FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
FERNALD, OHIO

USER GUIDELINES, MEASUREMENT STRATEGIES, AND OPERATIONAL FACTORS FOR DEPLOYMENT OF *IN-SITU* GAMMA SPECTROMETRY AT THE FERNALD SITE

JULY 1998

U.S. DEPARTMENT OF ENERGY
FERNALD AREA OFFICE

20701-RP-0006
REVISION B

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LIST OF ACRONYMS AND ABBREVIATIONS

A1PI	Area 1 Phase I
A1PII	Area 1 Phase II
A2PI	Area 2 Phase I
ALARA	as low as reasonably achievable
ASL	analytical support level
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CLP	contract laboratory program
cm	centimeter
COC	constituent of concern
CU	certification unit
DOE	US Department of Energy
DQO	data quality objective
EPA	US Environmental Protection Agency
FCS	field quality control station
FEMP	Fernald Environmental Management Project
FRL	final remediation level
ft	feet
g	grams
HPGe	high purity germanium
IRDP	integrated remedial design package
keV	kiloelectron volts
m	meter
MDC	minimum detectable concentration
mph	miles per hour
pCi/g	picocuries per gram
ppm	parts per million
PSP	project specific plan
QA/QC	quality assurance/quality control
Ra	radium

RDQ	remediation data quality
RTRAK	real-time radiation tracking system
SCEP	Soil Characterization and Excavation Project
SCQ	Sitewide CERCLA Quality Assurance Project Plan
sec	second
SEP	Sitewide Excavation Plan
SP5	Soil Pile 5
SW 846	Solid Waste, Tracking No. 846
Th	thorium
U	uranium
UMTRA	Uranium Mill Tailings Remedial Action
USID	uranium in soil integrated demonstration
WAC	waste acceptance criteria
WAP	Waste Acceptance Plan

DEFINITIONS

The definitions given below refer to terms that might not be clear to readers of this manual. Below each definition, the reader is directed to the most important topic (or topics) in the main body of the document to which the defined term applies.

Aggregated Measurements - the number of individual RTRAK measurements that must be averaged in order to meet a specified degree of precision or a specified MDC.

See Also: 4.5 Trigger Levels
4.15 Mapping Conventions

Comparability - Comparability refers to one of five criteria identified by the USEPA to ensure data quality. It is a qualitative expression of the confidence with which one data set can be compared to another. Analytical data generated by the same analytical procedures are comparable provided that relevant, specified quality control elements, such as detection limits, initial and continuing calibration performance, accuracy, precision, and matrix interference acceptance criteria; are met or exceeded. Data for the same analytes generated by different analytical procedures are also comparable provided that relevant QC performance criteria similar to those above are met or exceeded.

See Also: 1.0 Introduction

Coverage (%) - refers to the ratio of the cumulative area of fields of view of a number of measurements (either RTRAK or HPGe) divided by the total surface area of the area under investigation.

See Also: 4.10 HPGe Measurement Grid Configuration
4.3 RTRAK Multiple Measurement Field of View

Data Acquisition Time - synonymous with "count time." The length of time a detector counts the number of gamma photons impinging upon it. HPGe data acquisition times are typically 5 or 15 minutes; RTRAK data acquisition times are typically 2-4 seconds.

See Also: 4.4 HPGe Detector Height and Data Acquisition Time
3.1 Individual HPGe Measurements
3.2 RTRAK Measurements

Data Quality Level - the combined type, number, and degree of rigorousness of specific quality assurance and quality control elements associated with analytical data.

See Also: 2.1 Overview of HPGe and RTRAK Usage

Data Quality Objective (DQO) - qualitative and quantitative statements which specify study objectives, domains, limitations, the most appropriate type of data to collect, and the levels of decision error that will be acceptable for decision-making based upon the data.

See Also: 2.1 Overview of HPGe and RTRAK Usage

DQO Process - a quality management tool based on the scientific method and developed by the US Environmental Protection Agency to facilitate the planning of environmental data collection activities. The DQO Process enables planners to focus their planning efforts by specifying the use of the data (the decision), the decision criteria (action level), and the decision makers' acceptable error rates. The products of the DQO process are the DQOs.

See Also: 2.1 Overview of HPGe and RTRAK Usage

Detector Calibration - The process of calibration converts counts per unit time to pCi/g. At the FEMP, *in-situ* gamma detector calibration uses a geometric integration model to determine these conversion factors at gamma photon energies ranging between 32 and 1408 keV.

See Also: 5.7 Field Quality Control Considerations

Detector Resolution - the ability in a detection device to distinguish between different measurement data. In a gamma spectrometer, detector energy resolution, or simply detector resolution, is expressed as the full peak width in energy units, keV, at half the maximum peak height counts (FWHM) of a spectrum energy peak. On a comparison basis, sodium iodide detectors have a high FWHM (usually 50-60 keV) and poor resolution, while high purity germanium detectors have low FWHM (usually 2-3 keV) and good resolution. As a matter of convention, the resolution of all gamma spectrometers is evaluated at the 1332.5 keV peak of Cobalt-60.

See Also: 5.7 Field Quality Control Considerations

Field of View - the surface area that corresponds to the volume of earth from which 85% to 90% of the detected gamma photons originate.

