamination footprint and where waste stream segregation is not also an objective, characterization efforts can potentially be reduced to a radionuclide detection program, even when the primary risk concerns are associated with chemical constituents. In this setting, the availability of real-time radionuclide methods can be a boon from a chemical perspective since, in general, the capabilities of radionuclide real-time detection are significantly greater than the capabilities of real-time detection of nonradioactive species. For example, there currently is nothing as robust as a gamma walkover survey for producing spatially complete characterization information for chemical constituents of concern. The principal objective in this setting is determining a radionuclide-based proxy or surrogate that can be measured and that can be reliably used to identify and delineate problem areas. Developing this relationship between a radiological real-time technique (such as surficial scan) and the cleanup decision to be made typically requires a site-specific applicability study in which paired information exists for a number of locations (that is, where both real-time results and information pertinent to the cleanup criteria are available) and that the data in general can provide the needed assurance that by mapping the extent of radionuclide contamination the full extent of chemical (nonradionuclide) contamination will also be captured.

4.2.3 Potential for Buried Contamination

One of the most daunting problems that site remediation planners face is the possibility of buried contamination. “Buried contamination” refers to contamination overlain by uncontaminated material. The data collection issues posed by buried contamination are certainly not exclusive to radionuclides; generic hazardous waste sites have these issues as well. The principal problem with buried contamination is that its presence cannot be determined using surface scanning,

direct measurement techniques, or traditional surface soil sampling, all of which typically only measure activity within the top few inches of soil.

The scope of MARSSIM specifically does not include buried contamination issues, although the general concepts of MARSSIM still apply. As with large areas, the starting point for the design of a graded data collection program would be the conceptual site model (CSM). The CSM would identify those locations most likely to yield contaminated subsurface samples and would prioritize them in order of their likelihood to have contamination above levels of concern.

A number of real-time or near real-time techniques are applicable to subsurface soil contamination identification. Surface-based techniques include a wide range of geophysical tools including seismic, electromagnetic, magnetic, gravity, and ground-penetrating radar surveys. While the surface-based surveys cannot identify specific contaminants, they can detect buried debris or areas of the subsurface that may have been disturbed as a result of waste disposal or dumping. In addition, they can be used to identify important subsurface pathways such as conductive hydrogeologic layers, utility races, or subsurface cavities.

Intrusive tools may or may not be capable of detecting specific contaminants. Typical intrusive techniques include direct-push in situ sensors that might be associated with a CPT or GeoProbe^{®5} system, ex situ core scanning technologies (ranging from simple scans of cores or subsurface soil samples with a handheld probe to more sophisticated core scanning systems), and real-time measurements of sampled intervals from the core (e.g., onsite gamma, alpha or beta spectroscopy, or x-ray fluorescence [XRF] for contaminants such as total uranium). In all cases, the objective is the same: to quickly screen cores for the presence of contamination likely above levels of concern.

In most cases, both surface and subsurface techniques are best used to reduce spatial uncertainty and to more clearly identify subsurface regions where focused sampling (real-time or traditional) can be conducted. These are the key steps in selecting an appropriate approach to address areas with the potential for buried contamination:

- developing a site-specific CSM that captures what is known about the presence or absence of buried contamination above cleanup goals across the area and the level of confidence associated with conclusions drawn from that information
- using this CSM to identify locations across the area that are most likely to yield subsurface samples with contamination above levels of concern
- determining whether geophysical techniques may have potential for reducing spatial uncertainty in the subsurface
- determining whether the characteristics of the suspected contamination lend themselves to real-time detection using retrieved cores or in situ gamma spectroscopy
- developing the optimal mix of approaches and decision-making logic within a dynamic work strategy setting (e.g., if a core scan yields a given result, then a follow-on analysis of a soil sample by alpha spectroscopy will be required)

⁵ Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

4.2.4 Inadequate Previous Characterization

Under the CERCLA process, the primary step for characterization work is the RI. The primary purpose of the RI is to support a baseline risk assessment, to determine whether remediation is warranted, and to provide sufficient information to support an FS. RI rarely produces sufficient information to adequately support remedial design and implementation, much less fulfill the needs of final status survey design. Shortcomings in RI work can take many forms. There may be complete areas of a site that were not characterized or were under characterized. Areas may have had adequate surface characterization but have incomplete subsurface data. Areas may have been well sampled, but the analytical suites may have been incomplete. Finally, in cases in which characterization and remedial work have persisted over a long period of time, existing data may no longer be considered representative of the current conditions of the site.

Inadequate characterization data can affect a remediation program in a number of ways. For example, it may lead to an incorrectly designed or scoped remedial effort (e.g., contamination volumes and extent are much more significant than RI data suggest); such an issue is primarily of concern to site owners who will have to bear the added expense after the incorrectly designed remedial effort has been revealed as a failure during cleanup. Alternatively, it may produce an erroneous final status survey classification in the MARSSIM closure process; this can be an issue for both site owners and regulators, since it can result in the discovery of unexpected contamination during the final status survey process and/or the collection of inadequate final status survey data collection for some areas, leading to the risk of missing unacceptable levels of contamination. Inadequate characterization becomes a particularly pressing problem as pressures mount to begin site remediation work or to bring a site to closure. In these settings, there may be neither time nor patience to design and implement another round of traditional characterization work.

Inadequate characterization should be reflected in the CSM that is produced by systematic planning under the Triad approach. Inadequate characterization manifests itself as unacceptable decision uncertainty for specific areas within the CSM. An example would be insufficient information to correctly designate MARSSIM final status survey unit classes for specific areas. Real-time measurement technologies within a Triad process can play a key role in addressing inadequate characterization problems while still maintaining required schedules. Since a Triad approach emphasizes the use of dynamic work strategies, contingencies can be built into work plans to accommodate unexpected results as they are encountered. Returning to the example of MARSSIM final status survey unit designations, if insufficient data were available to support classification for a particular area, the RA plan might incorporate the use of additional real-time data collection within the area of concern, with the contingency options of remediation and Class 1 survey unit designation if contamination above DCGL requirements were discovered, or Class 2 survey unit designation if nothing was discovered. Real-time data access would ensure that decisions could be made in a timely manner in response to results without compromising overall schedules.

4.2.5 Elevated Area or Hot Spot Cleanup Criteria

MARSSIM presumes that sites will have two types of cleanup requirements: a DCGL_w (or wide area average criterion), and a DCGL_{EMC} (or elevated area comparison criterion). Establishing

compliance with elevated area or hot spot cleanup criteria can be one of the most daunting technical challenges of closure data collection programs. By definition, “elevated area” refers to relatively small areas easily missed by traditional sampling programs that might have activity concentration levels so high that they exceed site dose or risk standards. While statistical methods exist for developing gridded sampling programs to identify elevated area concerns with a specified level of confidence, realistically the required grid spacing may result in cost-prohibitive data collection programs.

Real-time mobile scanning technologies have the potential for cost-effectively addressing $DCGL_{EMC}$ compliance demonstration requirements. In fact, MARSSIM presumes that if a scanning technology exists with appropriate detection sensitivities, this would be the preferred approach simply because scanning technologies can guarantee complete, or nearly complete, spatial coverage for exposed surfaces, something impossible with discrete sampling programs. The key steps in selecting an appropriate scanning approach to address $DCGL_{EMC}$ compliance needs include the following:

- determining whether the characteristics of the likely contamination at $DCGL_{EMC}$ levels lend themselves to real-time scanning detection
- matching detection sensitivities, the sizes of areas that would be of concern, and the overall size of the area requiring characterization with the appropriate scanning approach (walk-over versus drive over versus flyover, as well as appropriate instrumentation)
- developing the optimal mix of approaches and decision-making logic within a dynamic work strategy (e.g., if a walkover measurement yields a gross activity value above this investigation level, then a follow-on measurement by discrete sampling will be required)

For many commonly encountered radionuclides such as Th-232, Ra-226, cesium-137 (Cs-137), cobalt-60 (Co-60), Ra-228, and U-238, there are scanning technologies available that will perform well for $DCGL_{EMC}$ requirements. For others, including Thorium-230 (Th-230), various plutonium isotopes, technetium-99 (Tc-99), and tritium, directly identifying the presence of these radionuclides at likely $DCGL_{EMC}$ levels with a scanning technique may not be possible. Instead, they may be collocated with other gamma-emitting radionuclides that can act as proxies or surrogates during a surface scan.

Elevated areas in the subsurface are extremely difficult to address completely. Unlike surface contamination, there are no options for providing 100% coverage of subsurface soil, sediment, or groundwater to guarantee that elevated areas do not exist. However, a surface scanning approach can be applied to subsurface contamination during excavation. The surface survey strategy is singularly applied to set excavation intervals or layers (e.g. surface scans at every 1 meter lift).

5. ADDRESSING UNCERTAINTY IN DECISION MAKING WITH REAL-TIME MEASUREMENTS

Remediation decisions are based on information. This information can take many forms: interviews with knowledgeable people, historical records, site walkovers, aerial photographs, non-intrusive geophysical survey results, fate and transport modeling, and, of course, physical samples of soils, water, sediments, and biota. Together, these various sources of information

support decision-making. The coverage, support, accuracy, and precision of these information sources, as well as their relationship to the actual cleanup standards that apply to a site, determine the probability of making an incorrect decision about the status of a particular site or area. This section provides an overview of how decision-making uncertainty can be managed, and the challenge of developing cost-effective data collection programs.

By directly analyzing for the particular COCs required by a cleanup standard, traditional sampling and laboratory analysis can minimize the decision-making uncertainty about the relationship between the sampled parameter and the cleanup standard. The spatial variability typically associated with many field sites, however, creates much larger decision-making uncertainty in terms of the ability of discrete sampling to adequately cover the site in a cost-effective manner. It is in addressing this area of decision-making uncertainty that real-time measurements can provide a significant benefit to the total data collection program. By balancing the amount of discrete sampling and laboratory analysis with real-time field measurements during each phase of the CERCLA characterization and remediation process, the remedial project costs and uncertainty for making cleanup decisions can be effectively managed.

An understanding of statistical techniques is important since a discussion of uncertainty is best conducted within an objective statistical framework. The literature on Triad states that Triad's central concept is uncertainty management and this discipline is inherently statistical. As an example, the selection and implementation of statistical procedures for Triad projects is always based on both the project-specific CSM and on specific project decisions, since common statistical procedures are based on assumptions of homogeneity that may easily be violated by the distribution of contaminants at a site. Similarly, MARSSIM provides a process for collecting, organizing, and interpreting data and for making decisions about populations of data from samples. Statistics are useful for inferring population characteristics from a set of samples and also facilitate decision making in conditions of uncertainty. MARSSIM recommends nonparametric statistical tests, such as the Wilcoxon Rank Sum Test and Sign Test, to evaluate environmental data, but it permits a wide variety of statistical tests designed for specific situations.

5.1 Sources of Uncertainty in Environmental Decision Making

Although one of the principal goals of CERCLA is to reduce the risk associated with hazardous waste sites, risk (or dose) is never directly measured. Instead, contaminant concentrations are used as a proxy for risk or dose. The presence of contaminants above or below cleanup concentration levels determines whether a site has met, or failed to meet, cleanup goals. Complete specification of a concentration-based cleanup requirement includes both the concentration level and the area over which it must be applied. Traditionally, concentration levels have been measured by collecting and analyzing discrete samples from the media of concern. In reality, the very nature of trying to measure the concentrations of contaminants at a field site using any measurement method, be it traditional sampling and laboratory analysis or real-time field measurements, introduces uncertainty about what the contaminant levels truly are. Recognizing this inherent uncertainty is critical in order for decision makers to make realistic judgments about site cleanup needs.

5.1.1 Three Basic Sources of Uncertainty

There are three basic sources of uncertainty introduced into decision making by the use of environmental measurements. The first is the strength of the relationship between what is being measured and concentration-based standards (inferential uncertainty). The second (analytical measurement uncertainty) is associated with measurement errors (precision and accuracy). The third is associated with establishing conclusions about the state of an area from limited sampling points (spatial uncertainty, or coverage and support).

5.1.1.1 *Inferential uncertainty: Relationships between measured parameters and cleanup criteria*

The strength of the relationship between what is being measured and the concentration-based standard is particularly important from a real-time measurement system perspective, since what is being measured is often not a COC, but rather a proxy. A common example is measuring gross gamma activity with a mobile scan as a proxy for radionuclide-specific cleanup criteria. There are analogous examples in the chemical world, such as immunoassay test kits and total organic carbon sensors.

One means of capturing the relationship between a measured parameter and cleanup criteria is through the use of statistical regression analysis. Regression analysis is applied to correlate a measured parameter value with a particular contaminant concentration. Linear regression is the most common technique used, but it often fails to provide satisfactory results for a number of reasons. One is the fact that real-world relationships are rarely linear over the complete range of measured parameter values and corresponding contaminant concentration levels, non-detects and outliers can interfere with linear regression results. In addition, fundamental statistical assumptions (e.g., normal data distributions) underpinning regression analysis often are not valid.

Figure 5-1 shows the results of a regression analysis used to relate FIDLER results to Th-230 concentrations at a particular site. The data are presented as a scatter plot of FIDLER gross activity readings taken before samples were collected and analytical laboratory results (Th-230 concentration) from the samples were evaluated. The relatively poor regression “fit” and visually disappointing correlation are not uncommon.

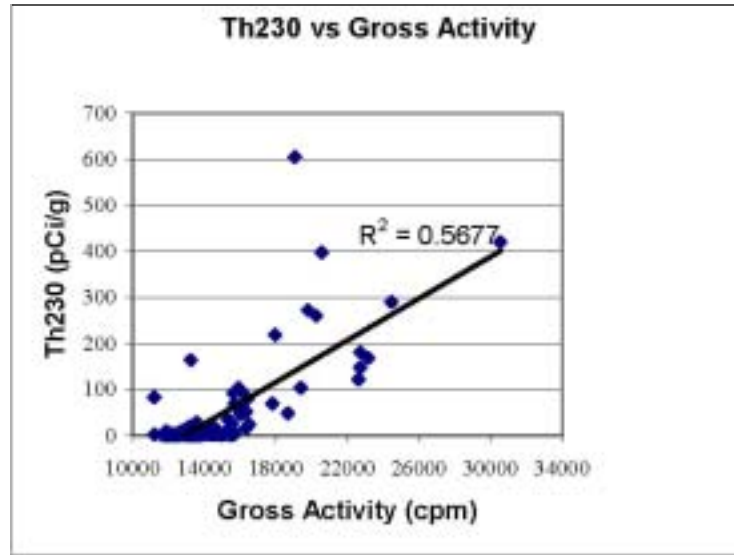


Figure 5-1. Scatter plot of gross activity (cpm) and Th-230 activity concentrations

A second method for capturing the relationship between measured parameters and contaminant concentration cleanup standards is through the use of nonparametric statistical techniques. These recognize that the decision to be made must be binary, e.g., is a contaminated area above or below the relevant cleanup criteria? The goal of this analysis is to relate a measured value with the probability that it represents a cleanup goal exceedance. Figure 5-2 presents the same data as Figure 5-1 but in a different format. Even though a linear regression analysis suggests there was only a marginal relationship between gross activity and the Th-230 concentration measured at the site, Figure 5-2 shows that, in fact, for wide ranges of observed gross activity, there is a strong relationship to data being either above or below the Th-230 cleanup criteria (40 pCi/g Th-230).

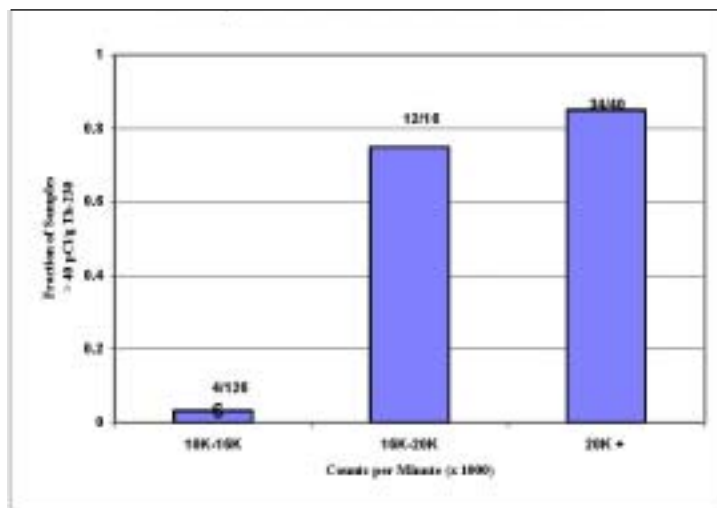


Figure 5-2. Relationship between gross activity and probability of exceeding Th-230 DCGL

5.1.1.2 Analytical measurement uncertainty: Accuracy and precision for measurement systems

Accuracy is the degree of agreement between the measurement and the true value of the parameter being measured. In some cases, the parameter may be the actual contaminant itself (e.g., Th-230). In other cases, it may be a parameter with some relationship to the COC (e.g., gross activity). Issues associated with accuracy are either related to the presence of measurement bias or problems with precision.

Bias measures the difference between the average of repeated measurements and the true value of the parameter. For traditional laboratory analysis of samples, addressing bias concerns is an intrinsic part of the laboratory QA program. Bias is managed by proper calibration procedures and is monitored using blanks and spikes. For real-time field measurement systems, there may be other sources of potential bias that can be minimized in the analytical laboratory. Principal among these are environmental effects (e.g., soil moisture, climatic conditions, etc.) and potential interference from other constituents in the media being measured.

The precision of a measurement system refers to the scatter observed in results from repeated measurements of the same sample: the larger the scatter, the less the precision. Precision is usually expressed as the standard deviation or standard error associated with repeated measurements. Measurement systems can have excellent precision but poor accuracy (i.e., significant bias). Measurement systems can also have no bias but poor precision. Poor precision can mask bias problems. For standard laboratory analyses, bias and precision are sometimes lumped together as “measurement error” and expressed as control limits on sample results (e.g., recovery for a known spike must be within 30% of the spiked value, or similar types of requirements for replicate sample analyses on the same aliquot).

5.1.1.3 Spatial uncertainty: Coverage and support for measurement systems

The concept of measurement or sample support refers to the actual volume or area of material being measured by a particular analytical or measurement technique. Traditional soil samples measure a half liter of soil or less. Direct measurement techniques, such as an in situ XRF measure a quantity of soil significantly less than this. In contrast, a stationary NaI gross activity reading taken one foot above the ground may measure several square meters of surface area down to a depth of several inches. An in situ HPGe reading, uncollimated and set at a height of 1 m, may measure a 100 m² area down to a depth of several inches. In general, when a contaminated area is exhaustively measured or sampled, the smaller the sample or measurement support, the greater the variability in the results, assuming measurement errors to be negligible (i.e., highly precise measurements).

Coverage refers to the fraction of an area of concern that is actually measured by a sampling or measurement program. For most sampling programs involving discrete samples, the coverage is infinitesimally small. In contrast, measurement programs that make use of mobile scans can produce coverage that is complete for an area, assuming the focus is surficial soils. The concept of sample support, coverage, and the averaging-area definitions associated with cleanup criteria are intimately linked. All complete specifications of cleanup criteria include a definition of the area (or volume) over which the criteria must hold, on average. There would be no uncertainty

associated with a decision about whether contamination for an area exceeds cleanup standards if a data collection method could meet certain conditions:

- cost-effective, complete coverage of an area with a technology that had a sample support equivalent to, or less than, the cleanup criteria area definition
- minimal measurement error
- a perfect relationship between the measured parameters and whether or not the COCs exceed the cleanup objective

5.2 Relative Importance of the Sources of Uncertainty in Environmental Decision Making

Traditional QA/QC programs for environmental remediation projects generally focus on only one of the three sources of uncertainty—analytical measurement error (precision and accuracy). The predominant source of uncertainty for CERCLA decision making, however, can be either measurement error, incomplete coverage, or the relationship between measured parameters and COCs. The source of uncertainty at a given site will depend on the type of data collection program and technologies used.

For data collection programs based solely on limited, discrete sample collection and traditional laboratory analysis, errors arising from incomplete coverage combined with natural spatial variability predominate. Because traditional laboratory analysis usually directly measures COCs, the strength of the relationship between measured parameters and cleanup criteria is irrelevant. Traditional laboratory analyses involve QA/QC requirements that usually limit relative measurement error to about 30% of the true parameter value. This level of error turns out to be insignificant when compared with errors arising from incomplete coverage. In practice, measurement errors associated with traditional sample analyses can be typically ignored for decision-making purposes, with sample results treated as relatively errorless. The real source of decision error in the case of traditional sampling programs comes from inferring the contamination status of an area based on limited sample results. The only way to reduce this uncertainty is to increase the number of samples collected.

For data collection programs based primarily on field analytics applied to discrete samples and/or stationary in situ measurements with direct measurement systems, such as an in situ HPGe gamma spectroscopy system, the remaining two general sources of error (inferential and analytical measurement) become much more important. Because real-time measurements are typically less expensive than traditional laboratory analyses, many more samples can be collected and analyzed in the field or more in situ measurements can be made for the same data collection budget. This, in turn, can reduce the error associated with incomplete coverage to acceptable levels, at the expense of potentially greater measurement error relative to analytical laboratory results and weaker relationships between measured parameters and COC-specific cleanup criteria. The uncertainty associated with these errors can be reduced by investments in QA/QC and the ongoing collection of data for validation purposes.

For data collection using scanning technologies, such as RSS or RTRAK, the uncertainty associated with incomplete coverage is not an issue because scanning systems typically provide 100% coverage for a particular area. Uncertainties associated with decisions based on data from

these systems are completely a function of measurement errors and inferential uncertainty. Once again, uncertainty reduction is achieved by investments in QA/QC and ongoing validation data collection.

5.3 Managing Environmental Decision-Making Uncertainty

The goal of an efficient and effective data collection program design should be to keep decision-making uncertainty at acceptable levels for a minimal cost. For any particular site, the most efficient and effective data collection program will likely be discrete sample collection and traditional laboratory analyses combined with alternative real-time data collection methods. The real-time methods provide more spatially comprehensive coverage and obtain results quickly enough to allow the program to adapt to what has been found. This is the essence of the Triad approach (systematic planning, dynamic work strategies, and appropriate real-time analytical techniques), and is completely consistent with MARSSIM guidance.

In general, managing decision-making uncertainty is synonymous with keeping the probability of making Type I and Type II errors at acceptable levels. In the case of false negatives (missed contamination), error rates are typically negotiated with regulators. False positive error rates, however, are in fact a characterization and remediation design parameter that must be considered in conjunction with other remediation factors, such as overall remediation costs. For example, if unit remediation costs are low compared with data collection costs, limited data collection and relatively high false positive rates may make the most sense for a particular project. If, on the other hand, unit remediation costs are high and data collection costs low, the best balance may be significant data collection resulting in low false positive rates.

6. QA/QC FOR REAL-TIME MEASUREMENT PROGRAMS

QA/QC requirements for real-time measurement programs are subject to the same requirements as traditional laboratory-based programs. Real-time programs, however, have not had the same level of programmatic development of QA/QC procedures and protocols that benefit traditional programs. Users of real-time approaches, therefore, face the additional burden of establishing the data quality levels that are achievable by real-time technologies and developing a QA/QC program that assures an appropriate level of data quality at each site where the technologies are used. The following sections present some key elements of establishing a real-time QA/QC program. In addition, the concept of DQIs—quantitative properties that describe the quality and reliability of the measurement process and that are an essential component of EPA required quality assurance program plans—are discussed in Appendix F.

6.1 Establishing Real-Time Data Quality

As in any measurement program, the requirements for data quality and measurement system performance are determined in the DQO process. These requirements are expressed in terms of the list of radiological constituents that must be analyzed, the minimum detectable concentrations that must be achieved, the reliability of measurements in terms of correct identification of analytes, and the overall allowable quantitative uncertainty in measurements. Once requirements are established, measurement technologies are selected that can achieve these

requirements based on principles of operation and general experience. Once selected, the actual performance capabilities of the technologies must be confirmed with an appropriate level of testing prior to use.

Some essential performance requirements and characteristics that must be established in advance for prospective real-time technologies that support soil remediation are as follows:

- identity of all applicable action levels relevant to the nuclides of interest
- identity of progeny with useful gamma rays if nuclide of interest has no useful gamma rays
- identity of surrogate nuclide with useful gamma rays if nuclide of interest has no useful gamma rays
- identity of interfering gamma rays for parent, progeny, or surrogate nuclides
- identity of prospective detector types for measuring the identified gamma ray emissions
- identity of detector types for measuring gross activity from nuclides of interest if isotopic measurements are not possible or desired
- energy and abundance of gamma rays emitted by radiological analytes
- estimates of total propagated uncertainty for the quantification of radionuclides of interest by prospective real-time technologies

Soil conditions and contexts, within which real-time measurements are to be made, strongly influence the performance of real-time systems used in support of soil remediation. Some important considerations in this regard are as follows:

- *Topography of survey areas.* Deviations from an ideal flat, smooth terrain must be noted. Such deviations will affect measurements to some degree and must be accounted for.
- *Surface coverage.* Measurements are calibrated to a bare soil surface. Grass and nonwoody vegetation minimally affect measurements, while concrete or asphalt covering have a large effect.
- *Soil moisture.* The water content of soil affects quantification. Measurements are typically reported on a dry basis after correcting for soil moisture. Measurements in soil with moistures above 30% by weight are problematic. Measurements should not be made over standing water or ice.
- *Measurement geometry.* Soil surfaces must be accessible to allow for a reasonable measurement geometry/detector orientation approximating that used in calibration. Obstacles at the fringes of the field of view have a greatly reduced effect on quantification and can often be ignored.
- *The parent material context.* Certain shales will contribute to elevated levels of gamma.

In addition to pre-established essential performance requirements and soil conditions, a third factor affecting soil measurements is contaminant distribution in soil. Real-time calibration models typically assume flat soil geometry with contaminants uniformly distributed within the

effective field of view of instruments. Some measurement considerations in this area are as follows:

- Lateral inhomogeneities are not “averaged” to produce a mean value of contaminant concentrations in the field of view but are affected by detector location with respect to areas of high or low concentrations because of the nature of gamma-ray fluence in flat geometry.
- Inhomogeneities, including those caused by obstructions, have the strongest influence directly beneath the detector and the weakest influence at the fringe of the field of view. For a quantitative measurement, the field of view should be moved or reduced to view an area that is as homogeneous as possible.
- Deviations from assumed uniform concentration with soil depth result in measurements that are biased high when contamination is confined to a thin surface layer and biased low when concentrations increase with depth or are covered with “clean” soil or any covering of uncontaminated material.
- In the application of real-time in situ measurement systems and in the interpretation of results, a conceptual model for the distribution of contaminants should be based on an understanding of the release, migration, and deposition of contaminants. The degree and direction of deviation from the assumed uniform distribution of contaminants should be estimated and a determination made on the acceptability of the effects of such deviations on data quality.

6.2 Developing a QA/QC Program

A central theme for approaches, such as Triad, that make use of real-time data collection is the explicit identification and management of the largest sources of decision error, especially the sampling representativeness of the data. A QA/QC program is essential to ensure that identification and management of these error sources is being accomplished properly. Once the measurement process described in the previous section has been well defined and parameterized, a QA/QC program should be developed that has the objective of maintaining the measurement systems within acceptable tolerances. The developed program should address all the measurement factors described above. The QA/QC program should consist of an initial set of tests to establish system performance and a program of a continuing set of operations, practices, and measurements that are designed to maintain system performance within established limits.

Both types of QA/QC measures involve a process of verification/validation. Initial system performance is validated and verified using a set of standard reference materials and a means of comparing system response to a theoretical ideal response. Continuing system performance QA/QC is itself a process of validation and verification of system performance as initially established.

6.2.1 Initial Setup and Calibration

Calibration of detector response to radionuclide concentration in soil is normally the first and most important initial performance test. There are two basic methods of calibrating in situ gamma detectors. The first method, known as the “point source” method involves the use of small standard sources placed at defined distances and angles relative to the detector crystal to characterize detector response. The gamma-ray fluence from the point source striking the detector is calculated from the strength of the source and basic geometric principals. The detector efficiency as a function of source orientation and gamma-ray energy is determined from the battery of measurements. This response function is then used in a mathematical model of soil contamination in a flat geometry that computes known gamma-ray fluence at the detector to determine detector response as a function of soil concentration for any gamma-ray energy. This model includes factors for gamma ray attenuation by soil and air. Therefore, it is valid only if the soils to be measured have a similar attenuation factor and contaminant distribution.

The second basic type of calibration involves the use of a calibration pad. A calibration pad is constructed using discrete sources or a uniformly distributed source in the calibration pad substrate, which may be soil, concrete, or some other material. With the use of discrete sources, the gamma-ray fluence field must be determined using a mathematical model that considers the strength, location, and orientation of sources, as well as factors for soil and air attenuation when sources are embedded in the pad. A uniformly distributed source is simpler to model but much more difficult to prepare. In either case, secondary standards are typically used in the preparation of the pad, since the amount of radioactive source material required is high compared to the point source method. The use of primary standards might be cost-prohibitive in many cases.

The calibration pad method is a more direct method than the point source method, since geometric factors are considered in the construction of the pad rather than in the calibration procedure itself. In either method, it is not necessary to use the actual radionuclides of interest, because calibration involves determining detector response as a function of gamma-ray energy. Note that when the isotopes of interest are used in a calibration pad, the calibration process is simplified further still.

Gamma detector response has been established to be linear over a fairly wide operational range of gamma fluence. As a result, it is generally not necessary to perform a multipoint calibration curve for the detectors. Such a linear response can be easily verified using a point source calibration where it is a simple matter to vary fluence strength by moving the source standard nearer or farther from the detector. This test is much harder to perform using a calibration pad.

The use of the point source method to verify the linearity assumption alludes to a broader strategy of calibration verification using elements of both types of calibration. Each method can be used to validate the other. While a calibration pad would not be built to verify a point source calibration, agreement between the methods would verify the respective sources and models used in each case.

6.2.2 Data Analysis and Reduction

The second major aspect of setting up the real-time measurement process that requires development and verification is in the area of data conversion and data reduction processes. The generation of real-time gamma measurement requires the collection of count rate data that must be converted to activity concentrations in soil using gamma-ray analysis and conversion equations and the inputs needed to perform the calculations. While detector data analysis is a part of the calibration process, data analysis can be considered separately in the context of a QA/QC program. Two basic types of gamma ray measurements are involved in real-time programs, gross count and isotopic. Both measurement types generally require that count rate data be converted to soil activity.

Gross activity data alone might be used in initial walkover surveys, but to compare soil conditions to action levels, a conversion of count data to soil activity is ultimately required. For gross activity measurements, this conversion requires knowing or assuming the radionuclide composition of the soil in terms of the relative concentrations of gamma-emitting radionuclides, and caution must be exercised here since these assumptions can be a source of significant uncertainty. Alternatively, spectrometric measurements determine this composition directly. Such measurements require additional data analysis and conversion steps.

Gross activity measurements can be related to soil concentrations by examining detector count rates in areas of known composition. While point source or calibration pad calibration would be useful in such cases, it is often possible to use site data to produce a useful correlation for the screening purposes. If this approach is used, gross activity measurements would be recorded over areas of known composition as determined by laboratory or in situ spectrometric methods. A regression of detector response to soil activity concentration would produce a workable calibration for screening purposes.

Isotopic measurements involve a spectral analysis step to strip out counts for individual gamma-ray peaks. Raw data in this case are processed through an MCA that sorts detector counts into channels, or energy bins, ranging from low to high energy. The output of the MCA, after a sufficient counting time, generates an energy spectrum in the spectrum record with distinct peaks for characteristic gamma-ray energies. The data analysis process begins by determining the identity, that is, the energy, of the various peaks in the spectrum. Characteristic peaks at low, medium, and high energies that are known to be present, either from a calibration run or from background radionuclides in soil, are located first. An exact energy per channel value is then determined to apply to other peaks to compute peak energy from channel number.

Identified peaks must then be stripped from the background to determine the number of counts attributable to individual gamma rays and thus specific radionuclides. Peak stripping can be accomplished by subtracting the background counts as determined in the vicinity of a given peak. Peaks that are not completely resolved can be handled by conventional peak separation or deconvolution techniques. Peak stripping algorithms in the data processing system of gamma spectrometers apply calibration factors to convert peak count rates to soil activity concentrations for radionuclides of interest. Inputs needed for this conversion include the detector efficiency for the incident gamma rays, a fluence-to-source concentration ratio for each gamma ray measured, count time, and soil moisture level. The automated peak stripping and data conversion process

performed by the gamma spectrometers data system must be reviewed by the system operator to check for interferences or other measurement complications.

The QA/QC program for the initial set up of real-time gamma measurements should include the following items:

- identification of primary standards
- verified calibration algorithms that convert detector channel counts to gamma-ray fluence
- verified data conversion algorithms that convert gamma ray fluence to soil concentration
- procedures for peak identification and stripping, including identification of reference peaks and background subtraction method
- procedures for reviewing spectra for interferences or system malfunctions
- procedures for performing the initial calibration
- procedures for confirming calibrations with check standards
- procedures for confirming the ability to resolve and quantify the radiological suite of interest
- procedures for determining the minimum detectable concentrations of the radionuclides of interest
- procedures for confirming the linearity of detector response
- requirements and procedures for verifying and validating all system software

6.2.3 Continuing Operations

The second major component of a QA/QC program for any analytical system, including real-time gamma systems, addresses the daily use of the system after initial setup and calibration. This component consists of a set of requirements, checks, measurements, and procedures that are designed to assure that measurement systems are operating within acceptable limits as established by the requirements of the measurement program and confirmed during the initial setup and calibration. A QA/QC program for real-time measurements would be similar to that for any measurement program and would contain many of the same basic components. While such a program is not described in detail here, it would contain the components listed below:

- pre-operations check list
- daily energy calibration check
- daily check of peak shape and resolution
- daily analysis of a soil control or background location
- post-operations check list
- daily GPS pre-operations and calibration checks
- daily pre-operations test on moisture determination instrument
- daily pre-operations tests on wireless data communications systems
- annual detector characterization/calibration
- procedure for updating calibration factors
- annual MDC determinations
- periodic comparison tests with alternate methods (e.g., laboratory)
- procedures for completing field logbook for routine and non-routine measurements

- procedures for data processing, management, and archiving
- procedures for performing soil moisture measurements
- procedures for preparing performance control charts, for example, for energy calibration, background levels, interference levels, and control station concentrations, etc.
- specification of periodic quality control field measurements, principally duplicates
- specifications of limits on soil and topographic conditions related to soil type, moisture, obstructions, debris content, surface cover, roughness, and deviations from flat terrain.

The components listed above reflect the requirements of a program involving isotopic measurements. Some of the requirements would be reduced or eliminated for gross activity measurements.

6.2.4 Data Documentation and Defensibility

Real-time gamma data collected in support of soil remediation must meet the data quality and documentation requirements of the regulatory program, typically CERCLA or NRC decommissioning, under which it is collected. Chemical analysis protocols established under CERCLA provide a good model for designing a program to meet such requirements. While detailed guidance documents, a long history of use, and a well-established market have rendered high-quality chemical analysis data a readily available commodity, a similar level of development has not occurred for radiological measurement and for real-time measurements in particular.

The above discussion of QA/QC for real-time measurements provides a foundation for designing a program that will meet regulatory requirements and stand up to technical scrutiny. While this guidance identifies the elements of such a program, those elements must be fully described and routinely documented in any measurement program that supports regulatory action, or any meaningful use for that matter. The documentation requirements established under the CERCLA program provide a useful guide for designing a similar program for real-time measurements. Similarly, the real-time programs established and approved at ongoing radiological cleanup sites, such as Fernald, provide a good model for designing programs for new sites.

6.2.5 Chain-of-Custody for Real-Time Measurements

The technical advantages of the Triad approach using real-time measurement systems are described in other parts of this document. A further advantage of this approach is a reduction in the number of parties and organizations involved in the collection, production, and processing of data. This advantage results in a reduced role for chain-of-custody documentation because most of the sample and data handling is performed within a single organization. Further, since much of this approach involves in situ measurements, there is often no material sample that requires custody documentation.

Chain-of-custody in a Triad-based real-time program reduces the documentation of the data collection process, but depends upon the accountability of field personnel who collect data and all personnel involved in the data processing chain. Accountability for the data is accomplished through the completion of field logbooks and the completion of log files in the various data systems associated with each measurement. The integrity of that information is assured through

the use of secure data systems and networks and through the log entries of all individuals who manipulate data from the point of its collection to its ultimate archiving in a secure database.

7. REGULATORY AND STAKEHOLDER ACCEPTANCE ISSUES

A number of regulatory and stakeholder acceptance issues have emerged from experience with deployments of real-time measurement systems at soil cleanup projects. While these systems represent novel and, in some cases, precedent-setting technologies and approaches that support soil characterization and remediation, they have not met with immediate acceptance by regulators or stakeholders. These individuals generally have long used and accepted baseline technologies consisting of physical sampling techniques and laboratory analysis of samples. The following section examines some of the regulatory and stakeholder acceptance issues that can arise at soil cleanup sites which use real-time characterization technologies.

7.1 Regulatory Issues

Most regulatory issues are based upon the traditional sampling issues of data quality, precision, and accuracy. CERCLA cleanups have historically required a very high degree of data quality and documentation due to the potential for litigation surrounding the characterization and remediation of the site. The potential for litigation has historically driven regimented sampling and analysis protocols that are repeatable and precise but might be limited in scope. These protocols often rely heavily upon statistical tests of laboratory data to support conclusions. It is with this background that most regulators will first review a real-time monitoring program.

In order for real-time technologies to find acceptance at a site, QA/QC protocols must be thoroughly evaluated and documented. Accuracy and precision are important aspects of this evaluation. The highly variable nature of environmental conditions may raise additional questions about repeatability and quality control. This will often result in the need to create a calibration pad to routinely check the instruments under varying environmental conditions. These QA/QC issues are covered in more detail in earlier portions of this document.

Factors such as soil moisture, vegetative cover, and time of day (among other factors) may significantly affect the results of data collection instruments. Thus site specific protocols must be developed and then rigorously followed in order to ensure proper data quality. Additional detail on the development of such protocols can be found in the Fernald case study in Section 8. The Fernald team developed detailed testing protocols, QA/QC requirements, a calibration pad, and data evaluation tools to support implementation of the real-time technologies at the site.

Regulators can quickly realize one of the greatest benefits of real-time measurement technology is the very high percent coverage achieved, which greatly reduces the probability of missing areas of contamination. Statistical analysis provides some level of confidence when using traditional sampling approaches, but these approaches never achieve the level resulting from a 100% survey via real-time. The possibility of missing significant areas of contamination between sampling points is greatly reduced with the use of this technology.

Another benefit regulators find in the technology is the ability to direct excavations in a more timely and confident manner. Coupling a real-time scanning approach with lift by lift excavation allows for accurate excavation while not significantly decreasing excavation efficiency. This is one way real-time data collection can be of use in retrieving buried contamination. This approach was used in multiple instances at the Fernald site.

One of the most controversial issues for real-time characterization is the use of the technology for final certification. The ability to use the technology for final certification will be highly dependent upon the contaminants in question and environmental conditions. At some sites, such as Fernald and Rocky Flats, the regulators decided against using real-time technologies for certification for a number of reasons. First, the technology was new at the time of program development, thus raising questions of data defensibility in the CERCLA process. Second, real-time measurements are generally less precise and accurate than discrete soil-sample analysis. Third, at some sites the need to use surrogate radionuclides could lead to greater inferential uncertainty. Another important and probably overriding consideration at Fernald was that other contaminants which could not be measured with real-time (such as metals or Tc-99) required certification. Certification of these compounds required collection and analysis of a physical sample. The need to collect a physical sample for other contaminants greatly reduced any benefits to using real-time measurements for certification, so the decision was made to use physical samples for the certification of all contaminants. Regardless, real-time technologies were heavily relied upon in pre-certification screening to ensure the area was adequately remediated prior to mobilizing a large physical sampling effort.

In general, a well designed and documented real-time characterization program should be seen as an asset to most site characterization plans. It allows for a more comprehensive characterization at lower cost and faster implementation than is typical of the baseline physical sampling paradigm. When presented with a well planned and documented real-time program, regulators have agreed that this approach can benefit the characterization, remediation, and closure process.

7.2 Stakeholder Issues

Stakeholders are all interested parties, public or private, who are not facility owners or their representatives, regulatory agencies, or government appointed review groups (such as the National Academy of Science). This designation also includes members of the public, Indian tribes, and municipal, county, or state elected officials who are interested in the cleanup and condition to which the facility or land will be restored. The techniques discussed in this technology overview are not familiar to most stakeholders, thus the facility or land owner and the regulatory agencies need to identify appropriate stakeholder groups and work with these citizens and their elected officials throughout the characterization and remediation process. A stakeholder information plan should be developed early in the process. This plan must be reviewed with the stakeholder groups so that they will understand what is being done and why. In regard to real-time measurement systems, the following considerations are important to the stakeholders:

- stakeholder implementation plan
- stakeholders' input to and acceptance of the stakeholder implementation plan
- adequate cleanup levels for end use of the land (appropriate cleanup criteria for industrial, residential or recreational use)

- frequent and understandable communication during the planning and implementation process and again at its conclusion
- agreement with owner/regulators on process to be used for survey and cleanup
- agreement in principle with many of the issues discussed in earlier sections of this report (QA/QC, surrogates used for contaminant of concern, etc.)
- explanation of the purpose of the monitoring vehicles and monitoring equipment and the limitations of this equipment
- access to the site to see vehicles and instrumentation, since first hand observation makes a lasting impression

Since the process being discussed involves a team of site owners and regulators working together in the field to expedite the process, stakeholders are often concerned about two significant issues:

- *Accountability and responsibility.* Who is providing oversight? How do stakeholders know that the process has not been compromised by pressure to get the job done?
- *Peer review.* Peer review by one or more uninvolved scientists is needed throughout the process. These reviewers brief the stakeholders on the direction and acceptability of the actions being taken, and specifically evaluate whether or not the actions meet the agreed upon goals for the process.

7.2.1 Stakeholder Implementation Plan

This plan should be developed as the systems are being selected. It should identify who stakeholders are, what will be communicated to them, and how communication will be conducted. Early in the process, the site owner and regulators should review the draft stakeholder plan with stakeholders and incorporate their input and concerns. The plan should be reworked as needed and presented to stakeholders for final input and agreement.

7.2.2 Stakeholder Education and Communication

Stakeholders should be educated as to what systems will be used and how it will accomplish the site objectives. Good communication on these details will educate stakeholders on the effectiveness of the planned program. Experience with stakeholder planning shows that viewing the equipment in the field will help stakeholders understand the planned effort. This should be done as soon as the equipment is available. Finally, stakeholders will want many of the same questions answered as regulators will, consequently, involving stakeholders as early as possible in the process prevents repetitive briefings and also enables the stakeholders to inform other stakeholders about site issues.

7.2.3 Cooperatively Addressing Concerns

The processes described in this document are targeted at performing the most efficient cleanup possible. An efficient cleanup requires both appropriate owner representatives and regulators to work on teams in the field to minimize the time lost in communicating findings from one organization to another. Stakeholders should agree with the concept proposed since it accomplishes three major concerns: 1) getting the job done as safely and quickly as possible; 2)

anticipating unexpected conditions; and 3) completing the survey so that it is unlikely that contaminants will be missed. Having the owners, regulators, and stakeholders working together minimizes the first concern; real-time monitoring should help minimize the second two concerns.

Stakeholders may be concerned that if regulators work directly with a responsible party, the regulators may lose their objectivity. Normally owners and regulatory personnel are thought to moderate each other and reach good decisions, but sometimes stakeholders may feel the need for further independent oversight of the work with findings being reported directly back to them.

7.2.4 Stakeholder Involvement

A key component in stakeholder relations is to establish a stakeholder group that will act as a liaison to the public and elected officials and then to keep this group informed throughout the process. Good communication between the various groups involved in a site can minimize problems associated with unforeseen circumstances. When these circumstances arise, the existing trust that has been developed through good communications can help to resolve needed changes in the process plan. All parties benefit from open, honest, and frequent communication throughout the planning and implementation process.

8. CASE STUDIES OF THE APPLICATION OF REAL-TIME MEASUREMENTS

This section provides brief summaries of five case studies—Oak Ridge, the Savannah River Site, the Tonawanda Formerly Utilized Sites Remedial Action Program (FUSRAP) site, Fernald, and Kirtland Air Force Base—of situations where real-time measurement technologies have been used in the field. Two of these case studies address surface contamination, two address sub-surface contamination, and one addresses both. Further information on these and additional case studies is provided in Appendix G.

8.1 K-25 Site, Oak Ridge, Tennessee

8.1.1 Background

ITS, a non-intrusive technology, was developed by Fluor Fernald to characterize radiologically contaminated surface soils. To test the technology, the U.S. Department of Energy conducted field tests at the K-901, a North Disposal Area (NDA) located at the East Tennessee Technology Park (ETTP, previously known as Oak Ridge K-25 Site) during July–October 2001.

8.1.2 The ITS Technology

The ITS system used included a 4x4x16 in NaI detector mounted on a mobile conveyance, a tripod mounted HPGe detector, a GPS, a Zeltex moisture meter, Ethernet communications, Lab View linking software, EG&G Office Gamma Vision analytical software, and Surfer-6 mapping software.

The NaI detector collected both gross counts and gamma spectral data every four seconds as it moved across the surface at 1 mph. The GPS documented the elevated areas identified by the

NaI detector. The HPGe system was set up at the identified elevated radioactivity areas to obtain high-resolution gamma ray spectra over a 2.5 m field view, using 15 min gamma ray count times. The Zeltex meter was used to adjust gamma data to account for shielding by soil moisture.

8.1.3 ITS Characterization Process

The NaI detector identified six areas of elevated radioactivity at the NDA. The gamma spectra was used to collect, analyze, and interpret the radioactivity concentration for Ra-226, Th-232, and U-235. Uranium levels in parts per million (ppm) for each of the six areas were also determined. The gamma ray special data were compared to the analytical results for soil samples collected from five of the six areas. To correlate and approximate the geometry of the HPGe's 2.5 m field of view, ten soil samples were collected from each of the areas, and for each radionuclide, a weighted-average composition was calculated.

8.1.4 Data Analysis

Based on ITS field test, the following conclusions were drawn regarding ITS accuracy. The ITS predicted concentrations were generally comparable to, though typically lower than, soil sample concentrations. The ITS field effectiveness for high contaminant concentration could not be gauged, however, because high concentrations—high or higher than action levels—were not encountered. While U-235 was not detected by the ITS, in some cases results for surface soil samples included non-detections of U-235 reported values. Thus, to get average concentrations, the value for a non-detect was taken to be the detection limit. Possible explanations for any discrepancy between ITS results and the results determined through laboratory analysis of soil samples may include the moisture correction factors used for ITS data, the weighting system used for analytical data, and non-detections used by both the ITS and validated soil sampling analytical results.

8.1.5 Results

Based on the above test, it was concluded that the ITS technology, with further testing for areas with elevated radioactivity readings, could be used as a screening tool for surface soil characterization. It was also recommended that additional testing should be done to check the system's accuracy in detecting uranium isotopes.

8.2 Savannah River Site, South Carolina

8.2.1 Site Description

The Savannah River Site (SRS), located near Aiken, South Carolina, was constructed during the early 1950s to produce tritium and plutonium-239 in support of U.S. defense programs. In 1957, a fuel element failure in the reactor disassembly basin resulted in the discharge of approximately 2,700 Ci of radioactivity into Basin 1, with overflow going to the other basins. As part of in situ detection of radionuclides in 1997, a spectral gamma probe developed by the USACE was evaluated for site characterization at the R-Reactor Seepage Basins. The probe was deployed in three of the six seepage basins that were constructed and operated between 1957 and 1964.

Limited technologies are currently available for in situ subsurface measurement of radionuclides. The baseline method for radiological measurements of contaminated sediments requires the use of CPT or drilling rigs to collect samples for field or laboratory analysis. Collecting physical samples provides a high degree of precision and accuracy, but is extremely costly and presents numerous risks associated with handling of highly radioactive samples. Since the distribution of subsurface contamination is not homogenous at most waste sites, a large number of samples typically are required to accurately delineate the extent of contamination. Due to the high cost per sample with the baseline method, budget constraints often limit the number of samples collected and analyzed. In many cases, this may result in inadequate site characterization, potentially leading to sub-optimal remedies.

8.2.2 Spectral Gamma Probe

The spectral gamma probe (DOE 2000) consists of a truck-mounted gamma radiation detection system. The sensor detects gamma radiation emitted by the radioactive waste and the energy spectrum is analyzed to identify radioactive constituents and their relative concentrations. The probe's downhole system consists of a detector containing a 1.0 in by 3.0 in cylindrical NaI crystal and a photo-multiplier tube; a temperature sensor; and a custom-designed preamplifier. The gamma probe detects radiation and provides count data in two different ways. The rate meter on the MCA provides the number of gross counts per second in real time. Additionally, an automated data processor (ADP) collects counts by energy level and differentiates various radionuclides. The ADP provides real-time data in the form of graphic representation of the spectrum during count-data collection.

Use of specialized software allows improved identification and quantification of the isotopes and also creates a data display in real time when the push is in process. While the raw spectral data are viewed in real time through the MCA software, the corrected data requires screening through another 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. In addition, use of longer counting intervals increases the sensitivity of the system, although only up to a certain limit. Both the maximum effective time and the sensitivity limit are functions of the system specifications and local conditions.

For site characterization, the probe is driven into the subsurface using a SCAPS or a CPT. As the CPT rods advance into the ground, the probe transmits analog signals that are recorded in the data acquisition system. As the rods are retracted, grout is injected to fully seal the hole. To prevent contamination of the truck during testing, soil sample CPT rods are decontaminated using a decontamination chamber attached below the truck. Removal of the soil particles from the rods is accomplished by a plastic blast system similar to sandblasting with small plastic beads. Further details of the spectral gamma probe are in Appendix G.

8.2.3 Spectral Gamma Probe Testing

The spectral gamma probe was tested at the SRS site in 1997. The specific objective of this testing was to assess its capability to accurately measure Cs-137 contamination in the subsurface. The data gathered with the spectral gamma probe was compared with laboratory data from soil samples sent to onsite laboratories. These soil samples were taken by a hand auger in two-foot

increments and composited for analysis to eliminate potential variations; the sampling interval for the gamma probe varied from three-inch to one-foot intervals. In each of the three basins (Basin 1, 3, and 6), the three gamma probe pushes were clustered around a hand-augured sample collection location. The laboratory-determined radius of influence for the gamma probe was 8 in. Each push was started at least 2 ft above the expected zone of contamination and counts were taken at 3 in to 6 in intervals as the zones of expected contamination were reached. Counting times varied from 10 min to 60 min.

The in situ measurements made with the spectral gamma probe were found to be comparable to the laboratory measurements on the core samples. Analysis of the data indicates that the spectral gamma probe provides a more detailed profile of the contamination than the baseline methods. The peaks of activity generally fell within the laboratory-measured peaks of activity. The gamma probe was also able to detect areas of activity not identified by the grosser sampling method used for the laboratory analysis.

At Basins 1 and 3 the lower limit of detection (LLD) for Cs-137 appears to have been approximately 5 pCi/g, and weaker gamma emitters had higher LLDs. In addition, the density and moisture content of the soil also affected the detection limit. In Basin 3, the Cs-137 level was calculated at 1 pCi/g. While 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.

Contamination in a few areas within Basin 1 and Basin 3 exceeded the dynamic range of the sensor designed for detection of low-level activities. In addition, an extremely high gross count rate was also noted due to the presence of 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 filtering generally resulted in fewer per second ADP gross counts as compared to the rate meter in the field.

8.2.4 Advantages of the Spectral Gamma Probe System

At SRS, the spectral gamma probe system offered numerous comparative advantages over the baseline approach. First of all, use of the CPT technologies provides a significant reduction in the secondary waste handling requirements. For instance, at the R-reactor seepage basin demonstration, the number of waste drums was reduced to one, compared to seven generated during the drilling activities. Also, in situ measurements eliminate the need for sample collection, transportation, and analysis.

Use of the spectral gamma probe significantly reduces the risk of worker exposure to hazardous conditions by eliminating the need for collection, shipment, and analysis of samples. The more rapid data collection also reduces the length of workers' exposure to hazardous materials. A decontamination system used for the rod system, as designed by SRS Environmental Restoration staff for the demonstration, performed well, enabling workers to use only modified Level D protection thereby saving time and costs.

The use of the spectral gamma probe system also minimizes potential environmental impacts because drill cuttings or secondary waste is virtually eliminated. The smaller-diameter penetrometer holes can be sealed during retraction of the rods, and the spectral gamma system

can be easily decontaminated. Use of this technology also eliminates a community's risks of exposure associated with shipping and analysis of highly radioactive samples. Since it is an environmentally friendly technology, the community's reaction to its use is more likely to be positive. Moreover, use of the probe requires less stringent permits compared to those needed for drilling and sample collection because investigation derived wastes are significantly minimized.

In situ soil characterization techniques for specific radionuclides offer significant cost reduction potential as compared to the baseline practice of sample collection and laboratory analysis. At SRS, these included: 1) \$800,000 in actual cost savings at the R-Reactor Basin demonstration; 2) low measurement cost of \$3,509 per sample, compared with \$7,961 for the baseline measurement; and 3) overall better economics when more than 30-35 samples for characterization were collected.

8.2.5 Implementation Considerations

The use of the spectral gamma probe is currently limited to sites where a cone penetrometer offers the ability to penetrate desired subsurface depths. However, deep (> 50 m) subsurface contamination and challenging (rocky) geologic strata restrict its use. Also, a wide variation in contaminant levels at some radioactive sites could present problems for quantitative analyses. The system used at SRS was optimized to measure very low levels of contamination and calibrated according to its performance specification. Locations with high radiation levels required significant post-measurement corrections.

The NaI detector used in the gamma probe has relatively high detection efficiency but has a relatively poor energy resolution. Also, its output varies with temperature. As a result, resolution of gamma ray peaks is difficult where signal-to-background ratios are relatively low. Compared to NaI detectors, HPGe detectors offer higher resolution; however, these detectors require cooling to liquid nitrogen temperatures for down-hole applications, potentially adding to costs.

8.3 Ashland 2 FUSRAP Site, Tonawanda, New York

8.3.1 Existing Site Situation

The privately owned Ashland 2 site (approximately 115 acres of undeveloped property) is located within the boundaries of the town of Tonawanda, New York. The site's use under the U.S. nuclear weapons program resulted in radionuclides and possibly chemical contamination due to the disposal of waste material from uranium ore extraction conducted at Ashland I Site. Subsequent land moving activities resulted in both surface and buried contamination. The Ashland 2 site needs remediation and closure to meet regulatory environmental compliance requirements. As a result, a Record of Decision (ROD) called for removal and offsite disposal of all contaminated soils exceeding site cleanup criteria.

As part of the ROD, RI of the site was performed by DOE. Analysis of 341 soil samples from 116 soil bores was conducted via gamma spectroscopy for U-238, Ra-226, and Th-230. RI identified Th-230 as the principal COC. Surface soil requirements were set at 14 pCi/g averaged over 100 m² areas. The detection limits for Th-230 using gamma spectroscopy were found to be

above the cleanup guidelines. Consequently, a subset of these samples was also analyzed for Th-230 via alpha spectroscopy. Based on RI data, minimum tension spline interpolation techniques, and the 40pCi/g cleanup level for Th-230, a total contaminated soil volume of 14,000 yd³ was estimated. A subsequent review of RI, however, indicated that this quantity was an underestimate.

Subsequently, by act of Congress, the U.S. Army Corps of Engineers (USACE) became the lead agency for the site. In consultation with EPA, USACE designed closure protocols to be MARSSIM consistent. Through negotiations with the New York Department of Environmental Conservation (NYDEC), the USACE also agreed to include elevated area criteria as well as to the clean up goal of 28 pCi/g for Th-230 for surface soils. The NYDEC provides oversight for ongoing remediation and closure activities.

8.3.2 Remediation Strategies

The baseline remediation strategy proposed focused on use of RI data sets to develop excavation footprints, dig to these footprints, and evaluate the exposed surface to determine whether cleanup criteria has been met. The cost of excavation and safe disposal of the material, however, was determined to be uneconomical (up to several hundred dollars/yd³). It was therefore essential to keep excavated materials and disposal costs to a minimum, while still meeting regulatory compliance requirements.

The USACE upon taking charge of the site proposed an alternative approach based on site excavation in 2 ft lifts, with dig face data collection using real-time measurement systems and data analysis turnaround time short enough to allow for modification of excavation plans as work proceeded. Final closure demonstration was to be achieved through final status surveys based on MARSSIM; an objective included keeping the excavation work as precise as possible. To support the site's remediation and closure, four technologies were considered. These included real-time NaI gamma scans, in situ HPGe measurements, onsite gamma spectroscopy laboratory for rapid soil sample analysis, and offsite alpha spectroscopy analysis of soil samples. While the standard for Th-230 analysis in soils is alpha spectroscopy, it has limitations in terms of per sample cost and a slow turnaround time of typically a week or more. In addition, NaI scans and HPGe systems were studied for technology performance as well as for protocol identification for use during remediation.

The NaI system proposed for use included a 2x2 in NaI detector, coupled to a differentially corrected GPS and data logging system. The system was deployed in a walkover mode, with a technician providing complete coverage of exposed soil surface by walking parallel lines. Data was acquired every two seconds. The NaI provided gross gamma activity estimates for exposed soil surfaces. Logged data was off-loaded and mapped and analyzed using a GIS.

The NaI data were intended to define new footprints for excavation after a particular surface had been excavated. The objective was to keep within a turnaround time of 24 hr or less. The USACE posted the resulting maps on a secure project support web site for onsite access by the contractor for the project. Turnaround times for NaI scan data analysis, mapping, and posting on the Web site were, in fact, within 24 hours of collection.

8.3.3 Limitations of the Strategy

Th-230, a weak gamma emitter except where there is high activity, is difficult to detect with NaI walkovers. At the Ashland 2 site, however, Th-230 was also collocated with Ra-226. A systematic analysis of RI data sets indicated that in cases where samples exceeded the Th-230 requirement, Ra-226 was always present at levels greater than 3 pCi/g. This level of Ra-226 is readily detectable by an NaI 2x2 detector with a 2 s acquisition. Given the presence of multiple elevated radionuclides at the site, a regression relationship between gross activity measurements and Th-230 activity concentrations was not developed.

8.3.4 Remediation Procedure

At the site, radionuclide contamination locations believed to be in the range of cleanup criteria were identified by the use of NaI 2x2. Approximately 40 samples were collected as a part of the performance evaluation. In addition, stationary NaI readings were also acquired before a sample was collected. Samples using alpha spectroscopy were analyzed to develop a lower gross activity investigation level, below which sample results above the required cleanup criteria were not observed. The results also produced a second gross activity trigger level above which soil samples almost always exceeded the cleanup criteria.

Based on the two trigger levels established above, dig faces were divided into three distinct areas: (1) areas with low probability of exceeding the cleanup levels that were ready for final status data collection, (2) high probability of areas exceeding the cleanup levels and requiring excavation, and (3) inconclusive areas with NaI detector results falling between the two triggers, requiring further soil contamination status investigation. Verification samples were periodically collected to check performance of NaI detector. Midway through the remediation work, the lower trigger level was adjusted downward to assure that the soils impacted above the cleanup criteria were excavated.

An in situ HPGe system to investigate areas where the NaI data were inconclusive was also evaluated for use in excavation support. According to its manufacturer, HPGe can yield detection limits below 40 pCi/g with reasonable measurement times for Th-230. Unfortunately, the results were disappointing, and the use of the HPGe was abandoned. An onsite gamma spectroscopy laboratory was used for rapid turnaround of soil samples. While the onsite unit's detection limits were marginal for detecting Th-230 at the required cleanup levels, it provided enough information so that excavation could proceed with confidence. In addition, offsite alpha spectroscopy was used for QA/QC purposes, and for final status survey sample analysis.

8.3.5 Performance Evaluation

During excavation and closure of the Ashland 2 site, over one million individual data points were logged and mapped using NaI scans. In addition, 146 composite samples were used to characterize excavated material for shipment; 97% of these exceeded the cleanup criteria for the site. Additional soil sampling at the Ashland 2 site was done to limit contamination to only those soil volumes that truly required it. In spite of this, the estimated volume was over three times the RI estimates that indicated potential removal of 10,000 yd³ in the surface lift—over 14,000 yd³ were actually removed. The RI's 10,000 yd³ would have included 4,000 yd³ of soil later

identified by NaI as below cleanup criteria and would have missed 8,000 yd³ of soil actually above the clean up criteria. Unless caught by the final survey, the missed volume would have presented human health risks. This large discrepancy was for surface soils where there was the greatest density of RI soil samples.

The additional costs (\$168,000 over a six months period) for remediation support data collection were more than compensated for by the precise nature of the excavation work, resulting in minimization of offsite soil disposal and savings of over \$1.5 million in offsite disposal costs. Since the excavation crew was paid on an hourly basis, all efforts were made to minimize delays in excavation and disposal processes. Also, efforts were made to ensure that the additional dig face data collection work at Ashland 2 did not impede excavation progress.

In addition to monetary savings, several intangible benefits also resulted. For instance, by producing quantifiable and recordable data for every lift, USACE also generated a documented and defensible record of what was excavated and why. This was especially important since the actual volume of soil excavated above the cleanup criteria was almost three times the original estimate. In addition, USACE also achieved an independent means for estimating volumes of contaminated soil being shipped offsite, a reimbursement measure for the prime remediation contractor. USACE's posting of the remediation support data over the Web provided a means to distribute site information to the project team, including the NYDEC, helping to improve coordination and confidence in the remediation work.

8.3.6 Results

NaI 2x2 gamma walkovers combined with GPS and data loggers were used to provide excavation and closure support. Use of dig face screening with the 2x2 limited the excavation to only those soils exceeding cleanup criteria. Final status survey work with the 2x2 confirmed that DCGL_{EMC} were attained. It also provided supplementary information for the DCGL_w evaluation. The principle COC was Th-230 (40 pCi/g), with collocated Ra-226 serving as a proxy. Based on the experience at the Ashland 2 site work, appropriate real-time measurement techniques combined with a dynamic work plan offer better opportunities for efficiency and cost savings as compared to standard remediation process. Effective use of real-time technologies, however, may require site-specific technology performance evaluation work to customize deployment protocols for site-specific needs. In addition, a complete QA/QC plan for real-time measurement deployment should also include ongoing performance verification data collection.

8.4 Fernald Environmental Management Project (FEMP), Ohio

8.4.1 Site Description

The Fernald Environmental Management Project (FEMP) was one of the first DOE cleanup projects to pursue the use of real-time measurement systems as the primary measurement systems supporting cleanup. The Soils Project at the FEMP encompasses over 1000 acres of soils impacted to various degrees and containing a number of below-ground waste disposal units. The greatest excavation depths and largest soil volumes were taken from the former 130-acre production area, from which over 200 structures were removed.

Real-time systems used at Fernald comprise two basic technologies, mobile platforms employing large, 4x4x16 in NaI detectors and tripod-mounted HPGe detectors. The mobile NaI systems employed GPS position tracking systems and data telemetry systems to perform full coverage surface soil surveys primarily for the purpose of identifying areas of elevated levels of gamma-emitting radionuclides. Mobile NaI scans combined with in situ HPGe gamma spectroscopy provided pre-design data to supplement existing RI information for soil contamination, excavation support to identify Waste Acceptance Criteria (WAC) concerns, and final status survey support to identify hot spots. Except for confirmation sampling, these real-time systems replaced all physical sampling for WAC and hot spot identification. Contaminants of concern include Th-232 (1.5 pCi/g), Ra-226 (1.7 pCi/g), and total uranium (55 pCi/g). All cleanup guidelines were inclusive of background. The HPGe systems were used in concert with the mobile systems to determine when Final Remediation Levels (FRLs) were achieved and an area was ready for final certification. The latter function was performed at the FEMP through the collection of physical samples. A third system employed, the EMS, was a hybrid system that employed either NaI or HPGe detection systems mounted on the arm of a standard excavator. The EMS was designed to support real-time gamma measurements in deep excavations as well as in trenches and in high contamination areas such as would be expected in the former production area.

8.4.2 Regulatory Issues Raised at the Fernald

Real-time gamma systems were approved for use in almost all aspects of the soil remediation program at the Fernald. The main exception was for use in final certification of remediation areas, for which physical samples are required. Otherwise, real-time systems have been approved for use in the three main phases of remediation, pre-design of excavations, excavation support, and pre-certification. Pre-design involves determining the excavation boundaries of soils above remediation levels, including the separate delineation of soils in excess of the WAC for the onsite disposal facility (OSDF). Excavation support involves lift-by-lift characterization of soil surfaces, while pre-certification determines that an area is free of hot spot areas and has average soil contamination levels below FRLs. The use of real-time gamma systems to support soil remediation represented a significant departure from the conventional approach used previously at radiologically contaminated sites. Such a departure was both necessary and warranted by the large scale of many of the federal cleanup sites entering the CERCLA program in recent decades, the associated characterization costs, and the need to contain cleanup times.

The site committed early on to the use of innovative in situ gamma spectrometry systems to support soil remediation efforts. This commitment was aided by funding under DOE's Accelerated Site Technology Deployment (ASTD) program supporting technology deployments. The ASTD project involved personnel from DOE-Fernald, Fluor Fernald, Argonne National Laboratory (ANL), Idaho INL, and DOE's EML. Ohio EPA and EPA were involved from the very beginning. A real-time working group of experts from the agencies, DOE, and Fluor Fernald met on a regular basis to discuss technical issues. The capabilities of the technologies and the numbers and types of platforms on which they are deployed have undergone continuous improvement and expansion since the beginning of the project.

8.4.3 Technical Issues

In response to the proposed use of the technologies, Ohio EPA and EPA raised a number of technical issues related to the production of data of known and defensible quality. Some of the primary concerns specific to real-time gamma measurements were as follows:

- undocumented data quality
- uncontrolled environmental conditions
- in situ definition of “a sample”
- differences between measurement and calibration soil conditions

Each of these overall concerns embodies a number of technical questions that had to be addressed before the systems could be approved for their proposed use. These questions and the manner in which they were addressed are summarized in the following paragraphs.

The FEMP undertook an extensive program to document the data quality of the measurements produced by the real-time gamma systems. A number of studies were performed to establish the performance characteristics of the systems and data quality produced. In order to establish the performance requirements of the systems, the Fernald site first identified the measurement type needs and uses they would support. For each of these needs and uses, an analytical support level (ASL) was assigned in accordance with the requirements that emerged from the DQO process. Four ASLs have been established that are analogous to the data quality levels identified by the EPA. Most data needs to be supported by the systems were identified as having ASL A or B, A being low. Certifying remediation levels, however, was designated ASL D, the highest level.

With respect to the NaI systems, these studies involved calibration of the systems, initially through measurements at known contamination areas, and later through the development of a calibration pad. Additional studies addressed the optimal scanning speed and count time and determinations of minimum detectable concentrations and measurement uncertainties. These studies, which were documented in a January 1999 report entitled *RTRAK [Radiation Tracking System] Applicability Study* (DOE 1999a) allowed the FEMP to gain approval of all proposed uses of the NaI systems, all of which involved ASL A or B measurements.

Extensive studies were conducted on the HPGe systems in an attempt to have the systems approved for use in performing final certification of remediation areas. These studies were documented in another January 1999 report entitled *Comparability of In Situ Gamma Spectrometry and Laboratory Data* (DOE 1999b). These studies examined the comparability of individual HPGe measurements to results of physical sampling and laboratory analysis. In addition, the results of certification unit outcomes by the two methods were compared. Finally, a number of technical questions were addressed in the studies, such as the potential effects of environmental conditions, the effects of radon emanation from soil on Ra-226 measurements, recognition of buried contamination, and the effects of external radiation sources.

8.4.4 Results

The results of the studies established that individual HPGe measurements of a contamination area produced comparable results to a weighted average of physical samples taken over the field

of view of the in situ measurement. Physical samples were weighted to account for the diminishing contribution to the in situ measurement from soils at increasing distance from the detector. The studies also established that the two methods produced similar certification results for the certification units sampled by both methods. Together, these studies addressed the concerns noted above related to data quality, environmental factors, sample definition, and calibration effectiveness.

On the basis of the studies performed, the DOE concluded that the HPGe systems were capable of achieving ASL D data quality necessary for final certification of remediation areas, when using proper controls and applying an appropriate correction for radon disequilibrium in soils for Ra-226 measurements. Regulators, however, continued to cite concerns for a perceived low bias from radon emanation as well as concerns for making accurate soil moisture measurements with field instruments. They ultimately disapproved the use of HPGe for making Ra-226 final certification measurements.

Because there would have been little economic benefit to using HPGe for final certification of total uranium and Th-232 alone when laboratory measurements would have to be made for Ra-226, DOE conceded to use laboratory analysis for final certification of all three of these primary radiological contaminants of concern. Additionally most certification sampling includes sampling for other inorganic contaminants, thus reducing the benefit of using HPGe for certification. Because of the relatively small number of samples required for certification compared to other RA support and the need to collect samples for inorganics, the savings from real-time measurements for this function would have been modest in any case. The greatest savings are achieved in surveys to detect elevated areas and in the delineation of excavation areas. These types of uses have been approved and strongly supported by Ohio EPA and EPA. The procedures for implementing these and other real-time platforms have been recently updated in the following manuals: *User Guidelines, Measurement Strategies, and Operational Factors for Deployment of In-Situ Gamma Spectrometry at the Fernald Site* (DOE 2004a) and *Measurement Uncertainties and Minimum Detectable Concentrations for the In-Situ NaI Gamma Spectroscopy Systems Used at the Fernald Site* (DOE 2004b).

8.5 Kirtland Air Force Base, Albuquerque, New Mexico

8.5.1 Site Description

TS4 is a 10.3 acre Defense Nuclear Weapons School (DNWS) radiation training site at Kirtland AFB, Albuquerque, New Mexico. Thorium oxide (Th-232) sludge was applied to TS4 as a plutonium simulant for use in training military personnel in alpha radiation monitoring and decontamination. Thorium distribution at TS4 is highly heterogeneous with surface activity ranging from 2.1 pCi/g to 151.3 pCi/g. Radiological studies indicate that thorium has been transported vertically into the top 61 cm (2 feet) in the hot spot areas. Periodic radiation monitoring of the site has revealed migration of thorium outside the fenced area and at depths of up to 38.1 cm. Concentrations of thorium 4.5 times higher than background were detected in soil at the western boundary of the site. The extent of thorium migration at TS4 has not been previously fully defined, and the mechanisms for offsite migration are unknown. Possible

mechanisms include surface runoff and sedimentation, wind erosion and transport, and unsaturated zone migration.

8.5.2 Characterization Strategy

The radiological characterization involved personnel from Stevens Institute of Technology (SIT), ERDC, Alion Science and Technology (Chicago, IL), and Mississippi State University (MSU), (Starkville, MS) and was performed using a mobile multisensor system developed by ERDC. The system had the capability to detect and identify surface and near surface gamma-emitting radionuclides, and coupled surface gamma activity with location and elevation data from a GPS in real time.

The data acquisition system was configured for ATV deployment. In the original configuration, an ATV was used to pull a cart onto which the data acquisition system was mounted. The gamma sensor array consisted of four 7.6 cm by 7.6 cm (3 in by 3 in) Bicron™ sodium iodide gamma detector/photomultiplier tube assemblies that were suspended behind the cart, 10 cm above and parallel to the ground. Each detector used in the system operated independently with separate computer and nuclear instrument data acquisition and processing modules. Data from each detector were collected by the data acquisition CPU, which also tracked corresponding location and temperature readings. Data were collected, processed, and stored for later processing and analysis. The configuration was later improved by using an ATV as the platform with the system being driven across the surface of TS4 at approximately 3.2 km/hr (2 mph).

8.5.3 Surface Data Analysis

The surface gamma activity data, collocated with GPS data, were collected with the four-detector array, summed, and processed to develop an activity level for a 1.2 m (4 ft) footprint beneath the detector array. Next, calibrated laboratory gamma activity was acquired at the MSU Calibration Facility using a thorium calibration disk fabricated in concrete with 50 pCi/g thorium oxide (with progeny in equilibrium). Since thorium is an alpha emitter, spectral gamma data were analyzed for actinium-228 gamma activity using 911- and 969-keV gamma emissions. Surface and near-surface gamma activities were measured outside the boundary of TS4 to determine the average gamma activity background for Kirtland AFB soils in the vicinity of TS4. Measurements determined that the average background gamma activity was approximately $2 \text{ pCi/g} \pm 2 \text{ pCi/g}$ and was consistent with onsite laboratory verification sample results. The processed gamma activity data was integrated with GPS coordinate data and displayed as a color contour map (see Figure 8-1).

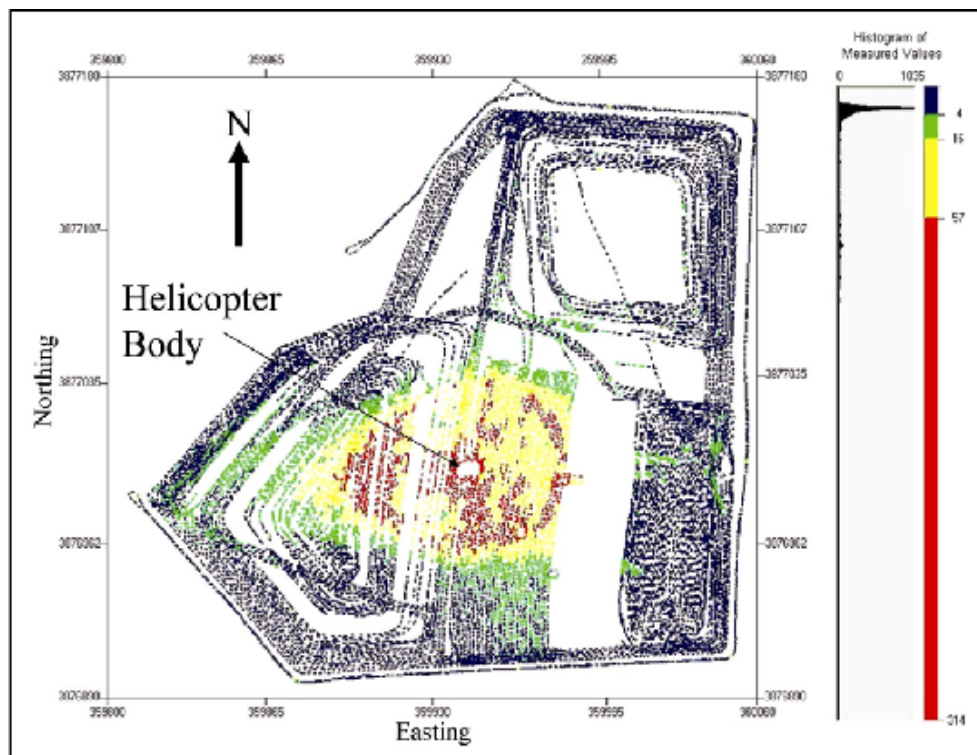


Figure 8-1. Color contour map of measured gamma and thorium activity at TS4

Due to the rough terrain at TS4, exact values of thorium activity could not be ascertained for all locations since the gamma detector array was not always positioned parallel to the surface and could not always be maintained at the calibration height of 10 cm above the terrain surface. Background levels of gamma activity are represented in blue and range from 0 to 4 pCi/g. Regions of low gamma activity (low thorium activity) range from 4 to <16 pCi/g and are shown in green. Moderate gamma activity range from 16 to <57 pCi/g and are shown in yellow. Regions of high gamma activity are shown in red and are located in the vicinity of the helicopter body.

The GPS elevation data indicated that site elevations measured from the northwest to the southwest ends of the site drop approximately 1.9 m. GPS data also indicate that elevation from the helicopter to the southwest corner drops approximately 0.5 m. It is likely that surface rainwater runoff could transport low levels of thorium-enriched soil toward the southwest quadrant of the site and possibly into soil adjacent to the southwest quadrant. Annual rainfall for Kirtland AFB is approximately 25 cm.

8.5.4 Subsurface Characterization

In order to determine the extent of vertical migration of thorium-232, soil borings were collected at 33 locations within and adjacent to TS4. An Earth Probe™ soil-sampling device was used to hydraulically hammer (push) sample chambers into the soil in 61 cm (2 ft) segments. Soil was sampled at each location to a depth of 3.05 m (10 ft) unless refusal to push occurred (often due to large rocks). Borehole closure was conducted to prevent future cross-layer contamination by way

of open boreholes. An ERDC mobile radiological laboratory was used to evaluate the soil borings collected at TS4. The mobile laboratory consisted of five independently operated gamma evaluation/counting stations and utilized the equipment used during the surface radiological site characterization phase of the project. The mobile laboratory was also used during calibration comparison studies at the MSU Calibration Facility. EPA standard method series for aqueous metal concentrations (including thorium) is 6000 (Inductively Coupled Plasma–Mass Spectrometry and Inductively Coupled Plasma–Atomic Emission Spectroscopy) and was used for offsite analysis of soil and plant samples.

Five NaI gamma detector spectrometers were assembled onsite using an inverted T-shaped PVC pipe surrounded by lead shielding material. Soil tubes were inserted through the horizontal portion of the inverted pipe in a manner that centered each soil segment. The NaI gamma detector was positioned vertically in the inverted T with the detector field of view positioned centrally above the sealed plastic soil tubes, and each tube was interrogated for 30 min. Since each tube had the capacity to hold four segments of soil, the spectral gamma interrogation of each tube required two hours to complete. The gamma energy spectrum was saved for later offsite processing and analysis.

Thorium levels greater than 2 pCi/g were seen at a maximum depth of 84 cm (33 in) below the surface and only for sampling locations near the helicopter. It was noted during soil sampling activities that surface soil sometimes fell into the open hole between sampling events. Some results indicate subsurface samples with elevated levels of thorium activity attributed to surface soil accumulating in the first segment of a subsequent 0.6 m (2 ft) sampling event. Lower levels of thorium activity in subsequent soil segments support this hypothesis. Activity levels that fell within the range of natural background were entered as 0 pCi/g.

8.5.5 Observations and Recommendations

Based on the work performed at Kirtland AFB, the following observations were noted:

- Natural radiation background measured 2 pCi/g (± 2 pCi/g) for offsite Kirtland soil. Elevated levels of gamma activity were defined as gamma activity exceeding 4 pCi/g. The highest levels of gamma activity were in soils near the site helicopter body.
- Probable routes of thorium migration were identified by contour mapping gamma activity of thorium progeny in surface soils. Low levels of gamma activity were verified by onsite radiological laboratory analysis.
- Data indicated that thorium-contaminated surface soils at TS4 are migrating to the southwest and west directions. Elevated activity was measured near the boundary of the southwestern quadrant of the site.
- Vehicular traffic between the site helicopter body and the east gate has likely spread some thorium-contaminated soil toward the east gate portal.
- Thorium contamination appears to be in the top 91 cm (3 ft) of soil.

- Vegetation is growing in thorium-contaminated soils and may be contaminated with thorium or thorium progeny in roots and shoots. Strong winds could possibly transport thorium-laden dead plant materials within and beyond site boundaries.

In light of these observations, the following recommendations are made:

- Stabilize TS4 soils with elevated levels of gamma activity (i.e., TS4 soils with gamma activity exceeding 4 pCi/g) to prevent offsite migration.
- Conduct laboratory analysis of vegetation growing in thorium contaminated soils to determine if thorium or thorium progeny have been absorbed in roots and/or shoots.

8.5.6 Results

In terms of the application of real-time measurement systems to the Kirtland site it is concluded that the ERDC-developed, ATV-carried Mobile Multisensor Radiological Data Acquisition System was successfully deployed at TS4, Kirtland AFB. It provided simultaneous mapping and in situ quantification of surface thorium and thorium-progeny radiation activity and allowed specific recommendations to be made regarding management of contamination at the site.

9. OBSERVATIONS AND CONCLUSIONS

Real-time measurement technologies, when coupled with sophisticated data collection approaches, allow the cleanup of a contaminated site to proceed with significant cost reductions, schedule accelerations, and reliability improvements. To achieve these results, real-time measurement technologies require a set of ancillary systems and approaches, such as systematic project planning, dynamic work plan strategies, and MARSSIM. Much information is available summarizing the status of these ancillary systems and this will not be duplicated here. The following sections highlight the major observations that may be drawn when focusing narrowly on the measurement technologies alone. These observations are presented in three groups addressing the broad overview, the technical dimensions, and the regulatory and stakeholder perspective of the measurement technologies. Section 9.2 summarizes the conclusions and recommendations drawn from this report.

9.1 General Observations

The following high-level, general observations can be made in a broad overview of real-time systems:

- It is now possible to rapidly screen or scan for a large number of potential contaminants in the field. Rapid screening is possible at increasingly lower detection limits.
- Field instruments commonly used for detecting radiological contaminants rely on the detection of gamma-ray emissions from either the radionuclides of interest or from their decay progeny if these are in secular equilibrium with the primary radionuclide.

- A number of different means are available for providing real-time location information during mobile scanning, some of which provide accuracy down to a sub-centimeter level and can allow for three dimensional location control during excavation. A number of sample acquisition systems are also currently available including direct push samplers and cone penetrometers; these bring the advantages of quantity and quality of the data as well as reduced cost for subsurface characterization.
- Although the overall system performance has been enhanced tremendously, the burden of technical knowledge has not been lightened at all and great importance is now placed on the availability of in-depth technical expertise.
- Real-time measurements are just one of a number of sources of information for environmental decision-making. Other sources of information such as historical information, interviews, aerial photos, etc, can be just as important in determining which areas should be subjected to enhanced sampling.
- For real-time measurement systems and the “smarter” streamlined remediation and characterization approaches that they support to achieve their full potential it is essential to have an understanding of regulatory and stakeholder acceptance issues and the barriers that these systems and processes pose, and to have methods to address the issues.

9.2 Technical Observations

Three basic sources of uncertainty occur in decision-making that uses environmental measurements:

- uncertainty in the relationship between what is being measured and concentration-based standards (inferential uncertainty)
- uncertainty due to measurement errors (analytical measurement uncertainty—precision and accuracy)
- uncertainty in conclusions about the state of an area due to limited sampling (spatial uncertainty)

For traditional data collection programs using limited sample collection and laboratory analysis, the predominant errors arise from incomplete coverage, natural spatial variability and the need to infer the contamination status based on limited sample results. In such programs, QA/QC requirements limit relative measurement error to about 30% of the “true” parameter value, a level that can be ignored for decision-making purposes as insignificant compared with errors arising from incomplete coverage. In such programs the only way to reduce this uncertainty is to increase the number of samples collected.

For data collection programs based on real-time measurements inferential uncertainty and analytical measurement uncertainty become much more important. Since many more samples can be collected and analyzed in the field for the same data collection budget, the error previously associated with incomplete coverage can be reduced to acceptable levels. Reduction

in the error associated with incomplete coverage comes at the expense of potentially greater measurement error relative to analytical laboratory results, however, and greater error in the inferences made between measurements and cleanup criteria. The uncertainty associated with greater measurement error and greater inferential error can be reduced by good QA/QC and data validation.

Data quality considerations and QA/QC programs are just as important for real-time measurements as for traditional laboratory analysis. Key considerations include the following:

- The requirements for data quality and measurement-system performance are determined in the DQO process and measurement technologies that can achieve these requirements are selected.
- Real-time measurement technologies are less likely than laboratory-based programs to have well-established performance parameters, so these must be developed before a QA/QC program can be devised to ensure the technology is operating within the established performance envelope.
- Real-time measurement technologies are less likely than laboratory-based programs to have well-established procedures for calibration, data conversion and data reduction, so care must be put into developing these procedures.
- Soil conditions and contexts (e.g. topography of survey areas, surface coverage, soil moisture, and measurement geometry) can strongly influence the performance of real-time systems.
- Real-time calibration models typically assume flat soil geometry with contaminants uniformly distributed; since this assumption may be untrue, a conceptual model for the distribution of contaminants should be consulted, the degree and direction of deviation from the assumed uniform distribution should be estimated, and a determination made on the acceptability of such deviations in terms of data quality.

9.3 Regulatory and Stakeholder Observations

In order for these real-time technologies to find acceptance at a site, a thorough demonstration of the QA/QC protocols must be made and documented. Factors such as soil moisture, vegetative cover, time of day and other factors may significantly affect real-time measurements, so site-specific protocols must be developed that are rigorously followed in order to ensure proper data quality. Furthermore, a well-designed and documented real-time monitoring program should be seen as an asset to most site characterization plans. It allows for a more comprehensive characterization at cheaper cost and faster implementation than is typical of the baseline physical sampling paradigm.

Regulators quickly realize one of the greatest benefits of real-time measurement technology is the very high percent coverage achieved thus greatly reducing the probability of missing areas of contamination. Another benefit regulators find in real-time measurement technology is the ability

to direct excavations in a more timely and confident manner. Coupling a real-time scanning approach with lift-by-lift excavation allows for accurate excavation and while not significantly decreasing excavation efficiency.

One of the most controversial issues for real-time characterization is its use for final certification. The ability to use the technology for final certification will be highly dependent upon the contaminants in question and environmental conditions. In one of the case studies the regulators decided against using real-time for certification since the technology was very new at the time of program development, and since other contaminants, such as metals or Tc-99, that couldn't be measured with real-time required certification by collection of a physical sample. As real-time measurement technologies continue to develop and accumulate field usage the significance of these problems may be reduced.

Real-time measurement technologies are used to survey contaminated land first to determine if cleanup is required and then after removal to show that end objectives have been reached. Since most stakeholders are unfamiliar with these techniques a process of educating the stakeholders may be necessary. Possible actions include the following:

- The site owner and the regulatory agencies should identify appropriate stakeholder groups and work with them throughout the process.
- A stakeholder information and implementation plan should be developed early in the process.
- This plan must be reviewed with the stakeholder groups so that they will understand what is being done and why.
- Real-time measurement technologies can reduce stakeholder concerns about the cleanup process because they reduce the likelihood of leaving unrecognized contamination since it is easy and inexpensive to resurvey after cleanup. Real-time measurement technologies are also more comprehensive and result in reduced likelihood that contamination will slip through the process unnoticed.

9.4 Conclusions

Based upon the information contained in this report and the personal experiences of the Radionuclides Team members in implementing real time radiological technologies, the following conclusions were developed:

- It is now possible to rapidly measure a number of radiological contaminants in situ. Field instruments used for detecting radiological contaminants rely on the detection of gamma-ray emissions from either the radionuclides of interest or from their decay progeny if these are in secular equilibrium with the primary radionuclide. Coupling these detectors with the latest in GPS equipment allows for rapid detection and mapping of radiological contaminants.
- There are numerous platforms for deploying the two primary real-time detector types (NaI and HPGe). These platforms allow for multiple opportunities to use real-time detectors

throughout the characterization, remediation and verification process under varying environmental settings.

- These technologies present the possibility of substantial cost savings through improving excavation control; reducing data analysis time; supporting real-time field decision making during characterization and remediation; and through reducing equipment and staff re-mobilizations.
- These systems are limited in their ability to assess contamination at depth, are affected by environmental factors such as soil density and moisture, and apply a weighted averaging measurement to contaminants in the field of view.
- Though standardized QA/QC protocols such as those for traditional chemical contaminants do not exist, a detailed site-specific QA/QC program must be developed and maintained during operation. Often regulators require some integration of traditional sampling, in particular, where it applies to verification measurements, with the real-time technologies.
- Real-time measurement systems offer the opportunity for improved risk reduction both in terms of timeliness and thoroughness of characterization data.
- These systems can also greatly reduce generation of secondary wastes as well as the potential to expose workers during collection, transportation and analysis of samples.
- One of the greatest advantages of these technologies to regulators, stakeholders, and site owners is the very significant reduction in characterization uncertainty with regard to aerial extent and the delineation of hot spots.
- To maximize the benefits of real-time measurements, a decision-making process and team must be developed that addresses and understands these systems and their limitations. The process and team will ideally allow rapid incorporation of the data into the ongoing characterization or remediation project.

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Appendix A

Acronyms and Units of Measure

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ACRONYMS

Ac-228	actinium-228
ADP	automatic data processing
AFB	Air Force Base
Am-241	americium-241
ANL	Argonne National Laboratory
ASL	analytical support level
ASTD	accelerated site technology deployment
ATV	all-terrain vehicle
BNL	Brookhaven National Laboratory
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
Co-60	cobalt-60
COC	contaminant of concern
CPTs	cone penetrometer technologies
CPU	central processing unit
Cs-137	cesium-137
CSM	conceptual site model
D&D	decontamination and decommissioning
DCGL	derived concentration guideline level
DCGL _{EMC}	derived concentration guideline level: elevated measurement criterion
DCGL _w	derived concentration guideline level: Wilcoxon Rank Sum Test
DEQ	State of Michigan Department of Environmental Quality
DNAPL	dense nonaqueous phase liquid
DNWS	Defense Nuclear Weapons School
DOD	Department of Defense
DOE	Department of Energy
DQI	data quality indicator
DQO	data quality objective
DVS	dynamic verification study
EMC	elevated measurement criteria
EML	Environmental Measurements Laboratory
EMS	excavation monitoring system
EPA	United States Environmental Protection Agency
ERC	environmental restoration contractor
ERDC	United States Army Engineer Research and Development Center
FEMP	Fernald Environmental Management Project
FID	flame ionization detector
FIDLER	field instrument for detecting low energy radiation
FRL	final remediation levels
FS	feasibility study
FUSRAP	Formerly Utilized Sites Remedial Action Program
GIS	geographic information system
GPERS-II	Global Positioning Environmental Radiological Surveyor System
GPS	global positioning system
HPGe	high purity germanium

HSA	historical site assessment
HSP	health and safety plan
INL	Idaho National Environmental and Engineering Laboratory
ISOCS	in situ object counting system
ITRC	Interstate Technology and Regulatory Council
ITS	integrated technology suite
L-40	potassium-40
LAN	local area network
LARADS	laser-assisted ranging and data system
LBGR	lower bound of the gray region
LIF	laser-induced fluorescence detector
LLD	lower limit of detection
LUC	land use controls
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MCA	multichannel pulse height analyzer
MCB	multichannel buffer
MDC	minimal detectable concentrations
MED	Manhattan Engineering District
MSU	Mississippi State University
NaI	sodium iodide
NFA	no further action
NIM	nuclear instrument model
NORM	naturally occurring radioactive material
NRC	United States Nuclear Regulatory Commission
NYDEC	New York Department of Environmental Conservation
ORNL	Oak Ridge National Laboratory
OSDF	onsite disposal facility
PA	preliminary assessment
PCB	polychlorinated biphenyls
PID	photoionization detector
PMT	photo-multiplier tube
PSA	preliminary site assessment
PVC	polyvinyl chloride
QA/QC	quality assurance /quality control
Ra-226	radium-226
Ra-228	radium-228
RA	remedial action
RCRA	Resource Conservation and Recovery Act
RI	remedial investigation
Rn-222	radon-222
ROD	record of decision
ROIs	regions of interest
RSS	radiation scanning system
RTRAK	radiation tracking system
SCAPS	site characterization and analysis penetrometer system
SCQ	sitewide CERCLA quality assurance project plan

SI	site investigation
SIT	Stevens Institute of Technology
Sr-90	strontium-90
Th-230	thorium-230
Th-232	thorium-232
TPP	technical project planning
U-238	uranium-238
USACE	United States Army Corps of Engineers
USRADS	ultrasonic ranging and data system
VOC	volatile organic chemicals
WAC	waste acceptance criterion
XRF	x-ray fluorescence

UNITS OF MEASURE

Bq	becquerel
cm	centimeter
cm ²	square centimeter
cpm	counts per minute
dpm	disintegrations per minute
ft	foot
g	gram
hr	hour
in	inch
KeV	kiloelectronvolt
kg	kilogram
m	meter
m ²	square meter
MeV	mega-electronvolt
mg	milligram
min	minute
mph	miles per hour
ppm	parts per million
pCi	picocurie
s	second
V	volt
yd ²	square yard

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Appendix B

Glossary

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GLOSSARY

accuracy. The degree of agreement between the sample mean and the actual population mean.

alpha spectrometry. A sample analysis technique that detects alpha particles emitted from radioisotopes at energies between about 4 and 6 MeV.

analytical measurement error. The degree to which a laboratory is able to measure a constituent in a given sample within its actual value.

bias. The degree to which the sample mean strays from the actual mean.

Class I survey area. A type of final status survey that applies to areas with the highest potential for contamination and that meet the following criteria: (1) impacted, (2) potential for delivering a dose above the release criterion, (3) potential for small areas of elevated activity, and (4) insufficient evidence to support classification as Class 2 or Class 3. Available on-line at <http://www.epa.gov/radiation/terms/>.

Class II survey area. A type of final status survey that applies to areas that meet the following criteria: (1) impacted, (2) low potential for delivering a dose above the release criterion, and (3) little or no potential for small areas of elevated activity. Available on-line at <http://www.epa.gov/radiation/terms/>.

Class III survey area. A type of final status survey that applies to areas meeting the following criteria: (1) impacted, (2) little or no potential of delivering a dose above the release criterion, and (3) little or no potential for small areas of elevated activity. Available on-line at <http://www.epa.gov/radiation/terms/>.

collimating shield. A window-like device made of a material that is impenetrable to gamma rays, such as lead, that can be attached to a scintillator to decrease the size of the detection field.

comparability. The degree to which one set of measurement data agrees with another for similar samples and sampling conditions; it is an overall indicator of data quality that combines accuracy, precision, and representativeness.

conceptual site model. A compilation of pertinent information about a site—historical land use, waste disposal records, analytical data sets, etc.—that helps investigators to identify existing data gaps. The conceptual site model supports the development of data collection strategies that target those data gaps.

cone penetrometer technologies. Widely used in both federal and private sector cleanups, CPTs are a type of direct-push technology. Instead of producing a borehole as with traditional drilling equipment, a hydraulic ram mounted onto a 20- to 40-ton truck is used to drive a narrow steel cone (e.g., 1.75 in) with attached geotechnical sensors and analytical detectors directly into the ground, saving time and eliminating the potential need for hazardous waste disposal.

constituent. A chemical species present in a system; often called a component, although the term component has a more restricted meaning in physical chemistry.

data quality indicators. Quantitative properties that describe the quality and reliability of the measurement process.

data quality objectives. Qualitative and quantitative statements on analytical data that originate from a formalized, seven-step DQO process and are developed to ensure that data are of known, documented, and legally defensible quality

decay. The decrease in the amount of a radionuclide due to the spontaneous emission of atomic particles from the nucleus.

decay chain. The series of decay intermediates that radionuclides proceed through until a stable state is reached.

dense nonaqueous phase liquids. Chemicals that are denser than and immiscible with water upon environmental release.

derived concentration guideline level. A derived radionuclide threshold value that relates dose to an acceptable amount of risk relative to a specific remedial site. DCGL is calculated based upon various risk exposure pathways and scenarios and is usually expressed in activity per surface area or activity per mass.

electron-hole pairs. In a semiconductor crystal, a gamma ray can excite an electron up from its valence band to a higher energy level. The electron leaves behind a “hole” that acts like a positively charged particle. The electron-hole pairs are held together with their opposite charges and can carry electric current throughout the crystal.

final remediation levels. Media-specific cleanup goals that are indicative of a site that requires no further remediation.

fluence. A measure of the strength of a radiation field.

gamma ray. Any photon with an energy greater than 1 MeV that is emitted from an atomic nucleus during its transition between two energy levels. Gamma rays consist of electromagnetic radiation with the highest energy and the shortest wavelength.

gamma spectrometry. A sample analysis technique that detects and characterizes gamma rays emitted from radionuclides.

global positioning systems. Using satellites in orbit over the earth, a GPS unit can identify a person’s location using built-in internal triangulation calculations. With three satellites in view, latitude and longitude can be calculated; with four satellites in view, latitude, longitude, and elevation can be calculated. Differentially corrected GPS units have an error of approximately 2 m horizontally and tens of meters vertically, while civil-survey grade systems can provide sub-centimeter accuracy in all three dimensions.

gray region. A quantitative statistical value that expresses the degree of the variability associated or expected with measurements of the radioactivity at a site and captures the range of values over which radiological measurements are expected to vary. The upper bound of the gray region is defined as the DCGLw. The lower bound of the gray region (LBGR) is set so that the gray region spans a range equal to between one and three times the known or estimated value of the standard deviation (σ) of the measurements.

gross activity. The total activity measured from a dry sample.

homogenized sample. A sample that has been thoroughly mixed so that the concentration of constituents in subsequent subsamples would be equivalently distributed.

HPGe detectors. A real-time instrumentation technology used to detect gamma rays at low activity levels or when many nuclides are present in a sample. This detector produces electron-hole pairs upon the photoionization of the germanium crystal by high-energy gamma rays.

inferential uncertainty. The relationship between the measured parameters and the contaminants of concern.

in situ sample. Measurements of a constituent taken directly in the field.

laser-induced fluorescence probe. A real-time technology sensor used to determine the presence of chemicals that fluoresce at standard excitation wavelengths.

lower bound of the gray region. The expected average residual contaminant levels when remediation is complete.

MARSSIM. The *Multi-Agency Radiation Survey and Site Investigation Manual* is a tool developed by EPA, NRC, DOE, and DOD to determine if constituents at a radiologically contaminated site have been cleaned up to concentrations that fall below regulatory limits.

minimal detectable concentrations. The lowest obtainable concentration of a constituent that can be detected in a sample.

multichannel pulse height analyzer. A device that sorts the pulses of energy leaving a scintillation detector by amplitude. The amplitude of the energy that leaves the detector is proportional to the energy that entered it, allowing investigators to determine the relative concentration and type of radionuclide present in a sample.

NaI scintillator. A device that uses crystals made of an alkali-halide salt to detect high levels of radionuclides. When an NaI crystal is hit by high-energy gamma rays, the crystal produces charged particles that react within the crystal itself to emit lower energy photons in the visible range. This detector is used when simple spectra resulting from few radionuclides are expected.

photomultiplier tube. An evacuated glass tube consisting of an anode, cathode, and a series of dynodes that amplifies the detection of a photon. Radiation hits the photocathode; normally, due to the photoelectric effect (in which electrons are emitted from metal when hit with incident electromagnetic radiation) many electrons would be emitted and collected at an anode for the purposes of amplifying the original signal. In a PMT, electrons are deflected toward a series of dynodes that are maintained at a positive potential before finally hitting the terminal anode. Typically, the original photon is amplified by 5 to 7 orders of magnitude and is collected at the anode.

polypropylene core liner. A deflated ribbon-like liner that can be inserted into a borehole and then pressurized to allow contact with the surface of the hole. A dye impregnated in the liner changes color when it comes in contact with the substance under investigation, for example, DNAPLs. The liner can be pulled from the hole inside out for determination of the zones that contain the contaminant.

precision. The degree of agreement among repeated measurements of the same sample.

problem definition. Step 1 in the process of moving from site characterization through remediation and closure with a focus on the determination of whether excessive risk exists and the determination of the nature and extent of the contamination leading to the excess risk.

quality assurance/quality control. The process by which a laboratory can determine the accuracy and precision of sample analysis techniques and analytical results.

radionuclide. An isotope that exhibits radioactivity.

real-time instrumentation. Sampling technologies that allow the collection of data in the field with the immediate return of results. This allows investigators to scan a site in order to map areas of contamination and the extent of contamination.

range. The concentration levels in samples over which useful measurements can be made. It is limited at the low end by the detection limit and at the high end by detector saturation.

remedy. Step 2 in the process of moving from site characterization through remediation and closure with a focus on cost-effectively reducing risk to acceptable levels.

representativeness. The degree of agreement between the characteristics of the sample and the underlying population from which it was drawn.

sampling error. Error resulting from the collection or storage of samples.

scintillation type crystals (NaI crystals). When hit by high-energy gamma rays, these crystals produce charged particles and give off low-energy photons that are collected by a

photomultiplier tube. These crystals are a component of a device used in the real-time detection of radioactive constituents at remedial sites.

secular equilibrium. Relationship in a parent/progeny radionuclide system where the half-life of the parent is much longer than that of the progeny; with time, the radioactivity of the parent becomes equal to that of the progeny within the series (e.g., radium-226 to radium-222).

semiconductor-type crystals (HPGe crystals). Crystals that are composed of an element with four available electrons, such as those in column IVa of the periodic table, with an introduced impurity. Elements like carbon and germanium can form four covalent bonds with neighboring like atoms to form a crystal structure. When an impurity element with either three or five available electrons is introduced, the extra or missing electron allows for the creation of electron-hole pairs that offer partial resistance to electricity.

sensitivity. The efficiency of the detector response to radionuclide concentration—it is the slope of the detector signal.

shine. Radiation originating from sources other than the material directly under a detector. Shine is of concern in remedial surveys because it can bias results.

soil corings. A soil sample obtained by driving a hollow tube into the ground. The tube is removed along with a narrow soil sample that reflects the soil profile and, if present, contamination with depth.

spatial uncertainty. Error in a sampling plan associated with the incomplete coverage of a contaminated area.

stakeholder. Stakeholders are all interested parties, public or private, described in this report excepting facility owners or their representatives, regulatory agencies, and government appointed review groups (National Academy of Science, for example). Stakeholders can include members of the public, Indian tribes, and municipal, county, or state elected officials who are interested in the cleanup and condition in which the facility or land will be left.

Triad. The U.S. Environmental Protection Agency's environmental data collection design program consisting of three primary components: 1) systematic project planning, 2) dynamic work plan strategies, and 3) the use of real-time data.

Type I decision error. The rejection of a true null hypothesis denoted by the symbol α . Type I errors occur when an area is declared clean, but in reality, contamination is above the cleanup criteria.

Type II decision error. The failure to reject a false null hypothesis denoted by the symbol β . Type II errors occur when an area is declared dirty, but in reality, contamination is below the cleanup criteria.

verification. Step 3 in the process of moving from site characterization through remediation and closure with a focus on confirming that the solution chosen for decreasing risk to acceptable levels was effectively implemented.

waste acceptance criteria. Level of contamination set by a waste disposal facility that defines the type of waste it will accept.

Appendix C

The Triad Approach

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THE TRIAD APPROACH: SYSTEMATIC PLANNING AND DYNAMIC WORK STRATEGIES

The Triad Approach consists of combining real-time data collection with systematic project planning and dynamic work plan strategies. Real-time measurement technologies are the subject of this document and the Triad approach in general has been outlined in section 3 of the document. This appendix provides further information on the systematic project planning and dynamic work plan elements that combine with real-time measurement technologies in the Triad approach.

C.1 SYSTEMATIC PLANNING

Systematic planning must take place prior to undertaking data collection efforts. The key stakeholders should meet to assess the current knowledge about the site, develop project objectives, and recommend actions to be carried forward in the SI. USACE has developed a process known as “technical project planning” (TPP) (USACE 1998), which is designed to meet the needs of systematic planning.

C.1.1 Technical Project Planning Process

TPP is a systematic process consisting of four phases: (1) assembling the project team to define short- and long-term objectives; (2) evaluating existing information and determining whether data gaps exist; (3) if data gaps exist, selecting appropriate methods and instrumentation to address them; and (4) finalizing the data collection program. USACE guidance suggests that a TPP meeting be conducted at the initiation of a project. In practice, it is useful to hold TPP meetings periodically during an extended project. In addition, it is important to revisit the objectives of the TPP while actual field sampling activities are ongoing to be certain all objectives are being met.

The team that is assembled consists of technical personnel, project decision makers, regulators, and other stakeholders. The process emphasizes EPA guidance on establishing and using DQOs. The DQOs are then documented in the project’s work plans.

The TPP process includes the following expectations:

- using the TPP process to establish an effective team, open communications, and document-specific project objectives
- considering the consequences of unacceptable decisions or decision errors
- considering data collection approaches, including when expedited site characterization and field analytical and screening methods would be appropriate
- deciding how data needs can be balanced within project cost and schedule constraints
- presenting data collection options
- ensuring that institutional site knowledge can be transferred to new people involved with a site through the use of various TPP documents and worksheets (USACE 1998)

The TPP process should be strongly considered for any complex environmental project in which significant data collection will be required. It is designed to be compatible with a Triad approach.

C.1.2 Conceptual Site Model

Essential to this process is the development of a CSM. The CSM is the working hypothesis for the site that serves to describe the nature and extent of contamination and the risk and transport pathways. The CSM must be developed within a context of what the remedial project must accomplish. Typically, this means reducing the risk to human health and the environment from site contamination to acceptable levels. The CSM must be developed in sufficient detail to allow project managers and regulators to determine what remedies are necessary to reduce risk to acceptable levels with an appropriate amount of certainty, and to demonstrate the action was successful.

The essential components of a CSM are as follows:

- detailed description of the current and historical processes and operations that may have produced contamination at the site
- comprehensive list of potential COCs and their physical and chemical properties, as well as other chemicals and compounds that may have been used at the site and could create impacts—for instance, sodium hydroxide may not be considered a COC, but it may have been disposed in a way that alters the pH and affects the fate and transport of COCs
- identification of potential receptors
- a conservative estimate of potential cleanup guidelines for each potential contaminant for every potentially affected medium
- detailed description of past and existing sources of contamination (disposal areas, sumps and drains, emission stacks, injection wells, etc.)
- detailed description of the media and past and current transport pathways at the site
- historical and recent maps of the site's topography, infrastructure, building plans, hydrology, road system, cultural features, etc.
- division of the site into appropriate risk assessment units. Units should be grouped by common characteristics, particularly with respect to contaminant fate and transport pathways to key receptors. Hydrologic and geologic factors, property boundaries, and site obstructions should also be considered.
- anecdotal information, especially if the potential for significant risk is indicated by the information; actions taken as part of the SI can then be targeted at confirming or dismissing such information

An effective CSM allows clear decision statements about the site to be developed. Decision statements should be structured so the type, timing, quality, and quantity of data necessary to make the decision can be unambiguously specified. Further, the CSM should be developed at a physical scale compatible with the scale at which the contaminants are distributed and consistent with the contaminant pathways to potential receptors.

Systematic planning should be conducted prior to all important phases of data gathering over the life of a project. By the time planning for closure activities takes place, the COCs should be established, exposure areas clearly defined, and cleanup criteria developed for each COC in each contaminated medium.

C.1.3 Decision Statements

Virtually all information collected as part of an environmental action should be used to make decisions about actions to be undertaken at the site. Therefore, clear decision statements should be included as part of the work plans developed to collect the information. These decisions drive the specifications for the type, timing, quality, and quantity of information to be collected. For a Triad/MARSSIM closure and verification, the decision statements should address whether each survey unit has been definitively demonstrated to be clean for each COC.

Ideally, the cleanup criteria have been developed so verification schemes can be designed to minimize each major type of uncertainty. In other words, the cleanup criteria should be stated to allow data collection that explicitly demonstrates the following:

- the measurements are of sufficient accuracy and precision to decide clearly that the minimum detectable concentration or activity is below the cleanup criteria (i.e., analytical measurement uncertainty)
- the spatial representation of the contamination is sufficient to demonstrate that no small areas exist within survey units where concentrations of contaminants remain that may pose unacceptable risks (uncertainty due to incomplete coverage) and the average value of the survey unit is below the DCGLw
- inferential relationships used to determine the residual levels of COCs not directly measured are of sufficient rigor to demonstrate compliance with the cleanup criteria (uncertainty associated with the relationship between the measured parameters and the COCs).

C.1.4 Example Decision Statements

For each survey unit, decision statements developed to verify cleanup of radium-226 may be stated in the following manner:

Survey Unit Average Criterion Decision Statement: Determine whether the average residual activity of Ra-226 in soil is less than 5 pCi/g above-background.

Elevated Area Criterion Decision Statement: Determine whether the residual radium activity in soil averaged over any area of 100 m² exceeds 50 pCi/g (without consideration of background).

At this point in the process, uncertainty due to inferential determination of the activity of Ra-226 does not need to be addressed because radium is presumably being measured directly.

As part of the EPA DQO process (EPA 1994), the step in which limits on the decision errors are established follows the step in which the decision statements are crafted. Note that at this point in the process, no decision has been made about the types of measurements to be used to demonstrate compliance. The first two types of uncertainty (i.e., analytical measurement uncertainty and uncertainty due to incomplete site coverage) have begun to be addressed by the structure of the decision statements. Analytical measurements must be performed so that the minimum detectable activity will not be greater than 5 pCi/g above background for measurements used to satisfy the first decision statement and no greater than 50 pCi/g to satisfy the second decision statement. The second statement is designed to address uncertainty related to the incomplete coverage associated with discrete sampling. Unit areas of 100 m² must be shown to be below 50 pCi/g.

The above decision statements could be addressed at some specified level of statistical certainty using data derived from discrete sampling and laboratory analysis. If discrete sampling was the only method used to collect data to address these decision statements, it is likely the sampling scheme would specify a density of samples statistically sufficient to ascertain whether any 100 m² area was clearly above or clearly below the 50 pCi/g activity level. Further, it is likely the sampling scheme would call for analytical certainty to determine whether the Ra-226 activity in any soil sample would be below 5 pCi/g above-background. In this way, both the analytical certainty and coverage (or spatial certainty) would be sufficient to make both decisions. Because the elevated area criterion would drive the sample number, the sample density required to meet the survey unit average criterion would be met by default. However, the cost of executing such a scheme may be considerably higher than other schemes using field scanning technologies that could provide the same or better overall levels of decision certainty.

Decisions statements and cleanup criteria are not developed in the absence of knowledge about the techniques used to quantify the concentrations of the COCs. In fact, the decision statements for the above example could have been written differently to account for the types of methods used to gather data to make the decision. An alternative statement of the decision criteria for each survey unit could be:

Survey Unit Average Criterion Decision Statement: Determine whether the average residual activity of Ra-226 in soil is less than 5 pCi/g above-background.

Elevated Area Criterion Decision Statement: Determine whether the gross gamma emissions as measured by a 2x2 NaI(Tl) detector exceed 50,000 cpm averaged over any 100 m² area of soil.

Because Ra-226 is not being directly measured in this case, an additional criterion would be needed to address the inferential uncertainty, such as:

Inferential Criterion Decision Statement: Determine by correlation that the 50,000 cpm gross gamma emissions threshold is equivalent to a discrete soil concentration of Ra-226 less than 50 pCi/g.

In this case, discrete soil sampling could be used to address the first and third criteria, and gamma walkover surveys could be used to address the second criterion. This could result in an overall spatial uncertainty much less than that using the discrete-sampling-only approach, and the cost of implementing the verification survey would likely be reduced, also.

Finally, it is possible that the decision statements could be written to use only gamma walkover surveys to decide both the survey unit average and the elevated area criterion decisions. In this case, the decision criteria for each survey unit might be as follows:

Survey Unit Average Criterion Decision Statement: Determine whether the average gross gamma emissions as measured by a 2x2 NaI(Tl) detector exceed 11,000 cpm over the area of the soil survey unit.

Elevated Area Criterion Decision Statement: Determine whether the gross gamma emissions as measured by a 2x2 NaI(Tl) detector exceed 50,000 cpm averaged over any 100 m² area of soil in the survey unit.

Once again, an additional criterion would be needed to address the inferential uncertainty because Ra-226 is not being directly measured:

Inferential Criterion Decision Statement: Determine by correlation that the 50,000-cpm gross gamma emissions threshold is equivalent to a discrete soil concentration of Ra-226 less than 50 pCi/g and that the 11,000 cpm gross gamma emissions threshold is equivalent to a discrete soil concentration of Ra-226 of less than 5 pCi/g above background.

As with the analytical measurements used for discrete soil samples, the EPA DQO process requires that the limits on the decision errors for all methods be established in a subsequent step in the process.

C.1.5 Identify Data Gaps

Once the CSM and decision statements have been developed, the next step is to determine what gaps exist in the available data and information that would prohibit a clear conclusion relative to the decision statements.

C.1.6 Resolve Common Regulatory Concerns

If key variables in the remediation and closure process are left as vague or undefined, various stakeholders may arrive at different conclusions about the approach and success of a remedial effort. Some of the most problematic issues have been discussed previously. It is absolutely essential that regulatory concerns be fully addressed as part of the systematic planning process prior to the development of work plans. Difficult issues should be identified and clarified. Decisions concerning approaches that most effectively reduce all types of decision uncertainty should be made. The approaches should be documented in the work plans using clearly and fully described decision statements and a decision tree. To guide data collection efforts, the decision

tree should be used while multidisciplinary teams are in the field collecting the data. Regulators should be actively involved in the planning and execution phases of the process.

C.2 DYNAMIC WORK STRATEGIES

Dynamic work strategies incorporated into work plans are used to guide field teams in optimizing the amount of reduction in uncertainty per sample. Work plans developed using dynamic strategies contain virtually all the information included in traditional work plans; however, dynamic plans possess additional important and defining components. They optimize the mix of traditional sampling and analysis and real-time measurement techniques. They also develop a chain of logic based on a robust CSM and the most current data to focus sampling activities in the near future on those areas where uncertainty remains the highest.

In contrast to the common practice of collecting a single sample to “show” that contamination has not affected an area, dynamic strategies consider and plan for what actions will be taken based on the results of that sample, whether above or below a particular criterion. The former approach has led to the unexpected result of discovering contamination without a clear understanding of the repercussions or what the next action would be.

C.2.1 Optimal Data Collection: Cost and Performance Considerations for Mixing Real-Time and Traditional Measurement Techniques

The best-designed dynamic work strategies blend traditional sampling and analysis with the most appropriate real-time measurement technologies. One way they do so is by judiciously pre-planning sample locations to satisfy data gaps identified during the systematic planning process. Because some data gaps are recognized in advance of deployment to the field, clear statements can be made about the type, timing, quality, and quantity of data required to fill them. It is common to conduct traditional sampling and analysis to determine the average concentration of contamination at very low detection limits for the purposes of risk analysis, defining the wide-area average as part of closure documentation, QA/QC of real-time measurement techniques, or waste characterization. Real-time measurement instrumentation is frequently used to identify elevated areas, guide remediation, and define the spatial variability of contamination across large areas.

Good work plans recognize that the results of traditionally collected and analyzed samples may take some time to become available. These activities are typically conducted first to allow for the availability of results before the field team demobilizes. Real-time measurement instrumentation is then used to address data gaps for which it is appropriate. In either case, the decisions to be made on the basis of the results are clearly identified in the work plan. Decision trees should be developed around each decision statement. As part of the decision-making strategy, a clear chain of decision-making authority should be provided in the work plan. Whenever possible, personnel with decision-making authority should be present in the field or available on a standby basis to allow field work to proceed expeditiously.

Another characteristic of a good work plan that incorporates dynamic work strategies is recognizing the need to collect sampling and analysis or other data that were not pre-planned.

Because it is frequently the case that new areas of contamination are identified as data gaps are addressed, it is important to have a reserve of funds, scheduling, and resources to accommodate the need for adaptability in the field. It is counterproductive to demobilize and then re-mobilize because the availability of adequate resources was not anticipated as part of the planning process.

This type of adaptability and the need to maintain adequate resources in reserve has implications for how project planning and contracting is implemented for an investigation. Project planning for traditional approaches is typically done using pre-planned sample locations. Resources are priced and scheduled prior to obtaining any data from the field. Therefore, contractor bids and schedules are based on the pre-planned sample locations, with very little flexibility for change either in location, type, or number of samples. This can lead to many challenges because laboratories base their workloads on these pre-determined estimates and attempt to run at capacity by contracting with other sites. In addition, subcontractors plan to begin new jobs when the scheduled samples are collected, and reserve project funds may not be available to support the investigation of new areas of contamination.

Another essential component of a work plan that incorporates dynamic work strategies is a clear data management strategy. Data and analysis should be quickly available to the technical team supporting the field characterization. Web-based dissemination of information is an excellent tool for assisting in real-time decision making.

C.2.2 Appropriate Validation and Verification Protocol

To obtain a similar level of confidence for the use of real-time measurement instrumentation that is enjoyed by traditional sample collection and analysis techniques, method-specific protocols should be established in the work plan. Such protocols may include correlation studies, establishment of reference areas to regularly confirm operation of the real-time measurement instrumentation, identification of adverse operating conditions, verification of results at offsite laboratories, and provisions for the standardization and maintenance of instruments in the field. These protocols should be established as part of the systematic planning process, discussed and agreed upon by the appropriate regulators, and documented in the work plan.

C.3 INTERNET RESOURCES ON THE TRIAD APPROACH

www.triadcentral.org/over/index.cfm
www.clu-in.org/conf/tio/triad_012303/

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Appendix D

The MARSSIM Approach

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THE MARSSIM APPROACH: KEY CONCEPTS, THE GRADED APPROACH AND THE ROLE OF FIELD MEASUREMENTS

MARSSIM, the *Multi-Agency Radiation Survey and Site Investigation Manual*, has been briefly outlined in Section 3 of this document. A complete and thorough discussion of MARSSIM is beyond the scope of this document but, to provide further context for its understanding, the following discussion below provides further information on some key concepts: the graded approach (which recognizes the tension and need for trade-off between MARSSIM's two primary goals) and the role of field measurements in MARSSIM.

D.1 KEY CONCEPTS

MARSSIM provides a defensible, standardized approach for demonstrating compliance with established cleanup criteria. During a site's remedial decision process, radionuclide-specific concentrations are calculated using exposure pathway modeling and then promulgated in a decision document. In MARSSIM terminology, these cleanup concentrations are expressed as DCGLs.

D.1.1 Derived Concentration Guideline Levels (DCGLs)

A key concept in MARSSIM is that concentration-based cleanup criteria are applied over areas consistent with the dose or risk scenarios developed as part of the exposure pathway modeling. It is desirable for DCGLs to be expressed in the same units as the method of measurement being used to demonstrate compliance (e.g., Bq/kg, Bq/m², pCi/g, or dpm/100 cm²) so that direct comparisons can be made between the survey results and the DCGL. MARSSIM guidance can be used for RAs where cleanup criteria were developed using methods other than those based in dose or risk. However, in every case, MARSSIM guidance calls for the use of survey areas over which the measurements will be collected. The survey areas, known as survey units, are discussed in more detail later in this section.

The management of uncertainty associated with the distribution and measurement of radionuclides is explicitly addressed by MARSSIM in a number of ways. One important technique for addressing uncertainty in site surveys is the use of two types of DCGLs to address heterogeneity in the distribution of radionuclides across survey units. These DCGLs are DCGL_w and DCGL_{EMC}.

DCGL_w is derived based on an average concentration over a large area. If the radioactivity appears as small areas of elevated activity within larger areas, the DCGL_{EMC} is used. The DCGL_{EMC} is derived separately for these smaller areas using different exposure assumptions than used in the DCGL_w calculations (EPA 2000). The principle behind the use of the DCGL_{EMC} is that the area of exposure and concentration of radionuclides are inversely related when calculating dose; equivalent levels of exposure may be received from a large exposure area with relatively lower concentrations of radionuclides or from a smaller area with relatively higher concentrations. In order to assure that the target cleanup exposure level is not exceeded either over entire survey units or from smaller areas of elevated activity within the larger areas, the two

types of DCGLs are typically used in tandem, with the value of the $DCGL_{EMC}$ being set higher than the $DCGL_w$. Scanning surveys are typically used to identify small areas of elevated activity.

D.1.2 The Gray Region

MARSSIM also addresses uncertainty by employing a concept known as the gray region. The gray region is a quantitative concept expressed in the units of measurement that are used for the DCGL. Conceptually, the magnitude of the gray region expresses the degree of the variability associated or expected with measurements of the radioactivity at a site. The gray region captures the range of values over which the radiological measurements are expected to vary. The breadth of the gray region is instrumental in determining the number of measurements that must be made to confirm that a survey unit is clean. The upper bound of the gray region is defined as the $DCGL_w$. The LBGR is set so that the gray region spans a range equal to between one and three times the known or estimated value of the standard deviation (σ) of the measurements. The difference between the two values is known as Δ (i.e., $DCGL_w - LBGR = \Delta$). If σ is not known, the LBGR is often initially set at one-half the $DCGL_w$.

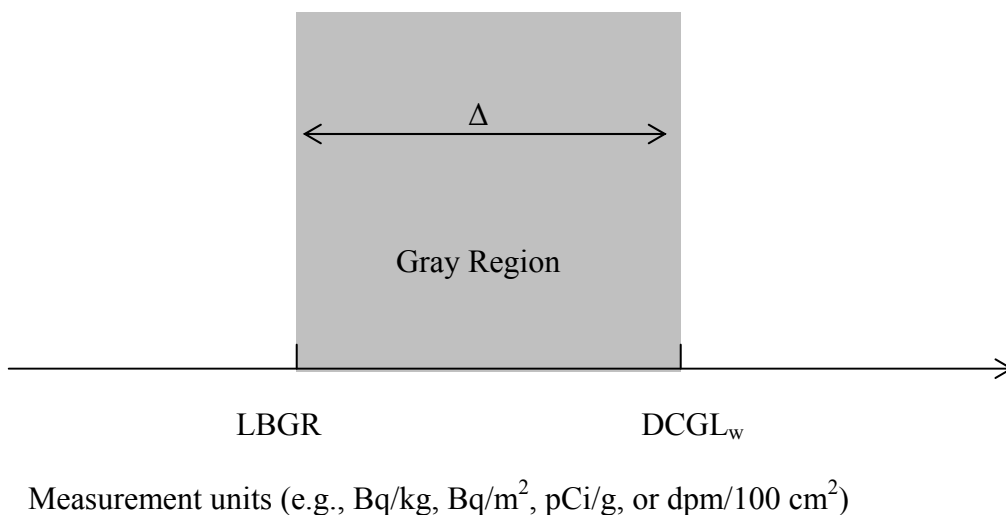


Figure D.1: The gray region expresses the degree of variability associated or expected with measurements of the radioactivity at a site

D.1.3 Graded Approach to Final Status Survey Design

Two primary goals of MARSSIM are to develop survey designs that can be efficiently implemented and to establish a standardized basis for making accurate remediation decisions. MARSSIM recognizes that the two goals are not necessarily mutually compatible. The need for data to make decisions must be balanced against the realities of maintaining project efficiency and controlling project costs. To achieve this balance, MARSSIM uses a graded approach in the design of final status surveys that applies effort commensurate with the potential for an area to contain radioactivity above the cleanup guidelines. The idea guiding this approach is to use measurement methods tailored to meet the survey's data quality needs, but not to use excessively sensitive or expensive methods if they are not necessary, and to collect the number of

measurements required to make a defensible decision, but not to collect excess or unnecessarily redundant data.

D.1.4 Limits on the Decision Error

Limits on decision error is a third important way in which MARSSIM explicitly addresses uncertainty in the site closure decision process. As part of the graded approach in the design of final status surveys, Type I and Type II errors are considered, and the probability of making either type of error is factored into the survey design. For MARSSIM surveys, Type I errors occur when an area is declared clean but, in reality, contamination remains above the cleanup criteria. Type II errors occur when an area that really is clean is declared still to be contaminated.

The probability of making a Type I decision error is denoted by the character α . The probability of making a Type II decision error is denoted by the character β . Clearly, from a health perspective, declaring a contaminated area to be clean (Type I error) is more serious than declaring a clean area to be contaminated. On the other hand, deciding that clean areas are contaminated is counterproductive from a cost and efficiency perspective. Therefore, MARSSIM guidance allows the limits on the decision error (i.e., the values of α and β) to be established as part of the calculations that determine the number of measurements required for each survey unit.

D.2 SURVEY UNIT DEFINITIONS

As previously mentioned, survey units are used as part of the graded approach that MARSSIM uses in the design of final status surveys. As part of the effort to balance accuracy in decision making versus efficiency, MARSSIM employs classes of survey units primarily distinguished by their size. The following text is excerpted from MARSSIM (EPA 2000):

Classification is a critical step in the survey design process. The working hypothesis of MARSSIM is that all impacted areas being evaluated for release have a potential for radioactive contamination above the DCGL. This initial assumption means that all areas are initially considered Class 1 areas unless some basis for reclassification as non-impacted, Class 3, or Class 2 is provided. Areas that have no reasonable potential for residual contamination, do not need any level of survey coverage and are designated as non-impacted areas. These areas have no radiological impact from site operations and are typically identified during the Historical Site Assessment.

Impacted areas are areas that have some potential for containing contaminated material. They can be subdivided into the three classes described below.

- *Class 1 areas.* Areas that have, or had prior to remediation, a potential for radioactive contamination (based on site operating history) or known contamination (based on previous radiological surveys). Examples of Class 1 areas include: 1) site areas previously subjected to remedial actions, 2) locations where leaks or spills are known to have occurred, 3) former burial or disposal sites, 4) waste storage sites, and 5) areas with contaminants in discrete

solid pieces of material high specific activity. Note that areas containing contamination in excess of the DCGL_w prior to remediation should be classified as Class 1 areas.

- *Class 2 areas.* These areas have, or had prior to remediation, a potential for radioactive contamination or known contamination but are not expected to exceed the DCGL_w. To justify changing an area's classification from Class 1 to Class 2, the existing data (from the HSA, scoping surveys, or characterization surveys) should provide a high degree of confidence that no individual measurement would exceed the DCGL_w. Other justifications for this change in an area's classification may be appropriate based on the outcome of the DQO process. Examples of areas that might be classified as Class 2 for the final status survey include: 1) locations where radioactive materials were present in an unsealed form (e.g., process facilities), 2) potentially contaminated transport routes, 3) areas downwind from stack release points, 4) upper walls and ceilings of some buildings or rooms subjected to airborne radioactivity, 5) areas where low concentrations of radioactive materials were handled, and 6) areas on the perimeter of former contamination control areas.
- *Class 3 areas.* Any impacted areas that are not expected to contain any residual radioactivity or are expected to contain levels of residual radioactivity at a small fraction of the DCGL_w, based on site operating history and previous radiological surveys. Examples of areas that might be classified as Class 3 include buffer zones around Class 1 or Class 2 areas and areas with very low potential for residual contamination but insufficient information to justify a non-impacted classification.

Class 1 areas have the greatest potential for contamination and, therefore, receive the highest degree of survey effort, followed by Class 2 and then Class 3 areas.

The criteria used for designating areas as Class 1, 2, or 3 should be described in the final status survey plan. Compliance with the classification criteria should be demonstrated in the final status survey report. A thorough analysis of HSA findings (Chapter 3 of MARSSIM) and the results of scoping and characterization surveys provide the basis for an area's classification. As a survey progresses, re-evaluation of this classification may be necessary based on newly acquired survey data. For example, if contamination is identified in a Class 3 area, an investigation and re-evaluation of that area should be performed to determine if the Class 3 area classification is appropriate. Typically, the investigation will result in part or all of the area being reclassified as Class 1 or Class 2. If survey results identify residual contamination in a Class 2 area exceeding the DCGL or suggest that there may be a reasonable potential that contamination is present in excess of the DCGL, an investigation should be initiated to determine if all or part of the area should be reclassified to Class 1.

D.3 MARSSIM PERSPECTIVE ON THE ROLE OF FIELD MEASUREMENTS

Sites frequently possess a number of different contaminants that often display heterogeneous patterns of distribution. Instrumentation and characterization techniques must be capable of assessing the levels of contamination over large areas (i.e., meeting the DCGL_w) and also determining whether smaller elevated areas exist (i.e., meeting the DCGL_{EMC}). For these reasons, it is unlikely that a single instrument would be capable of meeting all of the site's requirements.

The term “measurement” is carefully defined in MARSSIM to mean “1) the act of using a detector to determine the level or quantity of radioactivity on a surface or in a sample of material removed from a media being evaluated, or 2) the quantity obtained by the act of measuring” (2000). Direct measurement and scanning methods are techniques that are used in the field. MARSSIM encourages the use of field methods as part of a site’s measurement program. When field methods are not capable of detecting radiation levels below the DCGLs, discrete samples and laboratory methods are required.

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Appendix E

An Example Site Combining Triad and MARSSIM with Real-Time Measurement Techniques

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AN EXAMPLE SITE COMBINING TRIAD AND MARSSIM WITH REAL-TIME MEASUREMENT TECHNIQUES

The following example provides a summary of the general components of a possible protocol that could be used on a large and complex site for fulfilling the remaining characterization and site closure needs. This example protocol combines the Triad and MARSSIM approaches into dynamic work strategies. For any actual site, the work plans would evolve from and be consistent with this protocol. Ultimately, the work plans are the site-specific, fully developed end products of the systematic planning process.

E.1 EXAMPLE SITE BACKGROUND

A large federal facility is undergoing closure. The facility consists of large tracts of pristine land combined with localized sites where historical activities took place that may have resulted in contamination of soils. These localized sites include waste disposal areas, testing grounds, tank farms, potentially compromised infrastructure (e.g., buried waste lines that may have leaked), and manufacturing facilities where hazardous waste was handled. The approach to characterization of the facility uses a CERCLA perspective, with sufficient data collected during the RI using the *EPA Soil Screening Guidance for Radionuclides* (EPA 2000) approach to determine that known problem areas exceed risk standards and require remediation. These data have identified both radionuclides and chemicals as COCs. The primary radionuclides appear to be ubiquitous, while the chemicals appear to be more area specific in their spatial distribution. Historical data collection was not sufficient to accurately define contaminant extent for areas with known contamination, however, nor did it address all of the potential locations of concern.

The site is moving quickly toward remediation and closure and requires a data collection and decision-making strategy that will minimize total RA costs, expedite remediation and closure schedules, and provide stakeholders with confidence that risk goals, as embodied by DCGL requirements, have been met. Because radiological concerns predominate, a MARSSIM framework was selected for guiding closure activities. The Triad approach was used to leverage real-time measurement systems as much as possible. For the purposes of this example, it is assumed that DCGL requirements have been derived for a master list of COCs for the facility using a facility-specific dose model. It is also assumed that most, if not all, of the radionuclides involved are amenable to some form of real-time measurement with detection limits in the range of DCGL requirements.

E.2 EXAMPLE STRATEGY/PROTOCOL DEVELOPMENT

An example strategy for this site, consistent with MARSSIM and Triad, leverages available real-time data collection techniques has the following components.

E.2.1 Site Categorization

Using all available existing information, the facility as a whole is divided into areas of concern, each of which has characteristics that distinguishes it from the rest of the site. These may be relatively small (a burn pit disposal area less than an acre in size) or very large (500 acres of mature forest). This categorization process has the explicit involvement of stakeholders, since categorization will have significant impacts on what is done for each area. The categorization process is spatially complete, with every location within the facility boundaries assigned to an area. Each area eventually has its own CSM, including a list of potential COCs specific to that area.

E.2.2 Decision Statement Definitions

The primary decision to be made is whether or not COCs are present in concentrations greater than DCGL requirements for specific portions of each area. This decision is made for each MARSSIM final status survey unit before closure is attained. The assumption is that areas contain contamination greater than DCGL requirements unless proven otherwise. For some areas, historical data collected may suffice as proof, or additional, limited, biased data collection may be required. For other areas, particularly those that require remediation, more formal systematic data collection is required.

E.2.3 Integrated Characterization/Remediation Support/Closure Data Collection Strategy.

Generic closure data requirements are specified to support decisions that must be made, along with acceptable error rates for missing contaminated areas. Data collection strategies are developed so that all subsequent characterization data can be used to at least partially satisfy final status survey data area requirements.

E.2.3 Area-Specific CSM Development

For each area, an area-specific CSM is developed. While the details of the CSM may vary from area to area, all CSMs developed share these common characteristics:

- An area-specific COCs list, along with appropriate DCGL requirements. For areas with significant RI data, this list is definitive. For areas where RI data do not exist or are limited, the list includes those COCs most likely to be present if contamination exists.
- A description, based on existing information, of where both surface and subsurface contamination greater than DCGL requirements is believed to potentially exist. This description includes a statement describing the confidence associated with the assessment of contamination potential.
- A division of the site area into MARSSIM final status survey unit classes based on the description of contamination potential. For some areas, there may be insufficient information to confidently perform this classification process for all locations. These locations are either

flagged for additional biased post-closure data collection to support final status classification, or they are classified as MARSSIM Class 1 areas.

- Identification of area-specific complicating factors that require area-specific solutions from a closure perspective. For example, for a particular area there may be anecdotal evidence that a French drain was present and used for waste disposal. Its actual existence and location, however, have not been established. Closure requires either locating and characterizing the French drain and associated soils or establishing its nonexistence.

E.2.4 Deployment of Real-Time Measurement Technologies

For the COCs, appropriate real-time measurement technologies are identified and integrated with traditional sample and laboratory analysis techniques. Generic technologies and deployment strategies are established for the facility as a whole. Area-specific details of deployment are described in area-specific sampling and analysis plans. Deployment strategies include the following:

- *Technology-specific validation and verification work, if required.* For some real-time measurement techniques (e.g., onsite in situ gamma spectroscopy), performance may be well established for COCs. For surface scans and inferences drawn from gross activity data, however, validation and verification work may be required to establish appropriate investigation levels and detection limits for the instruments proposed for use.
- *Explicit balancing of investments in data collection with reductions in the possibility of remediating locations unnecessarily.* The acceptable probability of missing contamination establishes the minimum requirements for data collection.
- *The use of real-time measurement systems to screen for COCs that may have been missed in the area CSM, where this is a concern.* For example, the selective use of PCB test kits may provide a rapid and inexpensive (although false positive-prone) means of identifying PCB concerns.
- *The use of real-time measurement systems for evaluating elevated-area DCGL concerns. For example, a gamma walkover combined with GPS that logs data may eliminate surficial DCGL_{EMC} concerns.* A non-intrusive geophysical survey combined with a GeoProbe and in-field technologies (e.g., PCB test kits, handheld XRF, and down-hole gamma log) could be used to relatively quickly and inexpensively determine whether isolated buried contamination is an issue.
- *The identification of definitive investigation levels for real-time measurement techniques.* If a result is below a particular field-based investigation level, then the DCGL requirements for that location are met (contamination is at an acceptable level); if a result is above a particular investigation level, then the DCGL requirements for that location are exceeded (contamination is above acceptable levels).

- *The description of dynamic response actions expected in response to particular real-time measurement results.* For example, if a real-time measurement result is greater than a lower investigation level but less than an upper investigation level (i.e., the DCGL status of the measurement is inconclusive based on the real-time measurement result), then a discrete soil sample for laboratory analysis will be collected. As another example, if investigation of a subsurface MARSSIM Class 2 area unexpectedly yields a result greater than DCGL requirements, characterization work for that area will stop, the area will be slated for remediation, and the area will be reclassified as a MARSSIM Class 1 area.

E.2.5 Development of Appropriate QA/QC Procedures

The purpose of data collection is to support decision making. Data are assumed to be of some minimal quality to perform this role. QA/QC procedures assure that the minimum quality requirements have been attained. In addition to traditional sample blanks, splits, and spikes, the following are examples of these types of requirements for real-time measurement technologies for this facility:

- establishment and use of survey benchmarks to validate location control information generated during data collection and remediation work
- daily source response checks for surface gross activity scanning equipment
- specification of real-time scanning measurement density goals (e.g., one measurement per m²) and a post-data collection evaluation of goal attainment
- evaluation of the presence of environmental factors that might compromise real-time measurement data quality (soil moisture content, significant changes in background concentrations, differences in substrates, etc.)

E.3 DEPLOYMENT STRATEGIES

For an area with insufficient information to support MARSSIM final status survey unit class definitions (e.g., concerns about subsurface contamination potential), deployment strategies might include the following:

- Complete coverage of the area is accomplished with a gamma-scanning device with QA/QC standards such that the data can be used for final status survey purposes if nothing of significance is found. If anomalies showing COC concentrations greater than DCGL requirements are identified, discrete samples are collected and submitted for confirmatory laboratory analysis. If confirmatory analysis results are greater than DCGL requirements, the area is defined as a MARSSIM Class 1 area and it is slated for remediation. If not, it is a candidate for MARSSIM Class 2 status.
- An appropriate non-intrusive technique, combined with review of historical aerial photography, is used to identify areas most likely to have subsurface impacts. A GeoProbe is used to extract a soil core from the most suspect location. The core is screened for radiological and chemical COCs. If this and surficial scans yield nothing greater than DCGL requirements, the area is classified as a MARSSIM Class 2 unit area and subdivided, if

necessary, into individual survey units. Closure then follows MARSSIM Class 2 unit protocols. In this instance, since gamma walkover surveys have already been completed, additional final status survey data collection would focus on establishing compliance with DCGL_w requirements through limited discrete sampling and analysis and any additional subsurface DCGL_{EMC} coring, screening, and sampling required.

- If either surface or subsurface sampling yields results greater than DCGL requirements, the area would be classified as a MARSSIM Class 1 area. Remediation would be planned and implemented using real-time measurement techniques to minimize excavation volumes. Remediation support data collection would be designed so that investments in data collection during remediation balance expected reductions in waste streams, and the final round of data collection could be used to at least partially satisfy final status survey requirements for the exposed dig face. These would most likely include dig face scans with an appropriate gross gamma scanning technique, combined with discrete sampling and analysis if chemical COCs exist.

The process is completed with the remediated area divided into individual MARSSIM Class 1 units and final status survey data collection targeting data gaps left from the remediation data collection.

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Appendix F

DQIs for Radiological Measurements

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DQIs FOR RADIOLOGICAL MEASUREMENTS

DQIs are qualitative and quantitative measures (statistics) of data quality attributes. Data quality attributes are the descriptors (the words) used to express various properties of analytical data. For example, sensitivity can be measured by instrument detection limit, or sample detection limit, or quantification limit, so there is a need for rigor in definition to avoid confusion. The following sections provide definitions and discussion on some of the main DQIs used in QA/QC.

F.1 ACCURACY

For an individual sample measurement, accuracy is the degree of agreement between the measurement and the true value of the sample. When comparing in situ and laboratory sample measurements, it is instructive to examine the meaning of what constitutes a sample. A surface soil sample collected for analysis in a laboratory is typically a discrete subunit of the sampled soil, perhaps 3 in diameter by 4 in deep. The sample dimensions may be selected primarily for the purpose of providing sufficient soil quantity for analysis with little regard to the soil structure or the contaminant distribution within it. This sample is thoroughly homogenized prior to analysis so that the “true” concentration of a constituent is equal to the mass of the constituent in the sample collected divided by the total mass of the soil collected, irrespective of how the constituent was originally distributed within the sample.

Properly calibrated laboratory analysis techniques for radiological constituents typically provide results that are within 10% of the true values as defined above. When interpreting such a result, however, the meaning of the true value must be considered in relation to the soil profile from which the sample was taken. Depending on deposition mechanisms, the concentration in the top 1 cm of the soil might be much higher than the homogenized value. Likewise, the sample result gives no information on depth of constituent in the surface soil, which might have ended 2 cm into the sample or continued beyond the depth of the sample. Therefore, since the distribution of constituents in soil affects migration and exposure factors, even an accurate analysis of a discrete soil sample provides a somewhat limited picture of the potential for human exposure to the constituent.

In situ gamma measurements of radionuclides in soil are based on a model that assumes uniform distribution of the constituents within the field of view of the detector, both laterally and with depth. The model also assumes that the measured soil has the same attenuation coefficient for gamma rays as was used in the calibration of the detector. The moisture content of the measured soil must also be determined and the measurement corrected accordingly using a standard correction factor. Finally, in situ gamma measurements often must measure the progeny of the radionuclide of interest and assume that the two are in secular equilibrium (at the same activity). Differences in attenuation coefficients and errors in soil moisture determination can affect the accuracy of in situ gamma measurements, as can deviations from equilibrium. The greatest errors in practical applications, however, might be expected to result from deviations from the assumed homogeneous distribution of the constituents in soil. For Ra-226, further error is introduced when this radionuclide is determined from progeny of Rn-222. Emanation of Rn-222 from soil as

well as build up of Rn-222 in the atmosphere under certain weather conditions must be accounted for in the determination of Ra-226.

While vertical inhomogeneities are neutralized in laboratory analysis through sample homogenization, they do affect in situ measurements. For example, if constituents are concentrated in the top 1 cm of soil, the total fluence reaching the detector will be greater than if constituents are uniformly distributed, due to reduced soil attenuation. The increased fluence would contribute to a high bias in the result. So, while inhomogeneities in discrete samples are canceled out, they can affect in situ measurements. On the other hand, the laboratory measurement may only appear more accurate when the actual constituent distribution in soil is considered.

Lateral inhomogeneities will also affect the accuracy of in situ measurements. Such effects diminish with distance from a point directly below the detector due to a reduced contribution to the total fluence in the same direction. The effects of lateral inhomogeneities can be reduced by lowering the detector and reducing the field of view. This is done when attempting to delineate the boundaries of contaminated zones so that differences can be discerned. As most of the fluence contributing to a measurement originates from a relatively small region directly beneath the detector and diminishes rapidly with distance, lateral inhomogeneities have a smaller effect than might be expected. Useful measurements can often be obtained in areas of spotty contamination, particularly when taken at low detector height over a grid.

Individual discrete physical samples are little affected by lateral inhomogeneities; however, it is these very same inhomogeneities that give rise to sampling error that can only be addressed in the aggregate with multiple discrete samples. If an insufficient number or poorly located samples are collected, overall error will be great even when individual samples have high accuracy. In many cases, total error is limited by sampling, and high accuracy for discrete samples is of little consequence.

Given these various sources of error, it is still possible to make routine in situ measurements in soils with accuracies approaching those of laboratory analysis of discrete soil samples. Section 8.4 and Appendix G of this document discuss studies, performed at Fernald, which examined the comparability of in situ measurements with laboratory measurements. The average agreement of analyses of total uranium, Ra-226, and Th-232 was well within 20%.

Effective use of in situ measurements considers sampling and analysis error together in the same design. While this is also true of well designed conventional sampling and analysis programs, the use of in situ measurements provides the added benefit of having these objectives combined within a single entity when considering overall uncertainty, helping to ensure a more cost-effective design. A properly designed in situ program would consider the scale of expected inhomogeneities relative to sample spacing and to the selected field of view of the detector. The vertical distribution of contaminants can be examined through a separate analysis and through physical models. In cases where profiles diminish with depth, measurement errors would tend to be conservative relative to health protection. Other factors that must be controlled or verified are soil type and moisture factors, as discussed above.

F.2 PRECISION

Analytical precision is the degree of agreement among repeated measurements of the same sample. Differences between measurements arise from random error in the various parameters of the measurement, whereas a systematic bias would affect measurement accuracy. Random errors are often irreducible limitations of the measurement system, while systematic errors can generally be minimized through system controls, for example, through the use of standard reference materials.

In the case of in situ gamma measurements, and radiological measurements in general, random error arises from the random nature of the radioactive decay process. This error is manifested as counting error when a measurement is taken over a specific counting time. Counting error can be reduced by increasing counting time or by using a larger or more efficient detector.

A number of other parameters that make up in situ gamma measurements also have associated random errors. Such parameters include sample moisture measurements, background noise, and electronic noise. The associated errors are typically small and, for the most part, difficult to reduce. In order to reduce overall random error to a minimum (maximizing precision), while keeping count times to a reasonable level, measurement strategies typically use a count time that reduces counting error to a level comparable to other random errors in the measurement. Counting for a longer period would have little effect on increasing precision further.

The objective of measurement programs is to produce both accurate and precise measurements. When discussing the relationship between the two, the notion of sampling must be introduced. Any measurement that is accurate is also, by definition, precise; it returns a value close to the true value time and time again. Similarly, a single imprecise measurement cannot be considered accurate, although there is certain low probability that the measurement will be close to the true value assuming there is no bias in the measurement. Increasing the number (sample size) of low precision but unbiased measurements, however, will increase the accuracy of the aggregate measurement by reducing random error with improved statistics. This is effectively what is done when count time is increased in radiological measurements.

F.3 REPRESENTATIVENESS

Representativeness is the degree of agreement of between the characteristics of the sample and the underlying population from which it was drawn. With respect to soil sampling, this usually means that the sample, or samples, of the study population (area) have the same constituents in the same nominal statistical distribution of concentration, i.e., mean and standard deviation, as the study population.

In conventional soil sampling designs, representativeness is achieved by consideration of the known or assumed distribution of constituents in the study area. The physical distribution of constituents relates to the mathematical distribution of concentration values in samples randomly selected from the study area. Designs focus on determining the number of unbiased samples that must be collected to represent the variability in the actual soil conditions within an acceptable uncertainty (see the discussion of MARSSIM final status surveys in Section 3). The

representativeness of the collected samples must be maintained in the laboratory through sample homogenization and careful subsampling for analysis.

The same principles of achieving representativeness apply to in situ gamma methods applied under the Triad approach; however, the in situ nature of the measurements presents some complicating factors that must be considered during the collection of data. One factor of note is the nature of the response of in situ gamma detectors to non-uniformities in contaminant distribution. A second, related factor is the effect of deviation of the sample geometry from the assumed planar geometry used in the calibration of the detector. In situ gamma measurements of soil constituents typically rely on a model of uniform contaminant distribution in a planar geometry. Inhomogeneities within the field of view, both laterally and with depth, deviate from the assumed distribution applied in the calibration of the systems. This deviation imposes some degree of quantitative error; however, the influence of inhomogeneities diminishes rapidly with distance from a point below the detector.

Further, in situ gamma systems do not average the concentration of constituents within the field of view, as is assumed by many, but heavily weigh response to the area directly below the detector. A larger field of view may be applied in a screening mode in which any elevated measurement is of interest. Once detected, however, elevated areas that are heterogeneous can only be accurately measured by adjusting the detector field of view of the instrument or by adding a collimating shield so that the viewed area approximates uniform concentration. As long as the region nearest the detector is relatively homogeneous, a representative and accurate measurement of the soil concentration in that region will be obtained. Measurement strategies should be formulated with these response characteristics in mind.

Similarly, deviations from flat plane geometry affect the quantification of radionuclides by in situ gamma spectrometry. Bowl-like geometries will result in an upward bias of measurements by effectively raising the horizon of the measurement and increasing the gamma ray fluence from perimeter areas. Mound-like geometries have the opposite effect. The degree of these effects can be accurately modeled for ideal geometries. Correction factors are available in a report issued by the EML of DOE (DOE 1999).

In practice, the effect of uneven terrain can be estimated from the slope of the area to be measured. In bowl-like geometries, such as those commonly encountered in soil remediation work, a high bias produces a conservative measurement; uncorrected measurements may be acceptable, especially at levels far removed from action levels. For both bowl-like and mound-like geometries, deviations can be minimized by reducing the field of view in the same manner as for minimizing the effects of constituent inhomogeneities.

F.4 COMPARABILITY

Comparability is the degree to which one set of measurement data agrees with another for similar samples and sampling conditions. In this sense, it is an overall indicator of data quality that combines accuracy, precision, and representativeness. Comparability is achieved by controlling systematic and random error to levels within acceptable limits through the use of standard reference materials, robust analysis methodologies, and properly designed measurement

programs. Extensive studies of the comparability of in situ HPGe measurements and laboratory measurements of soil samples have been performed and documented at Fernald. These studies are discussed fully in Section 8.4 and Appendix G and are briefly summarized here.

The FEMP studies compared in situ methods with laboratory methods in two ways: by the comparison of results for the same soil locations and by the comparison of certification unit outcomes as determined by the two methods. In the point-by-point comparisons, roughly ten different locations with varying levels of contamination were analyzed using both methods. At each location, an HPGe measurement was taken at both 100 cm and 30 cm detector heights. Within the field of view of the HPGe measurements, soil samples were collected in concentric rings about the central detector location and analyzed by laboratory gamma spectrometry, alpha spectrometry, or both for total uranium, Ra-226, and Th-232. For the in situ Ra-226 measurements, a radon disequilibrium correction was applied to account for radon losses from the soil surface.

Under these carefully controlled conditions, the point-by-point comparisons were very good, typically within about 10%. Certification unit comparisons were similarly good, with few differences in certification unit decisions between the two methods of analysis. While this type of comparison is not a conventional means of comparing two analytical methods, it supports the ability of in situ methods to produce decision quality data. An examination of the individual soil samples analyzed in aggregate for comparison to the HPGe measurements reveals the importance of comparing similar samples for in situ and laboratory analysis. While many of the individual samples in these somewhat inhomogeneous study areas did not agree well with the in situ HPGe measurement being compared, the weighted average of all such discrete samples within the field of view of the HPGe measurement invariably compared much more favorably.

In these comparisons, the “sample” is the surface soil within the effective field of view of the HPGe. When such a sample is analyzed by both in situ HPGe and properly located and weighted laboratory samples, comparisons can be quite good, while comparisons of a single discrete laboratory sample and an in situ gamma measurement, particularly in heterogeneous contamination areas, will not fare as well. The effects of heterogeneity on in situ gamma measurements were discussed fully in Section F.3, Representativeness, above.

F.5 INTERFERENCES

Several types of interferences can affect in situ gamma measurements, including those from natural background radiation and those from local sources when using an unshielded detector. Spectrometric measurements are also subject to interference from gamma rays produced by multiple gamma-emitting radionuclides in the same sample. In the latter case, for example, the direct measurement of Ra-226 using its 186 KeV gamma ray will incur interference from a gamma ray at 185.7 KeV from U-235 when both isotopes are present at levels dictated by the decay of natural uranium. In this case, as is done at Fernald, Ra-226 can be measured from the gamma emissions of its own decay products, for example, from the 1765 KeV gamma from Bi-214. This decay chain, however, passes through an Rn-222 intermediate, an isotope that is subject to emanation from soil and buildup in the atmosphere. Both phenomena complicate the in situ measurement of Ra-226.

Background radiation can affect both gross activity and spectrometric measurements. In either case, the level of background radiation determines the level of radiological contamination that can be discerned by measurements. The minimally detectable concentration of extra-background activity is the level of radioactivity that produces a detector count rate that is statistically distinguishable from background count rates.

Interference from local radiation sources, also known as “shine,” can also be a significant problem at radiological remediation sites. Unshielded detectors will respond to gamma rays originating from all directions about the detector. While the strength of such interferences diminishes rapidly with distance, strong sources of shine can easily overwhelm the signal from soils with activities near remediation levels. At Fernald all major sources of shine, such as the K-65 silos, have been identified. Consequently, in situ gamma measurements are avoided in the vicinity of these areas. As part of the data quality review, in situ gamma spectrometry data are examined to detect the presence of any unidentified shine sources by using gamma ray ratios indicative of shine. Low energy gamma rays originating from shine sources are attenuated by air and by container walls, appearing relatively weaker than those originating from soils beneath the detector.

F.6 SENSITIVITY, RANGE, AND DETECTION LIMITS

Sensitivity, range, and detection limits are related performance parameters that affect the application and use of in situ gamma systems. The requirements for these parameters are determined in the DQO process for the prevailing measurement program. Sensitivity is essentially the efficiency of the detector response to radionuclide concentration—it is the slope of the detector signal. It is associated with the detection limit of a measurement system and is the lowest concentration that can be discerned from background. The range of a measurement system is defined by the concentration levels in samples over which useful measurements can be made; it is limited at the low end by the detection limit and at the high end by detector saturation.

The sensitivity, range, and detection limits of in situ gamma detection systems are a function of both the intrinsic and extrinsic properties of the detector systems, i.e., detector type (material) and detector size and shape. Counting duration is a further external factor that affects detection limits, as discussed previously. These properties can be adjusted through the selection of the detector type, size, shape, placement, and count time to configure a system that will produce measurements of the requisite quality.

With respect to soil remediation programs, system detection limits are often the primary consideration for assessing detector system performance. Sampling locations that are of a high enough activity concentration to saturate detectors can generally be managed appropriately on the basis of this information alone. Detector system requirements, therefore, are typically concerned with the assembly of a system that produces sufficient detection limits for the radionuclides or radioactivity measurements of interest.

Some considerations that affect the choice of detector systems for particular applications are as follows:

- Large NaI detectors are available at modest cost that can produce low detection limits for applications such as mobile scanning.
- Thin NaI detectors, such as the FIDLER, can have reduced detection limits for low energy gamma emitters due to reduced background noise from the high energy region.
- HPGe detectors are generally of relatively small size, but can produce low detection limits for individual radionuclides as a consequence of their high energy resolution when used in a static measurement mode of sufficient count time.
- The shape, symmetry, and orientation of the detector affect its angular response, i.e., its directionality. For example, simple, symmetrical, detectors (such as a vertical cylinder in the case of a tripod mounted HPGe) produce data that are somewhat easier to interpret in inhomogeneous areas than detectors of odd shape or orientation.

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Appendix G

Case Studies: Deployments of Real-Time Measurement Systems

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CASE STUDIES: DEPLOYMENTS OF REAL-TIME MEASUREMENT SYSTEMS

Specific examples of how real-time measurements systems have been used at various sites provide a sense of the roles they have played and highlight where real-time systems have been used effectively to address radionuclide contamination. The following sites have been developed as case studies:

- Ashland 2 FUSRAP Site, New York
- Brookhaven National Laboratory, New York
- East Tennessee Technology Park, Tennessee
- Fernald Environmental Management Project, Ohio
- INL, Idaho
- Kirtland Air Force Base, New Mexico
- Mt. Pleasant NORM Site, Michigan
- Nevada Test Site, Nevada
- Paducah Gaseous Diffusion Plant, Kentucky
- Rocky Flats, Colorado
- Savannah River Site, South Carolina

Section 8 of this document provided summaries of five of these case studies (East Tennessee, Savannah River Site, Ashland 2 FUSRAP Site, Fernald Environmental Management Project, and Kirtland Air Force Base). The following case studies include these five, with more detail, and present six other case studies to provide a broader perspective on the use of real-time measurement systems.

G.1 ASHLAND 2 FUSRAP SITE, TONAWANDA, NEW YORK

G.1.1 Site Description

The Ashland 2 property is located within the boundaries of the town of Tonawanda, New York. The Ashland 2 property includes about 115 acres of undeveloped property surrounded by former or active industrial sites. During the 1940s, the Manhattan Engineering District (MED) used facilities at a neighboring site to extract uranium from ore. The MED purchased property, currently known as the Ashland 1 Site, to use as a disposal location for ore refinery residues from the processing plant. Between 1974 and 1982 the Ashland Oil Company, which acquired the disposal site, excavated soil containing MED related low-level radioactive residues and moved it to the area known as the Ashland 2 Site. These land disturbances resulted in both surface and buried soil contamination; however, only a relatively small portion of the property was impacted by contamination. The Ashland 2 site is privately held and currently undeveloped. Future use for the site is expected to be industrial, and cleanup requirements developed for the site were based on that assumption.

The Ashland 2 site is part of FUSRAP. FUSRAP sites are privately held properties that were contaminated while supporting the United States' nuclear weapons program. Radionuclide

contamination is common at these sites; some have chemical contamination as well. The USACE has lead responsibility for the remediation of FUSRAP sites.

G.1.2 Regulatory Framework

The USACE Buffalo District inherited the responsibility for site remediation from the DOE. While the site was under DOE, a ROD was developed and signed. This ROD called for removal and offsite disposal of all contaminated soils exceeding site cleanup criteria. While there are several radionuclides of concern present at the Ashland 2 site above background levels, the RI combined with a dose analysis conducted by DOE identified Th-230 as the principal COC. Consequently the standards determined in the ROD targeted Th-230. Surface soil requirements were set to 14 pCi/g averaged over 100 m² areas. Subsurface soil requirements were set to 40 pCi/g averaged over 100 m² areas. Two other radionuclides of concern (and their progeny) were Ra-226 and U-238. While these were not the principal contributors to dose for the site, they were significantly elevated and collocated with Th-230.

Under the USACE, site remediation followed a CERCLA approach. Closure protocols were designed to be MARSSIM-consistent. EPA Region 2 had regulatory authority under CERCLA for the site. However, the New York Department of Environmental Conservation (NYDEC) took an active role in providing oversight for remediation and closure activities. Through negotiations with the NYDEC, the USACE agreed to include elevated area criteria (MARSSIM-based DCGL_{EMC}) along with the cleanup goals (DCGL_W). These criteria were 28 pCi/g for Th-230 in surface soils and 80 pCi/g for Th-230 in subsurface soils.

G.1.3 Contaminant Characterization

The DOE performed an RI for the site. From 116 bore holes, 341 soil samples were collected and analyzed via gamma spectroscopy for U-238, Ra-226, and Th-230. The detection limits for Th-230 using gamma spectroscopy were above the cleanup guidelines. Consequently, a subset of these samples was also analyzed for Th-230 via alpha spectroscopy. A DOE contractor used the RI data sets, minimum tension spline interpolation techniques, and the 40 pCi/g cleanup level for Th-230 to estimate the total contaminated soil volume at around 14,000 cubic yards.

G.1.4 Remediation Strategies

The baseline remediation strategy for the site was to develop excavation footprints based on the RI datasets, dig to these footprints, and then evaluate the resulting exposed surface to determine whether cleanup criteria had been met. If not, additional excavation work would have been undertaken until compliance with cleanup criteria had been achieved. All excavated soils were to be shipped offsite for disposal. Total unit excavation, transportation, and disposal costs were estimated to be several hundred dollars per cubic yard. The primary issue with the baseline approach was that additional review of the RI data sets indicated that the original contaminated volume estimates were unlikely to be accurate. Excavating to footprints derived from these data would likely also result in a significant volume of clean soil being removed and disposed of as well. The USACE needed an alternative approach that would assist them in controlling overall project costs by keeping excavated volumes and waste disposal streams to the minimum necessary to achieve compliance with site cleanup standards.

Rather than a work plan that specified the final excavation footprint, the proposed alternative approach included a dynamic work plan that required the site to be excavated in 2 ft lifts, with dig face data collection to determine subsequent contaminated soil excavation footprints as work proceeded. Dig face data collection was to be based on real-time measurement systems, with data analysis turnaround times short enough to allow for modification of excavation plans in response to what was measured. Final closure demonstration was to be achieved through final status surveys based on MARSSIM. The objective was to keep the resulting excavation work as precise as possible.

G.1.5 Data Collection Technologies

Originally, the suite of data collection technologies to support remediation and closure included real-time NaI gamma scans, in situ HPGe measurements, an onsite gamma spectroscopy laboratory for rapid soil sample analysis, and offsite alpha spectroscopy analyses of soil samples. The standard for Th-230 analysis in soils is alpha spectroscopy. The principal issues with alpha spectroscopy are its per sample cost and the slow turnaround times (typically a week or more) for sample results.

Before remediation work began, technology performance studies were performed to determine data collection technology performance for the NaI scans and HPGe systems and to identify appropriate protocols for the proposed work. The NaI data were intended for use as a means for defining new excavation footprints after a particular surface had been excavated. The NaI system proposed for use was based on a 2x2 NaI detector coupled to a differentially corrected GPS and data logging system. The system was deployed in a walkover mode, with a technician providing complete coverage of exposed soil surfaces by walking parallel lines. Data were acquired every 2 s. The NaI provided gross gamma activity estimates for exposed soil surfaces. Logged data were offloaded and mapped and analyzed using a GIS. Turnaround times of 24 hours or less were the objective. The resulting maps were posted on a secure project support website where the onsite the contractor could access them.

The principal issue with the proposed NaI walkovers was detection limits for Th-230. Th-230 is a weak gamma emitter and difficult to detect in the field except at very high activity concentrations. Fortunately for the Ashland 2 work, Th-230 was also collocated with Ra-226. A systematic analysis of RI data sets indicated that in cases where samples exceeded the Th-230 requirement, Ra-226 was always present at levels greater than 3 pCi/g. This level of Ra-226 is readily detectable by a NaI 2x2 detector with a 2-second acquisition. Because there were multiple elevated radionuclides present at the site, there was no attempt to develop a regression relationship between gross activity measurements and Th-230 activity concentrations.

Using the 2x2 NaI, locations were identified where there were impacts from radionuclide contamination and it was believed that those impacts were in the range of the cleanup criteria. Stationary NaI readings were acquired before a sample was collected. Approximately 40 samples were collected and analyzed via alpha spectroscopy as part of this performance evaluation work. The results from these samples were used to derive a lower gross activity investigation level, below which sample results above the required cleanup criteria were not observed. The results

also produced a second gross activity trigger level above which soil samples almost always exceeded the cleanup criteria.

These investigation and trigger levels were used to interpret dig face scanning by the NaI, allowing dig faces to be divided into three distinct areas: areas with a low probability of exceeding the cleanup levels that were ready for final status data collection, areas with a high probability of exceeding the cleanup guideline that would require excavation, and areas with NaI results falling between these two triggers. In the latter case, the NaI was not conclusive regarding the contamination status of the soils. These areas were candidates for additional sampling before excavation work proceeded. As part of the remediation program, verification samples were periodically collected from areas with NaI readings slightly below the lower trigger level to verify that the NaI was performing as expected. Based on the results of this verification work, the lower trigger level was adjusted downward midway through the remediation work to guarantee that soils impacted above cleanup criteria were excavated.

An in situ HPGe system was also evaluated for use in excavation support, in hope that the system could be used to investigate areas where the NaI data were inconclusive. Manufacturer performance expectations indicated that the detection limits for direct HPGe measurements of in situ soils might yield detection limits for Th-230 that were below 40 pCi/g with reasonable measurement times. A system was brought to the Ashland site for evaluation. Representatives from the EPA, Argonne National Laboratory and the USACE participated in the evaluation. The results, however, were disappointing, and the use of the HPGe was abandoned.

The onsite gamma spectroscopy laboratory was used for rapid turnaround of soil samples. While the onsite gamma spectroscopy unit's detection limits were marginal for detecting Th-230 at the required cleanup levels, it provided enough information so that excavation could proceed with confidence. Offsite alpha spectroscopy was used for QA/QC purposes and for final status survey sample analysis. Final status survey work with the 2x2 NaI detector confirmed that MARSSIM-based $DCGL_{EMC}$ criteria were attained and provided supplementary information for the $DCGL_w$ evaluation.

Over one million individual data points were logged and mapped using NaI scans during the excavation and closure of the Ashland 2 site. The ability of the NaI system to differentiate between soils above and below the cleanup criteria for the site was monitored throughout the excavation process through the collection of verification samples. Based on these sample results, the lower trigger level for the NaI walkover data was adjusted downward midway through excavation to ensure that performance goals were met. Turnaround times for NaI scan data analysis, mapping, and posting on the secure project support website were, in general, within 24 hours of collection.

Excavated soils that were above the cleanup criteria were stockpiled awaiting shipment via intermodals. Of the 146 composite samples that were collected to characterize the material for shipment, 97% exceeded the cleanup criteria. Of the four composite intermodal samples that were below the cleanup criteria, two were collected from soil excavated within the first two weeks of the remediation when the precise excavation process was still being refined. In contrast, more than 400 samples were collected from the final dig face surface as part of the final status

survey process. Of these, more than 98% were less than the required cleanup guidelines. These results show that the precise excavation approach employed at the Ashland 2 site was effective at limiting excavation to only those soil volumes that truly required it.

Of particular interest at the Ashland 2 site was the discovery that, when excavation was complete, almost three times as much contaminated soil was removed as was originally estimated to be present based on RI data. The NaI data sets provided a historical record that documented the contamination status of all soils removed, allowing a comparison of the resulting excavation footprint with the footprint developed from RI data. If excavation of surficial soil had been based solely on pre-existing RI data, a total of 10,000 cubic yards would have been removed in the surface lift, compared to the 14,000 that were actually excavated. This 10,000 cubic yards would have included 4,000 cubic yards of soil later identified by the NaI scans as below the cleanup criteria and would have missed 8,000 cubic yards of soil actually above the cleanup criteria. The latter would have either been caught by the final status survey, in which case they would have represented an additional excavated volume, or they would have been missed, left behind, and represented an unacceptable residual health risk. This large discrepancy was for surface soil where there was the greatest density of RI soil samples. The volume of soil above the cleanup criteria missed and the volume of soil unnecessarily excavated would have been even larger for deeper lifts where existing soil sample data were fewer.

G.1.6 Benefits

The principal concern with this type of approach to excavation is the potential for introducing bottlenecks in the excavation and disposal process. Since excavation crews are paid by the hour, any delay in excavation work translates into increased costs. In the case of Ashland 2, the additional dig face data collection work did not impede excavation progress. In fact, the bottleneck turned out to be the ability of the contractor to load and ship intermodals with contaminated soil.

Preliminary cost estimation work indicated that the additional cost of the remediation support data collection was approximately \$168,000 over 6 months of excavation. Over \$1.5 million in cost savings were achieved by avoiding unnecessary offsite disposal costs for just the first lift. As the analysis for the surface lift indicates, the additional investment in remediation support data collection was more than compensated for by the precise nature of the excavation work and the resulting minimization of offsite soil disposal. The introduction of real-time measurement technologies ultimately resulted in a project cost savings of approximately \$10 million. The bulk of these cost savings were achieved through waste minimization.

Aside from the obvious cost considerations, precision excavation also provided several benefits to the Ashland 2 remediation that are harder to quantify. First, by producing quantifiable and recordable data for every lift, USACE had a documented and defensible record of what was excavated and why. This became particularly important given that the actual volume of soil excavated above the cleanup criteria was almost three times the original estimate. Second, USACE also had an independent means for evaluating estimates of volumes of contaminated soil being shipped offsite, which was one measure for reimbursement for the prime remediation contractor. Finally, by making remediation support data immediately available on a website, USACE provided a means to distribute site information to the project team, including the

NYDEC, which improved coordination and confidence in the remediation work being completed.

G.1.7 Observations

Based on the Ashland 2 project, the following observations can be made:

- The use of appropriate real-time measurement techniques combined with a dynamic work plan can result in significant changes and improvements to standard remediation processes.
- The costs associated with additional data collection to support RAs were insignificant compared to the cost savings realized by the Ashland 2 project.
- Effective use of real-time technologies may require site-specific technology performance evaluation work to customize deployment protocols for site-specific needs.
- A complete QA/QC plan for real-time measurement deployment should include ongoing performance verification data collection.
- With appropriate planning, potential logistical issues associated with including real-time data collection within remediation programs can be addressed adequately.
- The Ashland 2 case study is an excellent example of merging Triad and MARSSIM approaches to support contaminated soil remediation and closure using real-time measurement technologies.

G.2 BROOKHAVEN NATIONAL LABORATORY, NEW YORK

At the Brookhaven National Laboratory (BNL), soils contaminated primarily with Cs-137 from the hazardous waste management storage area were inadvertently used for landscaping purposes at various locations throughout the site. Remediation of the contaminated soil was conducted in conjunction with a demonstration of the ThermoRetech Segmented Gate System. Following removal of the contaminated soils, a final status survey was conducted under the recommendations in the MARSSIM process. Similar to the ITS, the BNL soils characterization deployment was also conducted in two phases: NaI detection for screening and total coverage of the site with a GPS used to identify locations of hot spots, followed by in situ HPGe characterization using the ISOCS system.

According to MARSSIM, three area classifications were identified: Class 1 areas were known to be contaminated above the cleanup goals (23 pCi/g for Cs-137); Class 2 areas were known to be contaminated, but were below the cleanup goals; and Class 3 areas were those that were uncontaminated or not believed to be affected. For each classification, different sampling strategies were established and the number of samples required to provide statistically significant results were identified. The Class 3 areas were not surveyed because the land is expected to remain under DOE control. The cleanup guidelines for the contaminant of concern (Cs-137) were considerably higher than the minimum detectable concentration for the NaI system (7 pCi/g for Cs-137). Thus, even during the screening phase, there was a high level of confidence that the cleanup guidelines had been met. Rather than use NaI for hot spot identification only, the standard deviation of the NaI sensitivity was used to estimate the number of grid samples that were required by MARSSIM. A sample grid was then established and an in situ technique,

ISOCS, was used to take direct field measurements rather than collect field samples for conventional baseline analyses. The advantage to this approach was that data was available in a much more timely fashion, and the cost for each field sample analysis was greatly reduced (on the order of \$75 per in situ measurement, compared to about \$200 for conventional analyses). In addition, since the ISOCS detector has a relatively large field of view, the number of confirmatory grid samples was reduced accordingly. The NaI survey was conducted by a simple walk-over approach, since the total area was not unreasonably large.

G.3 EAST TENNESSEE TECHNOLOGY PARK, TENNESSEE

G.3.1 Background

The U.S. Department of Energy, Oak Ridge Operations Office, conducted a field test of the ITS in July 2001 at the K-901-A NDA, a 6-8 acre site located at the East Tennessee Technology Park (formerly the Oak Ridge K-25 Site) in Oak Ridge, Tennessee. Soil samples were collected by Bechtel Jacobs Company, LLC, in October 2001.

G.3.2 The ITS Technology

The ITS, developed by Fluor Fernald, is a non-intrusive technology that can be used to characterize radiologically contaminated surface soil. This technology was demonstrated at the K-901-A NDA site to test its capabilities. The system includes a 4 in by 4 in by 16 in (4x4x16) NaI detector mounted on a mobile conveyance (RTT), a tripod mounted HPGe detector, GPS equipment, a Zeltex moisture meter, Ethernet communications, Lab View linking software, EG&G Office Gamma Vision analytical software, and Surfer 6 mapping software. The NaI detector collects both gross counts and gamma spectral data at a rate of once every 4 s as it moves across the surface at a rate of 1 mph. The main purpose of the NaI detector is to identify areas of elevated radioactivity, which are documented by the GPS. The HPGe system is then set up at the areas of identified elevated radioactivity to obtain high-resolution gamma ray spectra over a 2.5 m field of view using fifteen-min gamma ray count times. The Zeltex meter is used to adjust gamma data (i.e., account for shielding by soil moisture).

Table G-1. ETTP measurements by NAI and HPGe detectors

COCs	ETTP Action Levels	Minimum Detectable Concentrations	
		HPGe**	RTRAK (8 s) – NaI detector
U-238*	50 pCi/g	1.9 pCi/g	78 pCi/g (234 ppm total U)***
Ra-226	3 pCi/g	0.076 pCi/g	9.8 pCi/g
Th-232	3 pCi/g	0.075 pCi/g	1.1 pCi/g

* Primary contaminant of concern at the K-901 NDA

** MDCs for HPGe were taken from the *User Guidelines, Measurement Strategies, and Operational Factors for Deployment of In Situ Gamma Spectrometry at the Fernald Site*, 20701-RP-0006

***Can be reduced with further aggregated measurements

G.3.3 The ITS Characterization System

Using the approach described above, six areas of elevated radioactivity were identified at the NDA using the NaI detector and gamma spectra were collected, analyzed, and interpreted to determine activity concentrations for Ra-226, Th-232, U-234, and U-235. In addition, the total uranium concentration in parts per million was also determined for each of the six areas. The gamma ray special data were compared to the analytical results for soil samples collected from five of the six areas. In an effort to correlate the soil sample results with the 2.5 m field of view of the HPGe system and approximate the geometry of the field of view, ten soil samples were collected from each area and a weighted-average composition was calculated for each radionuclide. Sample weightings were based on the location of each sample relative to the center point of the detector.

G.3.4 Data Analysis and Conclusions

Based on the results from the field tests, the following conclusions can be drawn regarding the accuracy of the ITS:

- In most instances the ITS-predicted concentrations were comparable to, but typically lower than, the soil sample concentrations.
- In some cases, U-235 was not detected by the ITS however, surface soil samples reported results included nondetections of U-235 as reported values. In creating the average concentrations, the value for a nondetect was taken to be the detection limit.
- No conclusions can be made regarding the ITS's effectiveness in detecting surface soil with high contaminant concentrations, because high concentrations were not encountered during the field test ranging as high or higher than action levels.

Possible explanations for any disparities between ITS results and the results determined through laboratory analysis of soil samples may include moisture correction factors used for ITS data, the weighting system used for analytical data, and non-detections used by both the ITS and validated soil sampling analytical results. Comparison results indicated the ITS could be considered as a screening tool for surface soil characterization; however, the above factors should be taken into account when using this system.

G.4 FERNALD ENVIRONMENTAL MANAGEMENT PROJECT, OHIO

G.4.1 Site Description

The FEMP was one of the first DOE cleanup projects to pursue the use of real-time measurement systems as the primary measurement systems supporting cleanup. Real-time systems at Fernald have been an essential part of the soils remediation program from the beginning of the remedial design and remedial action process in 1996. The Soils Project at the FEMP encompasses over 1000 acres of soils impacted to various degrees and containing a number of below-ground waste disposal units. The greatest excavation depths and largest soil volumes are from the former 130 acre production area, from which over 200 structures first had to be removed.

It was evident that conventional handheld survey meters would not achieve the data quality required for the job, and collecting physical samples over the entire site would have been cost prohibitive. Consequently, the site committed early on to the use of innovative in situ gamma spectrometry systems to support soil remediation efforts. This commitment was aided by funding under DOE's ASTD program supporting technology deployments in remedial actions. The ASTD project, the ITS, involved personnel from DOE-Fernald, Fluor Fernald, ANL, INL, and DOE's EML.

Under the soils remediation project and with the aid of the ITS project, promising technologies for supporting the remedial action objectives were identified, developed, and tested. The Ohio EPA and the EPA were involved from the beginning of this process. A real-time working group of experts from those agencies, the DOE, and Fluor Fernald met on a regular basis to discuss technical issues. The capabilities of the technologies and the numbers and types of platforms on which they were deployed have been continuously improved and expanded since the beginning of the project. The development and testing of the ITS technologies is described below.

G.4.2 Real-time Technologies

The ITS deployed at the FEMP was a real-time field analytical information system that combined gamma-ray spectrometry for both NaI and HPGe detector systems, GPS, and GIS to address radiological characterization needs. NaI-detector systems mounted on mobile platforms were used to perform full coverage surveys to identify areas of elevated radionuclide concentrations, to identify areas that were above waste acceptance criteria (WAC) for total uranium, and to map general distribution patterns. The MDCs achievable with the systems were typically in the low- to mid- pCi/g range for a 4 s scan. These levels were near the cleanup criteria for many remediation sites. Tripod-mounted HPGe systems were used to confirm and delineate areas of elevated radionuclide levels and above-WAC areas that were identified during mobile NaI scans. They were also used for direct characterization of soils in some cases using multiple adjacent measurements. In areas that had been remediated or were otherwise deemed ready for a final status survey, discrete HPGe measurements over a grid were sometimes used to compare soil levels to release criteria to determine if an area was ready for final certification. Final certification was performed through the collection and laboratory analysis of soil samples.

Real-time systems used at the FEMP comprised two basic technologies, mobile platforms employing large, 4x4x16 NaI detectors and tripod-mounted HPGe detectors. The mobile NaI systems employed GPS position tracking systems and data telemetry systems to perform full coverage surface soil surveys primarily for the purpose of identifying areas of elevated levels of gamma-emitting radionuclides. The HPGe gamma spectroscopy systems were used in concert with the mobile systems to confirm and delineate elevated areas and also to determine when FRLs were achieved and an area was ready for final certification. Certification was performed at the FEMP through the collection of physical samples.

A third system employed, the EMS, is a hybrid system that employs either NaI or HPGe detection systems mounted on the arm of a standard excavator. The EMS was designed to support real-time gamma measurements in deep excavations as well as in trenches and in high contamination areas such as would be expected in the former production area.

Table G-2. Contaminants of concern and minimum detectable concentrations

COCs	Fernald Final Action Levels	Minimum Detectable Concentrations	
		HPGe*	RTRAK (8 s)
Total Uranium	55 pCi/g	1.9 pCi/g	78 pCi/g (234 ppm total U)**
Ra-226	1.7 pCi/g	0.076 pCi/g	9.8 pCi/g
Th-232	1.5 pCi/g	0.075 pCi/g	1.1 pCi/g

* MDCs for HPGe were taken from the User Guidelines, Measurement Strategies, and Operational Factors for Deployment of In Situ Gamma Spectrometry at the Fernald Site, 20701-RP-0006.

**Can be reduced with further aggregated measurements

G.4.3 Regulatory Issues

Real-time gamma systems were approved for use in almost all aspects of the soil remediation program at the FEMP. The main exception was for use in final certification of remediation areas, for which physical samples are required. Otherwise, real-time systems were approved for use in the three main phases of remediation: pre-design of excavations, excavation support, and pre-certification. Pre-design involves determining the excavation boundaries of soils above remediation levels, including the separate delineation of soils in excess of the WAC for the OSDF. Excavation support addresses lift-by-lift characterization of soil surfaces, while pre-certification determines that an area is free of elevated contamination areas and has average soil contamination levels below FRLs.

The use of real-time gamma systems to support soil remediation represented a significant departure from the conventional approach used previously at radiologically contaminated sites. Such a departure was both necessary and warranted by the large scale of many of the federal cleanup sites entering the CERCLA program in recent decades, the associated characterization costs, and the need to contain cleanup times. In response to the proposed use of the technologies, regulators raised a number of technical issues related to the production of data of known and defensible quality. Some of the primary concerns specific to real-time gamma measurements were as follows:

- undocumented data quality
- uncontrolled environmental conditions
- in situ definition of “a sample”
- differences between measurement and calibration soil conditions

Each of these overall concerns embodies a number of technical questions that had to be addressed before the systems could be approved for their proposed use. The FEMP undertook an extensive program to document the data quality of the measurements produced by the real-time gamma systems. A number of studies were performed to establish the performance characteristics of the systems and data quality produced.

In order to establish the performance requirements of the systems, the FEMP first identified the measurement type needs and the uses they would support. For each of these needs and uses, an

ASL was assigned in accordance with the requirements that emerged from the DQO process. Four ASLs, A (lowest) to D (highest) were established that were analogous to the data quality levels identified by EPA. Most data needs supported by the systems were identified as having ASL A or B, but ASL D was needed when certifying remediation levels.

With respect to the NaI systems, these studies involved calibration of the systems initially through measurements at known contamination areas and later through the development of a calibration pad. Additional studies addressed the optimal scanning speed and count time as well as determinations of minimum detectable concentrations and measurement uncertainties. These studies, which were documented in a January 1999 report, entitled *RTRAK [Radiation Tracking System] Applicability Study*, allowed the FEMP to gain approval of all proposed uses of the NaI systems, all of which involved ASL A or B measurements.

Extensive studies were conducted on the HPGe systems in an attempt to have the systems approved for use in performing final certification of remediation areas. These studies were documented in another January 1999 report entitled *Comparability of In Situ Gamma Spectrometry and Laboratory Data*. These studies examined the comparability of individual HPGe measurements to results of physical sampling and laboratory analysis. In addition, the results of certification unit outcomes by the two methods were compared. Finally, a number of technical questions were addressed in the studies, such as the potential effects of environmental conditions, the effects of radon emanation from soil on Ra-226 measurements, recognition of buried contamination, and the effects of external radiation sources.

The results of the studies established that individual HPGe measurements of a contamination area produced comparable results to a weighted average of physical samples taken over the field of view of the in situ measurement. Physical samples were weighted to account for the diminishing contribution to the in situ measurement from soils at increasing distance from the detector. The studies also established that the two methods produced similar certification results for certification units sampled by both methods. Together, these studies addressed the concerns noted above related to data quality, environmental factors, sample definition, and calibration effectiveness.

On the basis of the studies performed, the FEMP concluded that the HPGe systems were capable of achieving ASL D data quality necessary for final certification of remediation areas, when using proper controls and applying an appropriate correction for radon disequilibrium in soils for Ra-226 measurements. Regulators, however, continued to cite concerns for a perceived low bias from radon emanation as well as concerns related to making accurate soil moisture measurements with field instruments. They ultimately disapproved the use of HPGe for making Ra-226 final certification measurements.

The FEMP conceded to use laboratory analysis for final certification of all three of these primary radiological contaminants of concern because there would have been little economic benefit to using HPGe for final certification of total uranium and Th-232 alone when laboratory measurements would have to be made for Ra-226. Further, because of the relatively small number of samples required for certification compared to other RA support, the savings from real-time measurements for this function would have been modest in any case. The greatest

savings were achieved in surveys to detect elevated areas and in the delineation of excavation areas—uses that were already approved by regulators.

G.4.4 Relevant Studies

The FEMP performed a number of relevant studies in support of the use of in situ gamma spectrometry systems for soil remediation; these studies include the following:

- baseline comparison studies
- RTRAK/RSS study
- Gator report
- EMS report
- NaI calibration report
- NAI MDC/trigger level report
- cost analysis report
- user manual for ITS

The objectives and outcomes of some of the key studies are summarized below.

G.4.4.1 Baseline Comparison Studies

Several comparison studies completed at Fernald focused on substituting in situ HPGe measurements for laboratory measurements of radionuclides in surface soils in support of soil cleanup and are documented in the January 1999 comparability study report. The comparability studies performed were of two basic types: direct comparison of soil results for in situ HPGe and laboratory methods, and comparison of certification unit outcomes for the two methods. The main challenge of the direct tests was to define a comparable “sample.” In situ HPGe, as used at the FEMP, views a large surface area in a single measurement, while laboratory analysis is performed on a 3 in diameter by 4 in deep cylindrical soil sample. A further complication of the study was that HPGe response to soil concentrations diminishes with distance from a point directly beneath the detector. This is strictly due to geometric considerations of gamma ray influence over a flat surface. In areas that are not homogeneous, such as the study areas, the varying response with distance from the center of the field of view had to be taken into account in the comparisons of the two methods. Results for the direct comparison of ten study areas showed good comparability for total uranium, Th-232, Cs-137, and K-40 between in situ HPGe and laboratory alpha spectrometry analysis for samples collected in the manner described above. Ra-226 results were also in good agreement after appropriate corrections were made to the in situ readings for radon disequilibrium due to emanation from soil. (Ra-226 is determined from the activity of gamma-emitting products in its decay chain, which passes through Rn-222). Average agreement was well within a 20% relative percent difference criterion for all radionuclides.

Comparability of in situ HPGe and laboratory analysis on the basis of certification unit outcomes was also very good. In only four of 135 cases (45 units x 3 nuclides) did certification outcomes differ when determined by HPGe and physical samples. In each case, the difference was due to Ra-226 slightly exceeding the cleanup criterion, while in situ HPGe results were just below the criterion (i.e., a false negative result). Uranium and Th-232 results were below cleanup criteria in

all cases, as were Ra-226, with the four noted exceptions. Regarding the four Ra-226 results, differences in outcomes relative to the cleanup criteria were attributed in three of the cases to inadequate corrections to the in situ results for radon emanation. The fourth result was simply due to similar results falling on either side of the cleanup criterion which, it should be noted, was only 1.7 pCi/g (about twice background). While the results described here demonstrated a very high level of comparability between in situ HPGe and laboratory analysis of physical soil samples, the in situ method was not accepted by the involved regulators for final certification measurements. The method was approved for all proposed uses up to that final step, including delineating areas of elevated concentration and confirming their removal.

G.4.4.2 RTRAK/RSS Study

The RTRAK applicability study (DOE 1999a) reports on performance testing of the tractor-based RTRAK and the manually pushed RSS NaI systems. The objective of the testing was to evaluate system performance relative to established DQOs for the soils cleanup project and to determine optimal operating conditions. Three primary data quality elements were evaluated, including measurement precision, accuracy, and MDCs of the radionuclides of interest. The measurements taken by the RTRAK and RSS were compared to those taken by established HPGe methods in a number of contaminated locations around the FEMP. Both mobile and static RTRAK/RSS characterizations of areas were compared to characterizations using static HPGe.

Agreement between the two in situ measurement methods was good in areas where contamination was fairly uniformly distributed. It was not very good in one area that had high heterogeneity when either mobile or static RTRAK measurements were compared to static HPGe measurements. Differences were attributed to incomparable sampling, i.e., detectors did not view the same sample, or portion of ground, in the heterogeneous areas for the measurements compared. MDCs were determined based on data from the field locations but have since been re-evaluated for all mobile NaI systems except the Gator using the recently constructed calibration pad; current values are reported below.

G.4.4.3 Gator Report

The Gator report (DOE 2000) mainly documents the results of field calibrations of this ATV-based mobile NaI platform. As discussed above, field calibrations were performed by making static NaI measurements over field locations that were also characterized by the established HPGe systems. The study effectively used the HPGe results to create “field standards.” A number of different locations served as calibration points. Calibration coefficients were determined by regression analysis. This approach was necessary because of the lack of a calibration pad for the mobile platforms at the time. All systems, including the Gator, have since been recalibrated using the recently constructed calibration pad. Modifications of the detector mounting hardware are planned for the Gator, in part to reduce shielding of the detector. The detector will require re-calibration after the planned modifications are made.

G.4.4.4 EMS Report

The draft EMS report (DOE 2002) was issued shortly after initial testing of the second-generation system was completed in December 2001. This report described the development

process of the system, which is a highly modified version of the first-generation system tested at the FEMP in the previous year. A detailed physical and functional description of the EMS, which was fabricated at INL, is provided in the report, as are the results of acceptance testing of the system performed at the FEMP in 2001. The results of initial calibration of the NaI equipped EMS using the FEMP calibration pad are also presented.

A major portion of the report describes the intended uses of the EMS in support of excavation of building foundations and utility trenches. An important aspect of such applications is the interpretation of either NaI or HPGe readings in uneven terrain. Since calibrations assume a flat geometry, measurements in uneven terrain will have inherent biases, all other factors being equal. In bowl-like geometries, such as pits and trenches, measurements will be biased upward; that is, they will be conservative with respect to cleanup criteria. The report discusses the effects of uneven terrain and the procedures and corrections that will be employed in such situations to ensure effective cleanups. Lastly, the report covers some of the day-to-day operational aspects of deployment of the EMS.

G.4.4.5 NaI Calibration Report

The NaI calibration report (DOE 2001) reports the results of the first comprehensive calibration of the mobile NaI platforms using the FEMP calibration pad. The report begins by defining the energy spectrum ROIs that have been chosen for the gamma ray energies used to identify the radionuclides of interest, U-238, Ra-226, and Th-232. A description of the calibration pad construction and calibration methodology follows, as does an evaluation and verification of the results for all the platforms. Finally, recommendations on how to perform subsequent pad calibrations are offered. Much of the technical detail of the report is presented in five appendices. In addition to the areas already mentioned, the appendices discuss the preparation and layout of the individual source standards used to construct the pad as well as the results of point source calibrations of the detectors used to verify the pad calibrations.

G.4.4.6 NaI MDC/Trigger Level Report

A report on NaI MDCs and WAC trigger levels based on data collected on the FEMP calibration report was issued in August 2002 (Davis 2002). Previous values were determined from field calibrations. WAC trigger levels are instrument flag values indicating that the uranium WAC action level may have been exceeded. They are a function of the uncertainty level of a given measurement (in the case of the MDC, being near the action level).

MDCs were determined using a modified version of the conventional method first established by Curie and are shown in Table G-3. The reported values account for soil moisture, and, in the case of Ra-226, for radon disequilibrium in soil. The MDC for Th-232 is below the 3x FRL action level for a single 4 s scan; however, total U and Ra-226 require two to five aggregated 4 s scans to meet the 3x FRL criterion. MDCs can be reduced through the aggregation of multiple 4 s scans, but at the expense of spatial resolution. Currently, an 8 s measurement is used to screen for elevated areas for all three radionuclides. To ensure the 3x FRL criterion is not exceeded for Ra-226, areas with elevated gross activity as measured by the NaI systems are investigated with HPGe measurements, which has a Ra-226 MDC well below the action level.

Table G-3. Minimum detectable concentrations for detectors

Quantity	System				
	RTRAK	GATOR	RSS1	RSS2	EMS
Total Uranium (ppm)					
MDC (4 s)	337	340	345	306	383
MDC (8 s)	234	233	239	207	258
MDC (12 s)	191	188	194	165	206
3× FRL	246	246	246	246	246
Ra-226 (pCi/g)					
MDC (4 s)	18.4	20.4	22.2	17.1	17.9
MDC (8 s)	9.8	11.1	12.1	9.5	9.7
MDC (20 s)	4.9	5.6	6.1	4.9	4.9
3× FRL	5.1	5.1	5.1	5.1	5.1
Th-232 (pCi/g)					
MDC (4 s)	1.6	1.7	1.5	1.6	1.6
MDC (8 s)	1.1	1.2	1.0	1.1	1.1
3× FRL	4.5	4.5	4.5	4.5	4.5

G.4.4.7 Cost Analysis Report

A draft detailed cost analysis comparing the costs of supporting the soils cleanup project at the FEMP with the ITS with those using conventional sampling and analysis methods was prepared under the ITS ASTD project. The June 1998 draft report, which has not been finalized, compared the costs of characterization support for all phases of soil cleanup, pre-design, excavation support, pre-certification, and final certification. Total estimated costs were \$17 million for the ITS technology and \$58 million for the baseline sampling and analysis. The savings accrued to the ITS approach are attributed almost entirely to savings during pre-certification. Characterization performed during this phase is performed to assure that no areas exceed hotspot criteria. Such characterization by conventional means over a sampling grid would require a very large number of physical samples. Use of mobile NaI scans in conjunction with HPGe confirmation of potential hotspots to perform the same function contributed most of the estimated savings.

G.4.4.8 ITS User Manual

The ITS user manual (DOE 1998) is primarily intended as a guide for field personnel and project managers in the FEMP soils project involved in the use of ITS technologies in support of cleanup. It describes how ITS technologies are used in the various measurement activities that support the various phases of soil remediation. It also provides detailed discussions of specific applications of the technologies, covering such topics as field of view, detector height, data acquisition time, trigger levels, topographic effects, and data mapping conventions. A number of general technical topics related to in situ gamma spectrometry are discussed, including MDCs, moisture corrections, and radon disequilibrium considerations in Ra-226 measurements.

G.4.5 Role of the FEMP Quality Assurance Project Plan

Procedures for the use of real-time gamma systems are fully integrated into the FEMP's *Sitewide CERCLA Quality Assurance Project Plan* (SCQ). Appendix H of the SCQ cites sections from a separate document entitled *Real-time Instrumentation Measurement Program Quality Assurance Plan* which describes the program in more detail. Appendix H of the SCQ also contains data verification checklists for both NaI and HPGe data collection that are used by field personnel to verify the quality of data as it is being collected so that bad data can be flagged before it is transmitted for further use and archiving. This verification also allows corrective actions to be made at the earliest opportunity to maximize the production of usable data.

G.4.6 References

DOE 1998. *Integrated Technology Suite: Users Manual*. Fernald Environmental Management Project, Cincinnati, Ohio.

DOE 2001. *Calibration of NaI In Situ Gamma Spectroscopy Systems*, Ohio 20310-RP-0006, Revision 0, Final, Fernald Environmental Management Project, Cincinnati, Ohio.

DOE 2002. *Developments and Deployment of the Excavation Monitoring System (EMS)*, Ohio 20310-RP-0007, February, Revision A, Draft, Fernald Environmental Management Project, Cincinnati, Ohio.

Davis, M. "Minimum Detectable Concentrations and WAC Trigger Levels for the In-Situ NaI Gamma Spectroscopy Systems Used at the Fernald Environmental Management Project-Final Draft", Argonne National Laboratory, August 2002.

G.5 IDAHO NATIONAL LABORATORY, IDAHO

Aside from routine surveillance and monitoring, real-time systems have been used in support of CERCLA activities at the INL. Specifically, the GPRS and ISO-CART[®] have been used extensively in characterization efforts to delineate the areal extent of radiological contamination at the INL Auxiliary Reactor Area (ARA)-23 CERCLA site. In general, the site was accessible by the GPRS; however, some areas were covered with large rocks. The ISO-CART[®] was used in these locations to complete the characterization survey. Use of the systems provided 100% coverage of the area, and calibration of the GPRS allowed the net count rate data to be converted to Cs-137 concentrations in pCi/g (Josten 1997; Giles 2000). Additional investigations have been conducted at the site to verify that the contamination was confined to the surficial soils.

The ARA-23 site was remediated in 2004. Remediation involved excavation and removal of contaminated soils with Cs-137 concentrations above 23 pCi/g. The final remedial design/remedial action work plan for the site and the verification field sampling plan identified the use of the GPRS and ISO-CART[®] to aid in directing the excavation and to provide verification, in conjunction with a limited number of physical samples, that the remedial action goals were met. It was demonstrated to the regulators and stakeholders that the GPRS and ISO-

CART[®] had detection limits that were a factor of 10 below the remedial action goal of 23 pCi/g; additionally, the systems provided 100% coverage of the site in a relatively short period of time.

G.6 KIRTLAND AIR FORCE BASE, NEW MEXICO

G.6.1 Site Description

TS4 is a Defense Nuclear Weapons School (DNWS) radiation training site northwest of the Tijeras Arroyo golf course at Kirtland AFB, Albuquerque, New Mexico. The TS4 radiation training site encompasses an area of 10.3 acres and is surrounded by a chain-link fence posted with radiation hazard signs. Thorium oxide sludge was imported from Brazil and applied to eight radiation training sites that totaled approximately 82.94 acres at Kirtland AFB. The eight sites established by the DNWS to train military personnel in alpha radiation monitoring and decontamination were designated as TS1 to TS8. Thorium, a low-level radioactive substance, was used to simulate plutonium contamination from nuclear weapons accidents. Sites TS5 through TS8 are currently undergoing remedial actions that involve excavation and offsite disposal. Sites TS1 through TS4 are active sites and are used several times per year for personnel training; TS4 is also available for site investigation and pilot studies.

Thorium distribution and activity at TS4 is highly heterogeneous. Radiological studies on soil cores from TS4 indicate that thorium has been transported vertically into the top 61 cm (2 ft) in the hot spot areas. A study conducted in 1985 found surface thorium activity ranging from 2.1 pCi/g in the less contaminated areas to 151.3 pCi/g at areas where larger masses of thorium sludge were applied. No historic information is available on vertical thorium migration for depths greater than 61 cm. Periodic radiation monitoring of the site has revealed migration of thorium outside the fenced area¹ and at depths of up to 38.1 cm. Concentrations of thorium 4.5 times higher than background were detected in soil at the western boundary of the site. Previous air sampling at the site indicated thorium concentration less than background.

The extent of thorium migration at TS4 has not been previously fully defined, and the mechanisms for offsite migration are unknown. Possible mechanisms include surface runoff and sedimentation, wind erosion and transport, and unsaturated zone migration. Although TS4 is an active site, it is rarely used for training; however, it may be utilized in the future to simulate urban environments that will require erection of various kinds of structures, paved roads, etc. It is therefore essential for the training operations to develop and implement a Th-232 management plan for the site that will allow long-term use and minimize vertical and horizontal migration outside the site boundaries.

G.6.2 Characterization Strategy

The characterization of the thorium-contaminated soil at TS4 was a cooperative effort involving personnel from SIT, ERDC, Alion Science and Technology (Chicago, IL), and MSU (Starkville, MS). Prior to field activities, a health and safety program was developed which included a health and safety plan, work plan, and radiation safety plan.

The radiological site characterization of TS4 was performed using a mobile multisensor system developed by ERDC. The system had the capability to detect and speciate (identify) surface and near surface gamma-emitting radionuclides. The system coupled surface gamma activity with location and elevation data from a GPS in real-time. GPS system accuracy was ± 2 to 3 cm horizontal and ± 3 to 5 cm vertical.

The data acquisition system was configured for ATV deployment. In the original configuration, an ATV was used to pull a cart onto which the data acquisition system was mounted. The gamma sensor array consisted of four 7.6 cm by 7.6 cm (3 in by 3 in) BicronTM NaI gamma detector/photomultiplier tube assemblies that were suspended behind the cart, 10 cm above and parallel to the ground. Each detector used in the system operated independently with separate computer and nuclear instrument data acquisition and processing modules. Data from each detector were collected via a multichannel buffer (MCB) by the data acquisition central processing unit CPU. The CPU also kept track of the corresponding location and temperature readings. In this configuration the data were collected, processed, and stored in parallel for later post processing and analysis.

The configuration was later improved by using an ATV as the platform for the data acquisition system. The four NaI detectors were suspended behind the ATV 10 cm above and parallel to the ground. This configuration performed much better in the rough desert terrain. As in the previous configuration, each detector used in the system was operated independently with separate computer and nuclear instrument data acquisition and processing modules.

Two trips to field site TS4 were needed to complete site characterization. The first was in October 2001 and the second was in December 2001. The ERDC spectral gamma data acquisition system was driven across the surface of TS4 at approximately 3.2 km/hr (2 mph). A GPS antenna was positioned at the center of the four-detector array to document changes in topography elevation and the position of the gamma detectors as real-time gamma activity data were collected. In this manner the gamma activity was collected and documented with GPS elevation and coordinate data. The ATV operator used surface landmarks and tire impressions from previous passes to guide the gamma detector array over the majority of the site. Time constraints and GPS dropouts prevented 100 percent site coverage. The original and modified mobile data acquisition system configurations are shown in Figure G-1.



Figure G-1. Mobile data acquisition system configurations

The original configuration (left) was an ATV, which pulled the cart-mounted data acquisition system. The modified configuration (right) was an Army Mule ATV with the detectors directly mounted to the rear of the ATV. Both configurations used four NaI gamma detectors and a GPS.

G.6.3 Surface Data Analysis

The surface gamma activity data, collocated with GPS data, were collected with the four-detector array, summed, and averaged. The processed data were used to develop an activity level for a 1.2 m (4 ft) footprint beneath the detector array. Next, calibrated laboratory gamma activity was acquired at the MSU Calibration Facility using the unique MSU-designed thorium calibration disk. The MSU calibration disk, measuring approximately 81 cm (32 in) in diameter by 5.1 cm (2 in) in thickness, was fabricated in concrete with 50 pCi/g thorium oxide (thorium with thorium progeny in equilibrium). The NaI gamma detectors were positioned approximately 10 cm above the center of the 50 pCi/g-thorium calibration disk. Since thorium is an alpha emitter, spectral gamma data were analyzed for the thorium progeny gamma activity. Since the Kirtland AFB thorium enriched training sites were established 40 years ago with material containing thorium in equilibrium with thorium progeny (radioactive daughter products), the presence of a second thorium decay product, actinium-228, was used to measure Th-232 activity. Actinium-228 (Ac-228) in equilibrium with Th-232 produces prominent photon (gamma) emissions at 338, 911, and 969 KeV. The Ac-228 911- and 969-keV gamma emissions were selected for evaluation and quantification for determining the activity level for Th-232.

Surface and near-surface gamma activities were measured outside the boundary of TS4 to determine the average gamma activity background for Kirtland AFB soils in the vicinity of TS4. The results of the calibration experiments were correlated with surface gamma activity measured at the Kirtland AFB training site. Measurements determined that the average background gamma activity was approximately $2\text{-pCi/g} \pm 2 \text{ pCi/g}$ and was consistent with onsite laboratory verification sample results.

The processed gamma activity data for TS4 was integrated with GPS coordinate data and displayed as a color contour map. Due to the rough terrain at TS4, exact values of thorium activity could not be ascertained for all locations since the gamma detector array was not always

positioned parallel to the surface and could not always be maintained at the calibration height of 10 cm above the terrain surface.

The contour map of TS4 corresponds to surface gamma activity and also to levels of thorium activity. Background levels of gamma activity are represented in blue and range from 0 to 4 pCi/g. The uncolored, oval shaped region in the middle of the radiation hot zone is the location of a helicopter body. Regions of low gamma activity (low thorium activity) range from 4 to <16 pCi/g and are shown in green. Moderate gamma activity (moderate thorium activity) ranges from 16 to <57 pCi/g and is shown in yellow. Regions of high gamma activity (high thorium activity) are shown in red and are located in the vicinity of the helicopter body. The helicopter body is represented in Figure G-2 as a white oval inside the red region since no data could be collected beneath the helicopter. The lower limit for red was selected as 57 pCi/g since the U.S. Department of Transportation does not allow unregulated shipment of thorium-contaminated material that measures 57 pCi/g or greater.

Gamma activity data were collected in the rectangular region in white on the east side of the helicopter body in Figure G-2. However, due to a GPS malfunction, the gamma activity data could not be accurately positioned for this region. Hence, no data are shown for this region. The gamma data processed for this region had low and moderate levels of gamma activity (thorium contamination) and would have extended the regions of yellow and green activity levels eastward in Figure G-2.

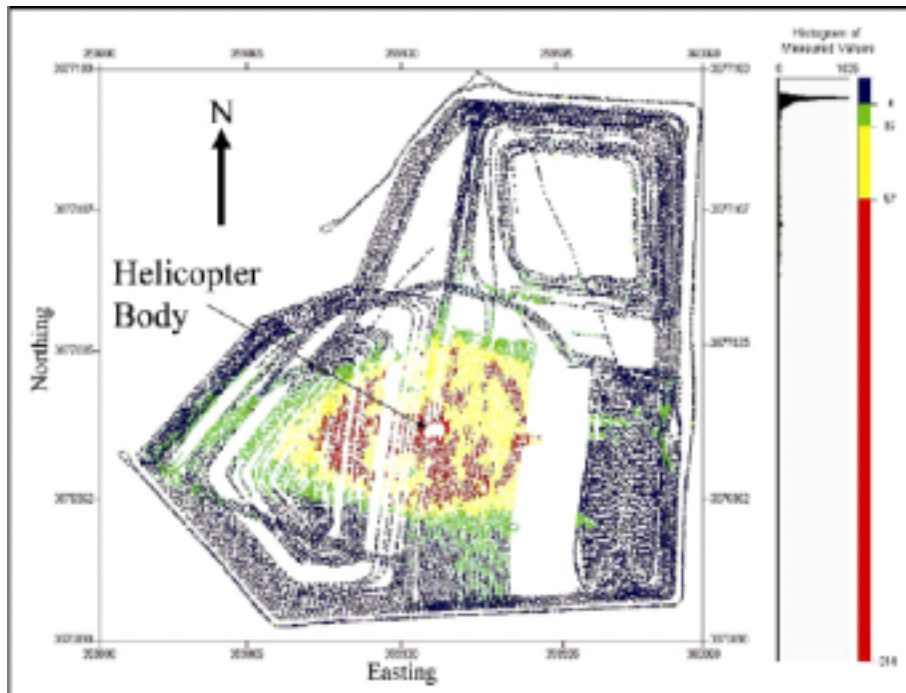


Figure G-2. Color contour map of measured gamma and thorium activity at TS4

The GPS elevation data indicated that site elevations measured from the northwest to the southwest ends of the site drop approximately 1.9 m. GPS data also indicate that elevation from the helicopter to the southwest corner drops approximately 0.5 m. Due to decreasing elevation

toward the southwest quadrant of the site, it is likely that surface rainwater runoff could transport low levels of thorium-enriched soil toward the southwest quadrant of the site and possibly into soil adjacent to the southwest quadrant. Annual rainfall for Kirtland AFB is approximately 25 cm. The west side of the site is positioned parallel to several large arroyos, one of which originates with the southwest quadrant of the site.

G.6.4 Subsurface Characterization

In order to determine the extent of vertical migration of Th-232, soil borings were collected at 33 locations within and adjacent to TS4. An Earth Probe™ soil-sampling device was used to hydraulically hammer (push) sample chambers into the soil in 61 cm (2 ft) segments. An Earth Probe™ 61 rod sampling segment consisted of outer steel housing, tip, and inner plastic sample chamber. During soil collection activities, the Earth Probe™ hydraulically hammered (pushed) 61 cm steel rods with retractable steel tips into the ground. During soil collection, the steel tip was pushed by soil into and through the plastic inner tube. Due to space occupied by the steel tip and other internal tip release assembly parts, a maximum of 54.6 cm (21.5 in) of soil was collected per 61 cm push. On pushes greater than 61 cm, the tip was locked in place until the desired sampling depth was reached. Once sampling depth was reached, an internal release mechanism was activated to allow subsequent pushing to force the tip and soil into the inner plastic sampling tube. In this manner, soil was sampled at each location to a depth of 3.05 m (10 ft). Some sampling segments provided less than 54.6 cm of soil. It is thought that soil compaction may have occurred in some cases and that soil insertion reached refusal in other cases. Soil not inserted into one 61 cm segment was not pushed into a subsequent tube since the conical steel sampler tip was locked in place during subsequent pushes and pushed soil aside as the conical-tipped probe was pushed to the next sampling depth.

Soil borings were collected to a depth of 3.05 m unless refusal to push occurred (often due to large rocks). Sample locations 1-15 were positioned outside the TS4 perimeter fence. Sample locations 16-33 were positioned within the thorium-enriched training site. Soil borings were collected in 55.2 cm (21.75 in) plastic tubes, decontaminated of surface radiological contaminants, and stored for onsite radiological laboratory analysis for radionuclide speciation and levels of activity. Borehole closure was conducted to prevent future cross-layer contamination by way of open boreholes.

The ERDC mobile radiological laboratory was used to evaluate the soil borings collected at TS4. The mobile laboratory consisted of five independently operated gamma evaluation/counting stations and utilized the equipment used during the surface radiological site characterization phase of the project. The mobile laboratory was also used during calibration comparison studies at the MSU Calibration Facility. EPA standard method series for aqueous metal concentrations (including thorium) is 6000 (Inductively Coupled Plasma–Mass Spectrometry and Inductively Coupled Plasma–Atomic Emission Spectroscopy) and was used for offsite analysis of soil and plant samples.

The 54.6 cm (21.5 in) plastic soil sampling tubes were removed from the Earth Probe™ 61 cm (2 ft) outer steel sampler housing and inspected for soil content. The soil content of each tube was measured and recorded, and 15.2 cm (6 in) segments of tubing containing soil were marked on the outside of each tube corresponding to the appropriate vertical position the soil represented.

For example, at each sampling location, tube one was marked for 0 to 15.2 cm (0 to 6 in), 15.2 to 30.5 cm (6 to 12 in), 30.5 to 45.7 cm (12 to 18 in), and 39.4 to 54.6 cm (15.5 to 21.5 in) segments. It should be noted that soil analyzed in the fourth position of each tube overlapped 6.4 cm (2.5 in) of soil in the third tube segment. In this manner, the detector-to-soil geometry used throughout the laboratory analysis was maintained (i.e., 15.2 cm of soil filled the field of views of the NaI gamma detector for each analysis). Next, tube two was marked corresponding to soil collected in 61 to 76.2 cm (24 to 30 in), 76.2 to 91.4 cm (30 to 36 in) segments, etc. This process was repeated for the five tubes collected at each sampling location. When soil tubes were not filled to capacity, the soil was divided into 15.2 cm segments using the soil available.

Five NaI gamma detector spectrometers with shielding were assembled onsite using an inverted T-shaped PVC pipe surrounded by lead shielding material. Soil tubes were inserted through the horizontal portion of the inverted pipe in a manner that centered each 15.2 cm soil segment. The NaI gamma detector was positioned vertically in the inverted “T” with the detector field of view positioned above the sealed plastic soil tubes. For spectral gamma data acquisition events, the detector was positioned above the center of each 15.2 cm soil segment that was situated horizontally in the PVC pipe and interrogated for 30 min. The gamma energy spectrum was saved for later offsite post processing and analysis. The tube was moved horizontally beneath the gamma detector to center each 15.2 cm soil segment for subsequent soil sample interrogation. Since each tube had the capacity to hold four 15.2 cm segments of soil, the spectral gamma interrogation of each tube required a maximum of two hours to complete. Tubes with less soil required less spectral gamma interrogation time.

Post-processing of spectral gamma data was conducted offsite after field and laboratory investigations were completed at Kirtland AFB. Spectral gamma data sets were analyzed for thorium progeny gamma activity. As with the surface characterization, the soil samples were analyzed quantitatively for Ac-228 gamma emissions during post processing activities by comparing spectral gamma results from the soil borings with spectral gamma results collected using the Th-232 calibration disk at the MSU Calibration Facility.

Figure G-3 shows the depth of thorium contamination at TS4. Thorium levels greater than 2 pCi/g were seen at a maximum depth of 84 cm (33 in) below the surface and only for sampling locations near the helicopter. It was noted during soil sampling activities that surface soil sometimes fell into the open hole between sampling events. Some results indicate subsurface samples with elevated levels of thorium activity attributed to surface soil accumulating in the first segment of a subsequent 0.6 m sampling event. Lower levels of thorium activity in subsequent soil segments support this hypothesis. Activity levels that fell within the range of natural background were entered as 0 pCi/g.

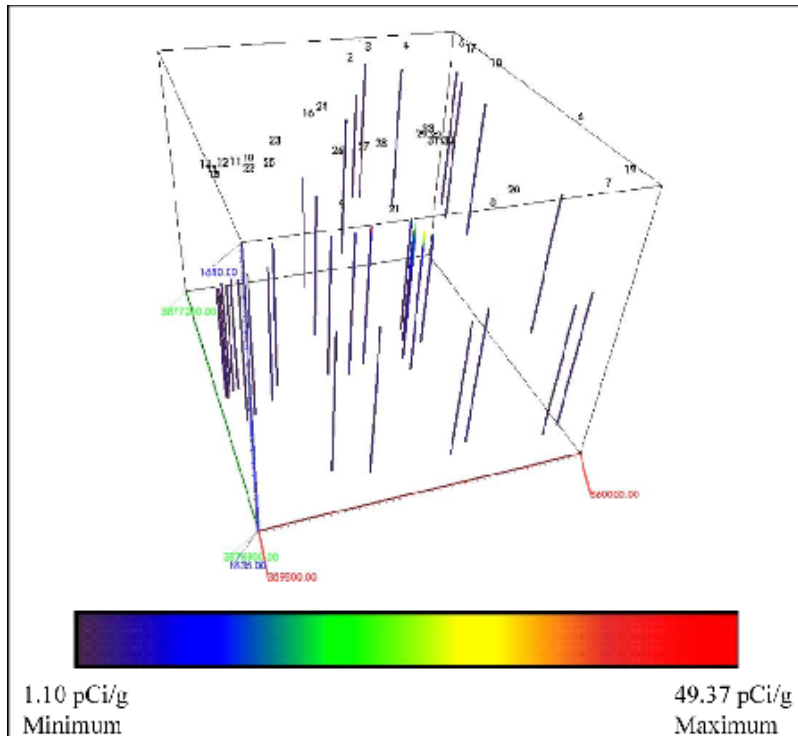


Figure G-3. Thorium distribution in three dimensions

Elevated thorium activity levels were measured at only a few sampling sites near the helicopter at the center of the site

G.6.5 Remediation and Closure Strategy

Samples of “clean” and “thorium-containing” soil, runoff water and sediment, and plants were collected during the field activities at TS4. Two barrels of clean soil (near background activity levels of ~2 pCi/g) were collected from a 1.2 by 1.8 m (4 ft by 6 ft) square (to a depth of 20 to 25 cm (8 to 10 in)) located outside the perimeter fence of TS4. This soil was used for laboratory characterization and stabilization studies. Soil was also collected from hot spots in the area surrounding the helicopter for desorption, column leaching, and stabilization studies. In addition, the soil cores harvested for subsurface characterization were saved for future laboratory studies.

Runoff may be a significant pathway for thorium migration; therefore, a water and sediment sampling system, the Isco 6712 Portable Sampler, was placed in the largest arroyo adjacent to the training site. Although several arroyos exist west of the site, water samples were collected from the largest arroyo because it appears to receive the majority of overland flow. The Isco 6712 Portable Sampler was programmed to sample when a liquid level actuator’s conductance changed in the presence of runoff water. A rain gauge unit was also present to act as a backup trigger in case the liquid level actuator failed. Twenty-four 1 l bottles were positioned inside the unit to collect rainwater according to a preprogrammed routine. One bottle was assigned for each sampling event. The unit was placed approximately 8 m (25 ft) above the sampling point on a hill adjacent to the arroyo (Figure G-4). A shelf was dug out of the incline and heavy link chain attached to the unit. Stakes attached to the chain were driven into the soil to prevent washout. A

12 V battery was placed in an all-weather cover box and then partially buried in the ground. The battery was recharged by an attached solar panel.



Figure G-4. Isco portable water and sediment sampler

The Isco unit was set up in the largest arroyo to collect runoff water and sediment.

An area that allows water to pool approximately halfway down the arroyo was chosen for placement of the liquid level actuator and intake line. Both the actuator and intake line were placed in a small, shallow opening. The stainless steel screen at the end of the intake line was affixed to the clamped liquid level actuator. The clamp was then staked to provide support for both mechanisms. A significant rain event did not occur from the start of field investigations to the date of publication of the site report; however, the unit was left in standby mode at TS4 and was monitored by DNWS personnel at Kirtland AFB.

It is possible that plants on the training site take up thorium or some of its progeny (daughter products). Thorium-laden plant debris (e.g., tumbleweeds) could possibly be transported from the site during strong winds. This could represent another possible means of thorium transport. To determine to what extent (if any) plants are taking up radionuclides at TS4, plant samples, both roots and shoots, were harvested from each of the 33 subsurface soil sample locations (Figure G-5). Laboratory analysis of plant samples was not within the scope of work of this project. However, plant samples will be analyzed for radionuclide content during follow-up work at ERDC.



Figure G-5. Plant sample collection and labeling

G.6.6 Observations and Lessons Learned

The following conclusions can be drawn from the experiences at the Kirtland site:

- The ERDC-developed Mobile Multisensor Radiological Data Acquisition System configured with an array of four gamma sensors collocated with GPS x-, y-, and z-coordinates was successfully deployed at TS4, Kirtland AFB and provided the simultaneous mapping and in situ quantification of surface thorium and thorium progeny radiation activity.
- Natural radiation background measured 2 pCi/g (± 2 pCi/g) for offsite Kirtland soil. Elevated levels of gamma activity were defined for TS4 soil as gamma activity exceeding 4 pCi/g. The highest levels of gamma activity were measured in soils in the vicinity of the site helicopter body. Probable routes of thorium migration were identified by contour mapping gamma activity of thorium progeny in surface soils. Low levels of gamma activity were verified by onsite radiological laboratory analysis of soil samples collected from suspect locations.
- An evaluation of the data indicated that thorium-contaminated surface soils at TS4 are migrating to the southwest and west directions. Elevated activity (three to five times background) was measured near the boundary of the southwestern quadrant of the site.

- Vehicular traffic between the site helicopter body and the east gate has likely spread some thorium-contaminated soil toward the east gate portal.
- Thorium contamination appears to be in the top 91 cm (3 ft) of soil.
- Vegetation was found growing in thorium-contaminated soils of TS4 and may be contaminated with thorium or thorium progeny in roots and shoots. Strong winds could possibly transport thorium-laden dead plant materials within and beyond site boundaries.

The following recommendations are made:

- Stabilize TS4 soils with elevated levels of gamma activity (i.e., TS4 soils with gamma activity exceeding 4 pCi/g) to prevent offsite migration of thorium and thorium progeny contaminants.
- Conduct laboratory analysis of vegetation growing in thorium contaminated soils of TS4 to determine if thorium or thorium progeny have been absorbed in roots and/or shoots.

G.6.7 Reference

“Evaluation of Thorium-232 Distribution at Kirtland Air Force Base, Defense Nuclear Weapons School, Training Site 4”, Steven L. Larson, John H. Ballard, Anthony J. Bednar, Melissa G. Shettlemore, John C. Morgan, Morris P. Fields, Environmental Laboratory U.S. Army Engineer Research and Development Center, and Christos Christodoulatos and Rebecca Manis, Center for Environmental Engineering, Stevens Institute of Technology, July 2004.

G.7 MT. PLEASANT NORM SITE, MICHIGAN

G.7.1 Site Description and Background

The Mt. Pleasant site is a privately owned pipe storage yard in central Michigan. Pipes salvaged from producing wells throughout the state were transported to this three acre pipe yard for cleaning, reconditioning, and storage. As is typical at all pipe yards, these pipes were stored on racks. Scale that had formed on the outside of the pipes while they were installed in wells fell off of the pipes during handling and through exposure to the elements. Both the operators of the wells from which the pipes were pulled and the owner of the pipe yard were initially unaware of the radioactivity of the scale. As a result, radioactive scale was distributed across the pipe yard, contaminating surficial soils.

In 1991, the site owner conducted a site survey and determined that portions of the site had elevated surficial gamma activity. The owner excavated approximately 38 cubic yards of contaminated soils that were identified by gross gamma activity. These soils easily ranged into the thousands of pCi/g for Ra-226. After the excavation work, the remaining pipe was removed from the yard.

In 1997, the State of Michigan's Department of Environmental Quality (DEQ) performed a cursory site survey and identified additional locations on site where elevated gamma activity was present. All of the radioactivity located by this survey was due to naturally occurring radioactive materials (NORM).

NORM is a ubiquitous problem for the oil and gas industry. For this industry, NORM problems usually take the form of elevated levels of Ra-226 and/or Ra-228. These radionuclides can be found at elevated levels in a variety of oil and gas industry waste streams, including sludge and pipe scale. Activity concentrations for individual pieces of scale could reach tens of thousands of pCi/g. The NORM designator is used to differentiate naturally occurring radioactivity from materials contaminated with man-made radioactivity. Figure G-6 shows a chip of NORM-contaminated scale on a shovel; this chip is typical of the NORM scale found in surface soils at the site. This form of contamination tends to be extremely localized and variable.



Figure G-6. NORM pipe scale on a shovel

After the 1997 DEQ survey, the owner expressed interest in being able to sell the property at some point and so the contamination at the site needed to be cleaned to be in compliance with State of Michigan regulations for unrestricted use. Future plans for the site include potential conversion into residential housing units.

The site owner recognized a surficial contamination problem in 1991 and voluntarily scraped and containerized about 38 cubic yards of soil that were stored in plastic drums onsite. No groundwater concerns were identified; only surficial soil contamination existed at the site. As

indicated in 1991, the site owner divided the sites into grids and performed direct measurements of gross activity in each grid to determine the extent of the contamination. Based on those measurements, the owner selectively removed and containerized solid material with elevated levels of contamination. In 1997, the DEQ performed a cursory site survey and identified additional locations on site where elevated contamination was present. The DEQ also sampled soils from the stored drums and found Ra-226 concentrations that ranged from 1.0 up to 3,000 pCi/g.

G.7.2 Characterization Strategy

The Michigan state soil cleanup criteria are applied over 100 m² areas and are stated as:

less than or equal to 5 pCi/g Ra-226 above background from the surface of the ground to 15 cm in depth, and
less than or equal to 15 pCi/g Ra-226 above background for each subsequent 15 cm depth interval.

The closure requirement for this site was that gamma walkover data, when averaged over 100 m², must be below the lower trigger level of 15 pCi/g Ra-226. If the data were not below this level, then supporting information from an in situ HPGe gamma detector had to show compliance with the 5 pCi/g requirement. In addition, to provide a greater level of comfort for the state of Michigan, direct measurements taken on a regular grid were required to produce results that, on average, were less than 5 pCi/g.

The DEQ has WAC for the disposal of NORM wastes in state landfills. These criteria require that the average activity concentration of NORM-contaminated soils placed in Michigan landfills be below 50 pCi/g. These WACs are particularly important because the alternative disposal options for NORM waste in Michigan are significantly more expensive.

The site required a means to identify and delineate remaining soil issues onsite, a means for demonstrating closure with cleanup standards, and a means for characterizing drummed material to support disposition. The strategy developed for the site was based on real-time measurement technologies and a dynamic work plan to support soil and drum characterization, and MARSSIM was used for final closure compliance demonstration. In the case of in situ soils, real-time technologies supported the identification, delineation, and removal of residual contamination above cleanup guidelines. Real-time technologies were used to provide data necessary for an MARSSIM-based closure program. Real-time technologies were also used to characterize and segregate drummed material to support disposition decisions.

Various technologies were used to provide characterization information for the site including: a small FIDLER (mini-FIDLER); an NaI scanning system; an in situ NaI gamma spectroscopy system; an in situ HPGe gamma spectroscopy system; and offsite (or ex situ) gamma spectroscopy. The mini-FIDLER system was coupled with a differential GPS and data logger. It measured and recorded gross activity readings from surficial soils, with one measurement every two seconds. The system was deployed in a walkover mode, with a technician providing complete coverage of exposed soil surfaces by walking parallel lines. Logged data were offloaded and mapped and analyzed using a GIS.

The in situ NaI gamma spectroscopic system used was a low-cost commercial system developed specifically for Ra-226 applications. The system was calibrated at test pads at Grand Junction, Colorado. This system was the primary source of location-specific Ra-226 activity concentration estimates at the site. The system was capable of accurately estimating Ra-226 activity concentrations in situ with detection limits well below the 5 pCi/g cleanup requirement with a 5 min measurement time. The performance of the system was monitored throughout the project by taking samples from selected measurement locations and sending them for offsite gamma spectroscopic analysis. Though not of significance here, the primary limitation of the system was that it was sensitive to interference effects from other radionuclides that might be present at elevated levels.

The in situ HPGe system also provided accurate activity concentration for Ra-226. Although significantly more expensive and difficult to operate than the NaI gamma spectroscopic system, the HPGe had the advantage of providing activity concentration estimates for Ra-226 that would not be affected by the potential presence of other elevated radionuclides. The in situ HPGe system was primarily used as a verification tool. Offsite gamma spectroscopy was performed by traditional laboratory sample analyses; it was primarily used to evaluate potential disequilibrium concerns, and for QA/QC of real-time results.

An initial walkover of the site was conducted to map spatial patterns of contamination. The mini-FIDLER encountered elevated readings sprinkled across most of the site. Based on this walkover, fifty locations with elevated readings were selected and measured using the in situ NaI gamma spectroscopic system. This provided activity concentration estimates paired with mini-FIDLER gross gamma activity results. Using these data trigger levels were derived for the mini-FIDLER. The lower trigger level denoted a gross activity below which it was unlikely Ra-226 exceeded its standard. The upper trigger level denoted a gross activity above which it was very likely Ra-226 exceeded its standard.

The mini-FIDLER data was spatially averaged using moving window averages to produce gross gamma estimates with a support equivalent to the cleanup criteria area definition (i.e., 100 m²). Using the trigger levels, each 100 m² area was evaluated to determine the likelihood of exceeding 5 pCi/g. This evaluation identified five distinct areas where exceedences were likely present. Confirmatory in situ HPGe measurements were taken over each of the five locations. These readings verified that activity concentration standards were exceeded. The five areas were scraped and re-walked with the mini-FIDLER. This process continued until the mini-FIDLER indicated that cleanup standards had been achieved.

Once scraping was complete, the site was divided into eight MARSSIM Class 1 survey units. Systematic grids consisting of nine measurement locations were superimposed over each survey unit. Ra-226 activity concentration estimates were collected using the in situ NaI gamma spectroscopy system for each location. The results were subjected to a nonparametric sigma test to demonstrate that average concentrations were below 5 pCi/g. All eight units passed this test. The NaI gamma spectroscopic data, combined with the post-remediation mini-FIDLER scans served as the primary basis for site closure.

Discrete samples were collected and analyzed by gamma spectroscopy by both ANL and DEQ. These samples had two purposes: first, to determine whether radon emanation and disequilibrium was a concern for the Ra-226 present at the site and second, to act as a source of QA/QC for the real-time data that had been collected.

A complete scan of the surface of the site was completed with a mini-FIDLER system linked to a GPS. This scan was accomplished using a 5 ft spacing between walked lines. Data was collected in 2 s intervals, which resulted in approximately a 3 ft spacing between data points. The technician performing the survey also flagged highly elevated areas based on meter readings, as would have been done if the data were not logged. The data were downloaded to a laptop on site and mapped using ArcView. The data were color-coded based on observed gross activity and reviewed for completeness of coverage. In a couple of instances, small areas were re-walked to ensure that adequate coverage of the site was obtained.

The data presented on Figure G-7 showed evidence of elevated activity scattered across the site, consistent with the contamination scenario involving bits of scale knocked off of piping. Gross gamma activity ranged up to almost 100,000 cpm. Based on this data, the bulk of the surface of the fenced area appeared to be impacted at least to some degree by NORM.

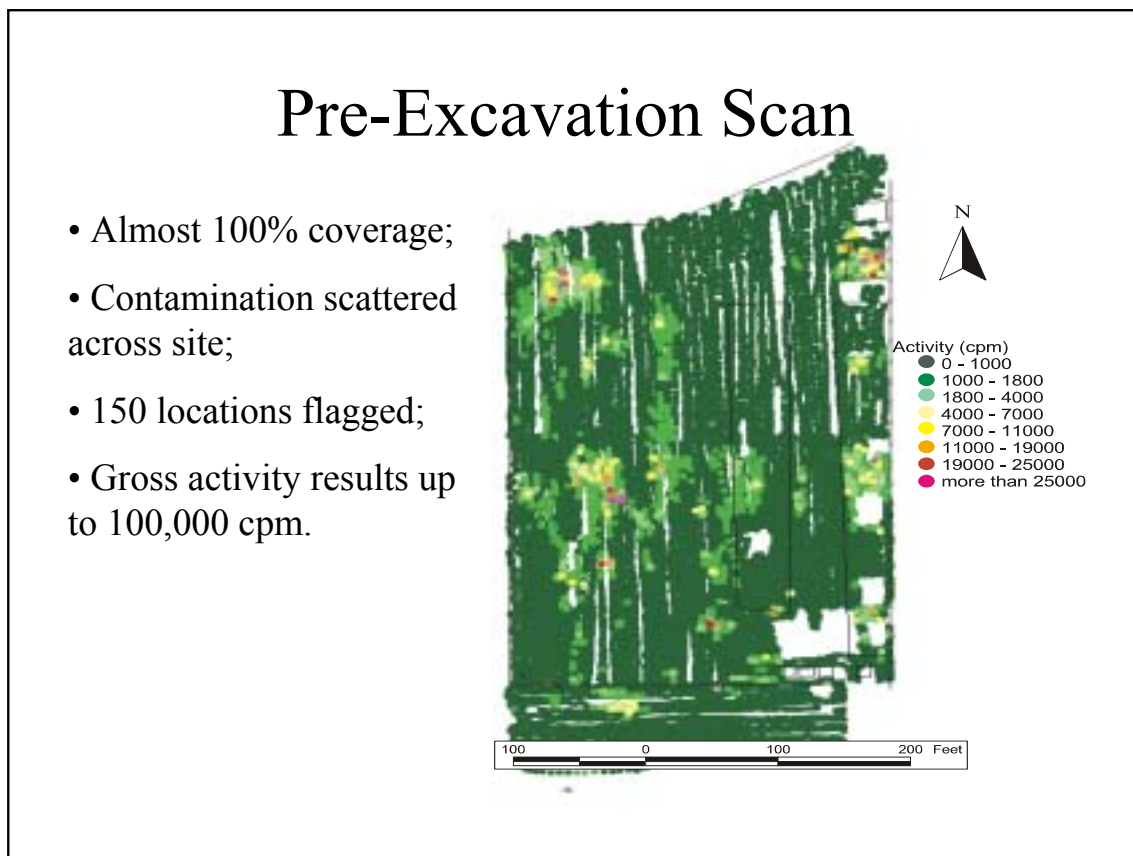


Figure G-7. Pre-excavation surface scan

With a complete surface scan in hand, the next step in this process was to determine a relationship between gamma walkover data collected by the mini-FIDLER and the probability of guideline exceedance. To do this, 49 hotspot locations were measured with an in situ NaI gamma spectroscopic system and the results paired with corresponding gross gamma results. The in situ NaI gamma spectroscopy (RadInSoil™) system results ranged up to almost 1,000 pCi/g. These data were then analyzed using a nonparametric approach. Based on this nonparametric approach, a lower trigger level of 1,800 cpm and an upper trigger of 2,500 cpm were selected for 5 pCi/g. Of the eight locations with gross activity less than 1,800 cpm, none yielded an in situ value greater than 5 pCi/g. Of the 32 locations with cpm values greater than 2,500 cpm, all yielded in situ values greater than 5 pCi/g. The performance of the in situ system was monitored throughout the project by taking samples from selected measurement locations and sending them for offsite gamma spectroscopy.

Since the cleanup criteria were to be applied over 100 m² areas, the gamma walkover data was spatially averaged using a 100 m² moving window average. Next, using these results and the trigger levels, site soils were partitioned into three groups: soils below the lower trigger (or clean), soils above the upper trigger (or contaminated), and soils between these two trigger values. The upshot of this analysis was that there were only five distinct areas that either had contamination above the guidelines or showed a potential for having problems.

Hotspots within the five areas were scraped with a front-end loader, and the resulting exposed surface was scanned. This continued until hot spots were removed. The resulting exposed surfaces for all five locations were measured with an HPGe to confirm compliance with the guideline. All were equal to or less than 3.3 pCi/g for Ra-226. The exposed surfaces were re-walked, and this new walked data merged with the pre-excavation data set.

Subsequent to the excavation, a MARSSIM-based closure survey was conducted and 72 measurements were made using the in situ NaI gamma spectroscopy system. Figure G-8 shows these results.

RadInSoil Final Status Results

- 2 of 72 RadInSoil readings > 5 pCi/g (2.7%);
- Consistent with post-excavation gamma walkover data (2.6% > 1,800 cpm)

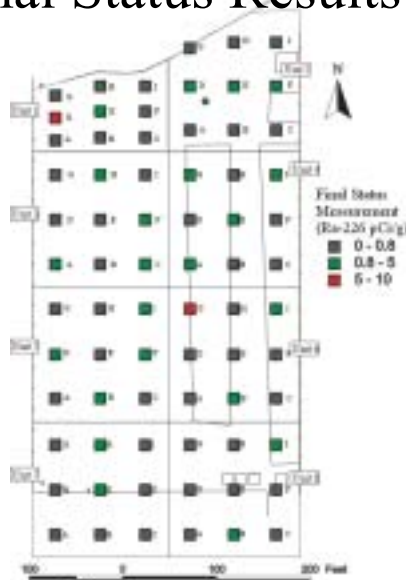


Figure G-8. MARSSIM-based closure survey (discrete measurements made using in situ gamma spectrograph)

G.7.3 Remediation and Closure Strategy

Standard laboratory methods were used for samples that were sent to an offsite laboratory as part of this project. Describing and quantifying this type of uncertainty has a long, well-documented history and needs no further discussion here; however, other measurements were made as part of this project that were not subject to laboratory analytical methods. They included two important types of measurements: those made by the in situ NaI gamma spectroscopy system and those made as part of the mini-FIDLER gamma walkover surveys. The quality assurance process for the RadInSoil™ system provided for routine checking of results against the results obtained by a standard offsite laboratory. The RadInSoil™ system was shown to be easily capable of providing the detection capabilities necessitated by the cleanup requirements.

G.7.4 Observations and Lessons Learned

A nonparametric technique was used to demonstrate the degree of uncertainty associated with the mini-FIDLER gamma walkover survey measurements relative to its ability to detect Ra-226 in soil. Figure G-9 shows the results of that nonparametric method. Because the results showed that no gamma walkover survey measurements of 1800 cpm or lower exceeded the cleanup criterion and all gamma walkover measurements of 2500 cpm or greater always represented soil contaminated above the cleanup criterion, these thresholds were used as the lower and upper trigger levels respectively. The gray zone was a relatively narrow window between 1800 and 2500 cpm.

Non-Parametric Results

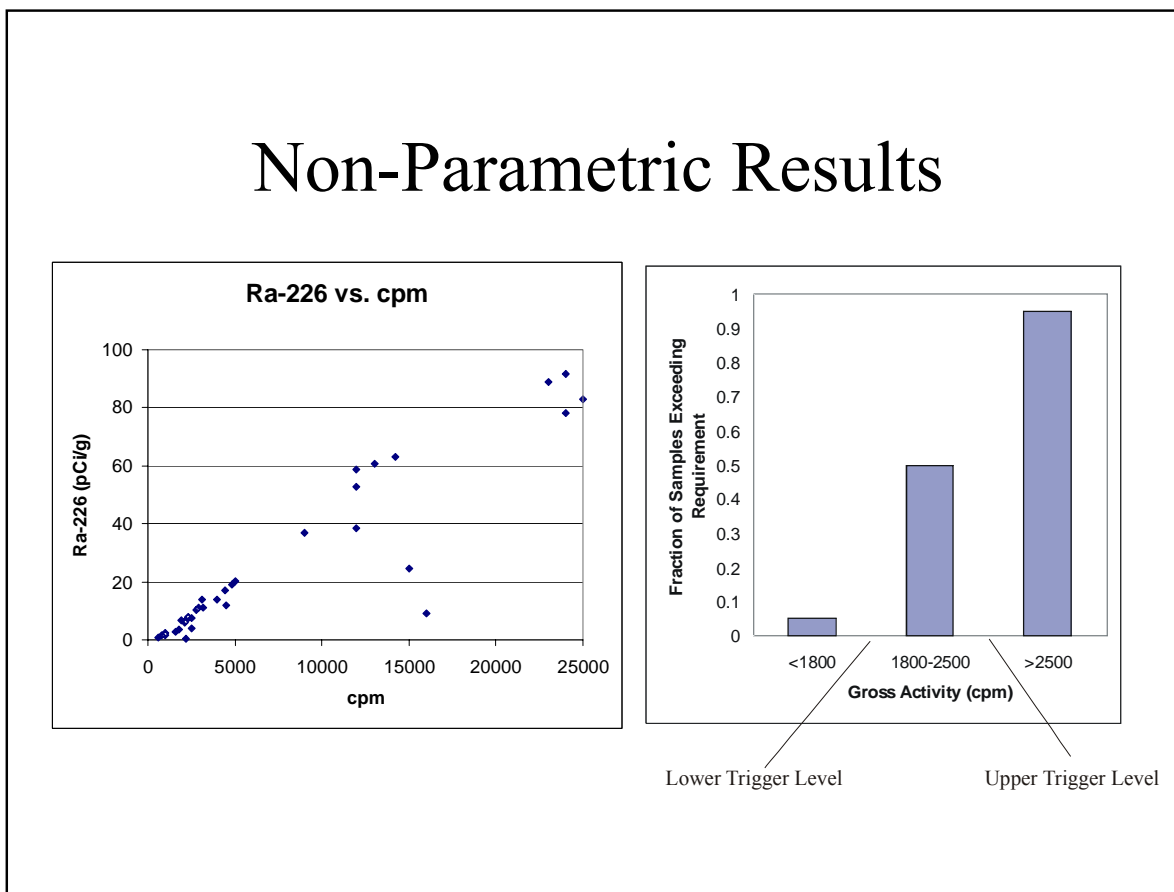


Figure G-9. Analysis used to establish gamma walkover trigger levels for spatial uncertainty

A powerful demonstration of the high degree of comparability between the mini-FIDLER gamma walkover surveys and the discrete soil concentrations measured as part of the closure protocol at this site is provided by the fact that of the 72 RadInSoil™ measurements, only two (or 2.7%) were above the criterion. This was consistent with the post-excavation mini-FIDLER gamma walkover data, where 2.6% of the approximately 18,000 measurements were above 1,800 cpm. If soil samples had been collected and sent to an offsite lab, similar results would have been expected since the RadInSoil™ results were constantly checked by standard offsite laboratory analyses. Any of the methods, if used independently, would have quantified the rate of exceedances of Ra-226 at this site to a similar level of certainty. An additional measure of certainty is provided by the gamma walkover survey. The graphical portrayal of the gamma walkover data set gives the decision-maker a more detailed view of the spatial distribution of the radium in soil.

Both the mini-FIDLER and in situ NaI gamma spectroscopic systems showed excellent performance at the site. The mini-FIDLER system provided an reliable, documentable means of determining site surface contamination status. The Pearson correlation coefficient for the mini-FIDLER gross activity results and corresponding NaI Ra-226 activity concentration estimates was 0.98, indicating excellent linear agreement between the two measurement systems. NaI Ra-

226 activity concentration estimates were compared with sample results from locations where both samples and NaI activity concentration estimates were obtained. Each sample was homogenized and split and each split was submitted to two different offsite laboratories for gamma spectroscopy analysis. The relative differences between the NaI activity concentration estimates and the laboratory results were the same as those obtained by comparing the two sets of laboratory results, indicating that the NaI was providing data of quality equivalent to standard offsite gamma spectroscopy analyses.

The real-time measurement systems provided data at a fraction of the cost of standard laboratory gamma spectroscopy analyses. The per-measurement cost of each mini-FIDLER data point was on the order of a few pennies. The deployment of the in situ NaI gamma spectroscopic system cost approximately \$10 per measurement. In contrast, the cost of collecting and analyzing a soil sample via gamma spectroscopy at an offsite laboratory is several hundred dollars. The conclusion is that the deployment of these real-time technologies for this particular site fulfilled data collection needs at a fraction of the cost of a more traditional data collection program with a greater reduction in the degree of uncertainty associated with the closure survey of the site.

Aside from data collection cost savings, the primary benefit of deploying a Triad-style real-time data collection program at the site was the ability to roll characterization, remediation, and closure into one round of fieldwork. The survey methods used for executing remediation and closure were nearly identical. Having the data available in real-time meant that remedial excavation work could quickly and precisely address elevated area concerns identified by walkovers. For this particular site, the fieldwork associated with characterization, remediation and closure was only a few days. Including real-time data collection in the closure program ensured that demobilization could occur with the assurance that the entire site met the DEQ closure standards. The mini-FIDLER and the in situ NaI gamma spectroscopic are near real-time measurements that can detect contamination quickly and allow its removal at real time. Other methods require much longer time for results that can be acted upon. These systems must be calibrated and maintained in good working order.

The following observations and lessons learned can be drawn from experiences at this site:

- Systematic planning must be used when deploying multiple technologies as part of remediation and closure. Decision-makers and regulators must understand and concur on the manner in which the technologies will be used and the contingency plans that will be used in the event that one or more of the technologies does not meet expectations.
- It is important to build performance validation and verification studies into the overall data collection strategy for a site if real-time measurement systems are to be used.
- Assuming that project-specific performance goals are met, real-time data collection can be used for site closure data requirements much more efficiently than standard samples for laboratory analysis.

- One of the key benefits of a Triad approach to characterization and remediation is the ability to design field work that integrates characterization, remediation, and closure into one effort. This ability results in abbreviated schedules and overall reduced costs

G.7.5 Reference

“The Use of Real-Time Instrumentation to Achieve Site Closure”, Prepared by Argonne National Laboratory–Environmental Assessment Division, Prepared for Bechtel Jacobs Company LLC and U.S. Department of Energy Oak Ridge Operations Office, January 19, 2004.

G.8 NEVADA TEST SITE, NEVADA

As part of the D&D program at the NTS, DOE Nevada (DOE/NV) deployed an innovative real-time radiation survey technology that effectively reduced costs associated with radiological characterization, waste determination, and site closure. DOE/NV used the ISOCS, developed by Canberra, in support of D&D activities completed at the Reactor Maintenance, Assembly, and Disassembly (RMAD) Facility, located in Area 25 of the NTS.

The ISOCS system consists of a portable HPGe detector and MCA connected to a laptop computer, loaded with specialized software developed by Canberra. The ISOCS software was used in tandem with a characterized detector, allowing the geometry of objects to be modeled, as well as producing an efficiency calibration for that object. The spectrum obtained with the specially characterized detector was then corrected with a mathematically developed efficiency calibration, resulting in an accurate, real-time estimate of the activity of gamma-emitting radionuclides contained within the object. To simplify the process, a calibration curve for a three dimensional model of a 55 gal drum, B-25 box, or sample bottle was developed by entering the geometric and physical description (density and molecular composition) of each container type into the software model to generate correction factors. The ISOCS detector scans the container and the spectrum data are corrected with the mathematically developed ISOCS efficiency curve to accurately estimate the activity within the container

ISOCS was applied in completing final MARSSIM release surveys for soils and building surfaces. DOE/NV used ISOCS to survey multi-layered roofs of various structures/buildings in a particularly cost-effective manner: instead of removing and screening by hand each portion of the roof, which is both costly and time-consuming, the ISOCS system was applied. DOE/NV efficiently screened all layers of the roof in situ, prior to removal. Activities recorded for the roofing material were then compared to project/site release levels and a waste determination was made prior to removal. The use of ISOCS, in conjunction with MARSSIM methodology, reduced project costs and accelerated baseline closure schedules.

In another application, DOE/NV used the ISOCS system as a primary tool for determining waste package activities at the NTS. Typically, waste package activities are determined by characterizing the waste before packaging (for small limited volume waste streams) or collecting discrete samples from each waste package (for larger waste streams). By applying ISOCS real-time technology to waste characterization, an acceptable concentration range was quickly established for each nuclide of concern. A scaling factor between Cs-137 (Cs-137 was chosen

because it is easy to detect and is present in all characterization samples) and each non-gamma-emitting nuclide of concern was developed. ISOCS was then used to measure the concentration of Cs-137 within the waste container, while activities for other nuclides of concern were calculated using the approved scaling factors.

ISOCS served as an effective tool in the process of remediating radiologically-impacted soil at the NTS. ISOCS was configured to analyze soil sample bottles. Results of the ISOCS sample bottle analyses were used to determine the appropriate amount of soil to be excavated as part of meeting site closure criteria (this approach was also used successfully at the BNL Graphite Research Reactor project). For site closure, ISOCS was used as a real-time screening tool for analyzing final verification samples. Instead of submitting all verification samples to the laboratory, samples were screened via ISOCS. With real-time ISOCS data, concentrations of nuclides above the closure criteria were identified, additional soil was excavated, and additional verification samples collected. ISOCS helped to 1) reduce the volume of soil excavated, 2) decrease the number of samples needing laboratory analysis, and 3) reduce the likelihood of the site not meeting closure criteria.

Deployment of the Canberra ISOCS at the NTS helped to accelerate MARSSIM final status roof surveys, reduce waste volumes of radiologically-impacted soil, and accelerate the baseline project schedule. Additionally, ISOCS was used to support waste characterization and verification, significantly reducing waste characterization costs. ISOCS operation and software training was provided by BNL, and was essential for the successful deployment of ISOCS at NTS.

G.9 PADUCAH GASEOUS DIFFUSION PLANT, KENTUCKY

The Paducah Gaseous Diffusion Plant's Waste Area Grouping (WAG) 17 consists of 37 acres of concern located outside the plant boundary. Three historical investigations for the WAG 17 area of concern showed isolated occurrences of above-background levels of radioactivity on some concrete surfaces and in some soil and sediment. Radiometric field screening surveys were performed using the UltraSonic Ranging and Data System (USRADS[®]), which recorded radiation measurements at one second intervals from a gamma-ray probe and an alpha/beta probe as the USRADS[®] technician walked over each area of concern.

At the same time, the system located the position of the technician and recorded this information with radioactivity measurements. Hence, 3,600 radiation measurements and locations were recorded each hour, resulting in a high density of coverage. Surveys were conducted at specified locations along obvious surface drainages from the area of concern and wherever radiological contamination was indicated by the results of the radiometric surveys. Visual surveys were performed by noting any plant-derived materials not been surveyed with USRADS[®]. No such material was identified, but had any been identified during the visual surveys, it would have been screened using handheld radiological instruments. In addition to the field screening effort and subsequent sampling and analysis, sediment samples were collected from surface water bodies adjacent to concrete rubble piles and sent to the laboratory to analyze for radionuclide contamination which may have been present at WAG 17.

A number of concrete and soil samples were collected for laboratory analysis in response to measurements of above-background radiation. Additionally, a number of sediment samples were collected for laboratory analysis owing to their position to relative concrete rubble adjacent to surface water bodies. Laboratory analyses of soil and sediment were performed by classical, whole sample techniques; however, analysis of concrete samples employed a leaching procedure in which surficial radiological contaminants were removed from the concrete by immersing it in a low pH solution. Table G-4 below summarizes the number of samples of each medium that were collected for analysis and the types of analysis performed.

Table G-4. Number of samples and types of analysis by media

Medium	Number of Samples	Numbers of Areas of Concern	Types of Analyses
Concrete	17	5	Radiological
Soil	12	6	Radiological (7 samples)
Sediment	16	4	Radiological

With one exception, regulators decided that the WAG 17 area of concern had been adequately characterized and that the project should proceed to the report writing stage.

G.10 ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE, COLORADO

G.10.1 Site Description and Background

The 903 Pad Drum Storage Area at Rocky Flats is a 3.4-acre area where drums containing radiologically-contaminated oils and volatile organic compounds were stored from 1958 to 1967. Approximately three-fourths of the drums contained liquids contaminated with plutonium, while most of the remaining drums held liquid containing uranium. The liquid in the drums was primarily lathe coolant and solvents in varying proportions. Leaking drums were noted at the 903 Pad in 1959. Drum removal and cleanup operations began in 1967, at which time more than 5,000 drums were at the site. Approximately 450 drums had leaked to some degree, and an estimated 50 drums had leaked their entire contents. The total amount of leaked material was estimated at around 5,000 gallons of contaminated liquid containing approximately 86 grams of plutonium (about 5.3 Ci). During drum removal and cleanup activities, wind and rain spread plutonium-contaminated soils resulting in wide-spread surficial soil contamination east of the 903 Pad.

G.10.2 Gamma-Emitting Surrogates for Alpha Emitters

Remediation of radiologically-contaminated areas at the Rocky Flats Environmental Technology Site was triggered by comparing measured radioactivity levels to action levels established for the radionuclides of concern: plutonium, americium and uranium. Since plutonium was the contaminant of greatest concern, an efficient method of measuring plutonium activity was critical. Plutonium, however, is a weak gamma emitter; its gamma emissions are generally undetectable at the low activity levels that are common cleanup goals. Alpha spectrometry

results normally take at least seven days—much too long for an efficient decision making process during remedial activities. Therefore, plutonium-239 (Pu-239) activity levels for soils in certain areas were determined by measuring Am-241 gamma emissions as a surrogate, providing a real-time measurement technique for plutonium.

Rocky Flats weapons-grade plutonium was formulated with a known mass fraction of isotopes (isotopic mixture by mass) when it was produced. Each isotope has a unique specific activity (activity per gram of isotope) associated with it, which allows the activity fraction (percentage of activity from each isotope) of each isotope in weapons-grade plutonium to be calculated. For example, the weapons-grade plutonium that was handled at Rocky Flats 34 years ago had a known mass fraction mixture of isotopes. Based on that mass fraction, the unique specific activity (SA in Ci/g_{isotope}) for each isotope can be used to calculate the activity fraction of each isotope in weapons-grade plutonium. Over time (34 years in this case), the isotopes in the mixture decayed, thus changing the mass fraction of each isotope, and in turn, the activity fraction. The calculated results at the time of production (Year 0) and after 34 years of radioactive decay are as follows:

Table G-5. Activities and activity fractions for weapons-grade plutonium isotopes

Isotope	Specific Activity (Ci/g _{isotope})	Activity Fraction Year 0 (% Total Activity)	Activity Fraction Year 34 (% Total Activity)
Pu-238	17	0.38	0.84
Pu-239	0.062	13.08	37.50
Pu-240	0.23	2.93	8.42
Pu-241	100	83.46	46.63
Pu-242	0	0	0
Am-241	3.4	0.14	6.61

It is evident that over time the proportional amount of Am-241 and Pu-239 increases in the mixture relative to the other isotopes. Because radioactive decay rates are constant for all of these isotopes, it is possible to determine the exact amount of each isotope that has decayed, or in this case, the exact amount of relative mass fraction for each isotope (the remaining amount of each isotope). Based on the new calculated mass fraction of each isotope for the given time period, the activity fraction is calculated. The Pu-239 activity fraction increases because the Pu-239 mass in the mixture decays more slowly than the other isotopes; the Am-241 activity fraction increases because the Am-241 mass in the mixture increases due to the decay of other isotopes into Am-241 (Am-241 in-growth). For 34-year-old weapons-grade plutonium, the ratio of the Pu-239 activity fraction (37.50 %) and the Am-241 activity fraction (6.61 %) is 5.7 to 1. This calculated ratio and the associated activity fractions are widely accepted at Rocky Flats and throughout the DOE weapons complex because they can be precisely calculated. Their use can be found in several determinations including waste activity calculations, U.S. Department of Transportation shipping criteria, and waste acceptance criteria.

The Pu:Am ratio can also be used to determine Pu-239 activity for soils from the measured Am-241 activity. This concept has been applied during the excavation of the 903 Pad to allow near

real-time measurements and facilitate decision making in the field. Several factors support using the theoretical Pu:Am ratio of 5.7:

- A linear regression analysis of data from over 400 sample locations in the 903 Pad area produced essentially the same ratio as the theoretical weapons-grade ratio.
- Process knowledge indicates that only weapons-grade plutonium was released at the 903 Pad site.
- It is believed that the plutonium released at the 903 Pad was all manufactured at about the same time.
- Due to isotopic decay and the half-life of the radionuclides involved, activities do not change significantly from year to year.
- The physical and chemical similarities of the isotopes of concern are not expected to contribute to varying transport mechanisms that would cause isotopic separation.
- Use of the actual known weapons-grade isotopic mixture avoids the uncertainties in analytical methods.

The Pu:Am ratio at certain other sites around Rocky Flats, however, is somewhat different. In some areas, very different ratios were created by processes which preferentially extracted americium. The americium-surrogate technique cannot be used in those areas where the Pu:Am ratio has not been verified.

During the removal action at the 903 Pad, composite confirmation samples were collected from each excavation cell, which provided a sufficient number of samples to achieve greater than a 90% confidence in decisions. These samples were analyzed with gamma spectroscopy (HPGe detectors) in the field. The quick turnaround time for gamma spectroscopy field results (about 10 min) allowed project managers to decide in the field whether further excavation was necessary. The samples were then sent to an onsite lab for preliminary (about 6 hours) and final (less than a day) gamma spectroscopic analysis, and were retained for offsite alpha spectroscopy (at least a week). The regulatory agencies—Colorado Department of Public Health and Environment and US EPA Region 8—require validated alpha spectroscopy data for final confirmation.

G.10.3 Final Radiological Survey

A final radiological survey was conducted at RFETS to confirm that all potential significant areas of surface soil contamination were identified. The entire site was wide-area scanned using an aircraft-mounted detector system. Additionally, localized ground-based scanning was performed in areas with a higher potential for contamination to verify that small areas of surface soil contamination had not been overlooked. These localized areas were primarily around remediated areas where contamination was once known to exist in selected areas where wide-area scanning could not be performed.

According to the cleanup agreement, small, known areas with elevated measurements (hotspots) may remain after remediation, as well as unknown areas within an acceptable confidence limit. The CERCLA process uses risk assessment to define successful cleanup; however, for purposes of the final radiological survey only, specific criteria for final survey success or failure are defined. To be successful, the average contamination for all scanned areas larger than 80 m²

must not exceed soil action levels. An 80 m² area is near the wide-area scan detection sensitivity for the Pu-239/240 soil action level, which is the primary isotope of concern. Measurements up to three times the action levels are allowed in hotspots, which for purposes of this final radiological survey, are defined as areas no greater than 80 m².

Table G-6. Soil action levels

Radionuclide	Action Level (pCi/g)	Hot Spot (pCi/g)
Pu-239/240	50	150
Am-241	76	228
U-235	8	24
U-234	300	900
U-238	351	1,053

If the results of the wide-area scanning and ground-based scanning meet the criteria above, then the final survey plan objectives have been met and no further actions are required. If the scanning results do not meet the criteria, then additional ground-based scanning and sampling may be required to confirm and define the extent of radiological contamination. Count times may be increased to provide better resolution, and the field of views may be adjusted to pinpoint isolated contaminated areas. If re-scanning results indicate that the area may still be above soil action levels, soil samples will be collected and analyzed. Any areas identified and confirmed to have surface radionuclides exceeding soil action levels will be evaluated for potential remediation.

The entire site will undergo wide-area scanning using an aircraft-mounted detector system. An array of twelve 2 in x 4 in x 16 in (2x4x16) NaI(Tl) scintillation detectors will be mounted on a rotary wing aircraft. The survey will be performed at an altitude of 15 m with a ground speed of 70 knots (81 mph). The aircraft will be equipped with differential GPS and a radar altimeter. A multi-processor data acquisition system, the Radiation and Environmental Data Acquisition and Recorder System (REDAR V) has been custom designed by the Radiation Survey Laboratory of Nevada. Radiation (full-energy spectra) and positional information is collected each second and is displayed in real-time. Gamma-ray spectra, aircraft position, meteorological parameters and time are archived.

The effective detector footprint is a complex function of detector shape, distance from source, air mass attenuation, aircraft speed, etc. For estimation purposes, however, the footprint radius is approximately the same as the detector distance above the source, thus the detector field of view footprint is approximately 707 m². Hence, flight lines 30 meters apart across the entire site will establish the flight pattern for wide-area scanning. The detector reports the average activity within its footprint (i.e., approximately 707 m²). Thus, for areas larger than the footprint, the reported activity is nominally the surface activity. If the region of activity is smaller than the field of view, the detector activity related to surface activity is approximated by the relationship:

$$\text{detector activity} = (\text{surface activity}) * (\text{activity area}) / (\text{footprint area})$$

Table G.7 lists nominal a priori MDAs for the proposed Rocky Flats wide-area scanning for selected isotopes and activity areas.

Table G-7. Soil concentration MDA—wide-area scanning

Isotope	729 m ² area MDA (pCi/g)	80 m ² area MDA (pCi/g)	75 m ² area MDA (pCi/g)	7.3 m ² area MDA (pCi/g)	1.2 m ² area MDA (pCi/g)
Am-241	0.95	8.7	9.3	95	590
U-235	0.55	5.1	5.4	55	340
U-238 (Th-234)	7.3	67	71	730	4550

The plutonium-239/240 concentration is determined by multiplying the Am-241 concentration (pCi/g) by 5.7, a conversion factor based on the calculated Pu:Am ratio in weapons-grade plutonium. Uranium-234 activity will be approximated based on the U-235 and U-238 activity detected. This approximation is reasonable for depleted and natural uranium. If enriched uranium is identified, however, as evidenced by elevated U-235 proportionate to U-238, then the MDA for U-234 is no longer valid. U-238 values are inferred based on Th-234 measurements.

Targeted ground-based scanning will be performed primarily around remediated areas where contamination was once known to exist, selectively in areas where wide-area scanning could not be performed, and for any areas that exceed the MDA of the wide-area scan. Scanning will be performed using an HPGe detector mounted on a tripod 1 m off the ground. Count time is expected to be approximately 20 min. The field-of-view for the HPGe detector in this configuration is a 10 m diameter circle (approximately 80 m²).

Table G.8 lists the nominal a priori MDAs for the targeted ground-based scanning for selected isotopes and activity areas.

Table G-8 Soil concentration MDA—targeted ground-based scanning

Isotope	80 m ² area MDA (pCi/g)	78 m ² area MDA (pCi/g)	7.8 m ² area MDA (pCi/g)	0.78 m ² area MDA (pCi/g)
Am-241	1.2	1.3	12.7	127
U-235	0.3	0.3	2.9	28.1
U-238 (Th-234)	4.0	4.1	40.1	406.8

Lower MDAs for smaller areas can be achieved by placing the detector closer to the ground reducing the field of view and/or increasing counting time. Initially, the 10 m diameter (i.e., approximately 80 m²) scans will be made along the boundary areas with a 100 or 200 ft spacing (depending on the potential for and type of contamination) and biased within the areas where buildings with radioactive contamination were demolished or where radioactive release sites required remedial action. Additional scan locations may be identified based on results of the HPGe scan, or for anomalous areas identified in the wide-area scanning, or for areas where wide-area scanning could not be performed.

Use of these scanning techniques has been well received by the public. While the regulators at Rocky Flats will base final confirmation evaluations primarily on lab-analyzed soil samples, they consider this real-time scanning system an important supplement. These scanning techniques will ensure 100% coverage of surficial soils and are capable of detecting concentrations below action levels within areas much smaller than accepted exposure unit sizes.

G.11 SAVANNAH RIVER SITE, SOUTH CAROLINA

G.11.1 Site Description

An innovative spectral gamma probe has been deployed as a real-time characterization tool at waste sites containing radionuclides in the subsurface at the SRS near Aiken, South Carolina. The probe was evaluated in three of the six R Reactor 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 Ci of radioactivity being discharged into Basin 1, with overflow going to the other basins. In late 1996, the basins and surrounding area were capped with soil and approximately 6 in of asphalt paving. The technology evaluation of the spectral gamma probe was conducted at SRS from May through July 1997. Figure G-10 is an aerial photo of the area around Basin 1 at the site.



Figure G-10. Aerial photo of the R-Reactors, with seepage basins showing the approximate locations of sampling locations under the asphalt cover installed in 1996

G.11.2 Gamma Probe System

An enhanced spectral gamma probe designed for real-time in situ detection of radionuclides was developed by the USACE Waterways Experiment Station under the sponsorship of the U.S. DOE. The spectral gamma probe system consists of a sensor deployed in subsurface with the CPT rods and a data acquisition system at the surface (Figure G-11). The enhanced spectral gamma probe consists of a gamma radiation detection system that is driven into the subsurface using a SCAPS or other CPT truck. The downhole system consists of a NaI detector, containing a 1 in by 3 in cylindrical NaI scintillation 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. Gamma rays emitted by the radioactive waste are collected and this energy spectrum is analyzed to identify radioactive constituents and their relative concentrations.



Figure G-11. SCAPS truck

The data acquisition system at the surface is equipped with industry-standard, rack-mounted NIMs capable of data processing and storage. A spectroscopy amplifier splits the signal to the MCA buffer and to the ratemeter. The data acquisition system is a NIM-mounted 16-bit MCA buffer with an onboard 68010 CPU.

G.11.2.1 System Operation

The spectral gamma probe is deployed with a cone penetrometer truck. As the 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 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. A decontamination system ensures that radioactivity adhering to the sample rods is not brought into the truck. A decontamination chamber, attached below the truck, cleans the CPT rods. Soil particles are removed from the rods by blasting the rods with small plastic beads. 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.

G.11.2.2 Technical Evaluation

The specific objective of the technical evaluation was to assess the capability of the spectral gamma probe to provide accurate measurements of Cs-137 contamination in the subsurface. The spectral gamma results were compared with the laboratory analytical results from soil samples collected in 1995 obtained by using a hand auger. In each of three basins (Basin 1, Basin 3, Basin 6), three gamma probe pushes were clustered around a hand-augered sample collection location. 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 ft soil sample. This procedure eliminates variations present at a scale of less than two feet.

During a push, counts were taken at 1 ft intervals in background zones and at 3 in to 6 in intervals as the zones of expected contamination were reached. Allotted counting times varied from 10 min to 60 min. One push at each basin was begun as shallow as 1-2 ft 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 ft above the expected zone of contamination. The ratemeter was monitored for gross counts per second as an indication of overall radioactivity. The gamma probe was calibrated by placing 1 mCi Cs-137 and Co-60 sources on the probe and counting for approximately 20 min. The laboratory-determined radius of influence for the gamma probe was 8 in. The in situ measurements made with the spectral gamma probe were found to be comparable to the laboratory measurements on the core samples.

In summary, the results of the evaluation are as follows:

- 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 in to 1ft 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 ft interval. The peaks of activity determined by the probe generally fell within the peaks of activity as measured by the laboratory analysis. The gamma probe was also able to detect areas of activity not identified by the grosser sampling method used for the laboratory analysis.
- The LLD for Cs-137 appears to be approximately 5 pCi/g. Weaker gamma emitters will have higher LLDs. 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.

G.11.3 Advantages of Spectral gamma probe System

In situ measurement of specific radionuclide concentrations can potentially result in significant reduction in the cost of characterization of hazardous waste sites with subsurface 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 the following:

- *Cost savings.* For a demonstration at the 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.

- *Better characterization.* Since the distribution of contamination is not homogenous at most waste sites, a large number of samples are 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.
- *Significant reduction in the generation of secondary waste during sample collection, analysis and disposal.* At the R-reactor seepage basin demonstration, the number of waste drums was reduced to one compared with seven generated during comparable drilling activities.
- *Reduction in transport issues.* This technology eliminates the need for transportation of hazardous radioactive samples to the laboratory for analysis.
- *Reduction in the risk of human exposure during sample collection, transport, 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. The hazards associated with the containment, disposal, and treatment of secondary waste are also significantly reduced. Data are collected in a more rapid manner thereby reducing the length of worker's exposure to hazardous materials.
- *Faster turnaround.* This technology reduces the turnaround time for sample analysis.
- *Reduced 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.
- *Less costly than 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.
- *Some reduction in 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.
- *Other potential applications.* This technology can be used anywhere to characterize underground gamma radiological contamination 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.

G.11.4 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 an HPGe detector, but it cannot be used for downhole applications because it must be cooled to liquid nitrogen temperatures.

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 (>50 m) 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, which needed significant post-measurement corrections.

Improvements to 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 (approximately 40 atm), operates as an ion chamber and has a detection efficiency slightly less than NaI, but has about five 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 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. 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.

G.11.5 Reference

“Spectral gamma probe, OST/TMS ID 2364, Characterization, Monitoring, and Sensor Technology Crosscutting Program and Subsurface Contaminants Focus Area”, July 2000.
<http://apps.em.doe.gov/ost/pubs/itsrs/itsr2364.pdf>

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Appendix H

Radionuclides Team Contacts, ITRC Fact Sheet, and ITRC Product List

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