See Also: 4.1 HPGe Detector Field of View
4.2 RTRAK Single Measurement Field of View

Field Quality Control Station - the field analog of a laboratory control standard that has been adopted to address the influence of environmental factors such as soil moisture, atmospheric temperature and humidity on *in-situ* gamma spectrometry measurements.

See Also: 4.11 Environmental Influences on Gamma Spectrometry Data

Fluence Rate - the number of gamma photons per unit area of soil per unit time impinging upon a detector; can be specified as a function of radial distance from the detector, depth in a soil column, or both. Typical units for this quantity are photons/cm^2 per second.

See Also: 4.1 HPGe Detector Field of View
4.9 Topographic Effects

Gamma Rays, Gamma Photons - electromagnetic radiation emitted as a by-product of alpha or beta decay, whereby a nucleus loses surplus energy as it transitions from a higher excited state (higher energy level) to a lower excited state (lower energy level).

See Also: 4.1 HPGe Detector Field of View

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Heterogeneity - the degree of non-uniformity of radionuclide concentrations in soil within the field of view of a HPGe or RTRAK detector. Heterogeneity must be specified in terms of scale of the non-uniformity (i.e., non-uniform at the 1-inch scale, 1-foot scale, 1-meter scale, 10s of meters scale etc.).

See Also: 5.5 Heterogeneity

High Purity Germanium Detector (HPGe) - the solid state hyperpure germanium crystal used for *in-situ* collection of gamma spectra at specified field locations. This crystal is mounted in a cryostate and connected to an electronics system for signal amplification and analysis.

See Also: 2.1 Overview of HPGe and RTRAK Usage

Minimum Detectable Concentration (MDC) - The MDC is the *a priori* activity concentration that a specific instrument and technique can be expected to detect 95% of the time. When stating the detection capability of an instrument, this value should be used. The MDC is the detection limit L_D multiplied by an appropriate conversion factor to give units of activity concentration (Marssim 1997).

See Also: 5.1 MDCs

Pass - the movement of an RTRAK run in a single, specified direction. RTRAK typically surveys a given area by moving in alternate back and forth passes.

See Also: 4.3 RTRAK Multiple Measurement Field of View

Radiation Scanning System (RSS) - Name given to the NaI gamma photon counting system mounted on a 1.0 manpower, 3-wheeled, modified jogging stroller.

Radiation Tracking (RTRAK) System - Name given to a NaI gamma photon counting system mounted on a tractor that is used at the FEMP.

See Also: 2.1 Overview of HPGe and RTRAK Usage

Remediation - For soils, remediation is the process whereby soil is progressively excavated until residual soil attains a regulatory limit. Thus, soil can be remediated with respect to WAC, with respect to hot spots, or with respect to FRLs.

Representativeness - Expresses the degree to which data accurately and precisely represent a characteristic of a population, a parameter variation at a sampling point, a process condition, or an environmental condition. Data representativeness is a function of sampling strategy; therefore, the sampling scheme should be designed to maximize representativeness.

See Also: 5.5 Heterogeneity

Shine - gamma rays detected by an RTRAK or HPGe detector that originate outside the field of view of that detector.

See Also: 4.12 Shine

Sodium Iodide (NaI) Detector - the scintillation detectors made of NaI that are used for detection and measurement of gamma photons emitted by radioactive decay processes occurring in soil.

See Also: 3.2 RTRAK Measurements

Total Activity - the summation of all of the counts per unit time in a gamma spectrum. Total activity is typically expresed as counts per second and is obtained by dividing the total number of counts by the data acquisition time. Total activity is a parameter used to interpret RTRAK data.

Trigger Level - a specified radionuclide concentration that, if exceeded by a HPGe or RTRAK measurement, provides the basis for some subsequent action to be taken.

See Also: 4.5 Trigger Levels

WAC Exceedance - the waste acceptance criterion for total uranium is 1030 ppm. Soil concentrations of total uranium equal to or exceeding 1030 ppm may not be placed in the on-site disposal facility.

See Also: 4.6 WAC Exceedance Detection
3.4 Excavation of Above-WAC Surface Soil

1.0 INTRODUCTION

This document addresses two basic questions:

1. "How exactly will *in-situ* gamma spectrometry be used at the FEMP?"

2. "How will FEMP personnel handle variables that have a potential impact on *in-situ* gamma spectrometry data?"

The answers to these questions are presented in the form of an extensive user's "help document" for conducting *in-situ* gamma spectrometry at the FEMP.

1.1 BACKGROUND

In 1997, a series of method validation studies pertaining to *in-situ* gamma spectrometry were issued. These studies addressed analytical aspects of *in-situ* gamma spectrometry such as precision, accuracy, detection limits, robustness, comparability with laboratory analytical data, and data quality levels. One report and three addenda concerned High Purity Germanium (HPGe) detectors, and one report and one addendum dealt with the Radiation Tracking System (RTRAK). These reports and addenda are listed below and in Appendix B.

- Comparability of *In-Situ* Gamma Spectrometry and Laboratory Data, July 1997
- Comparability of Total Uranium Data as Measured by *In-Situ* Gamma Spectrometry and Four Laboratory Methods, September 1997 (Addendum #1)
- Comparability of *In-Situ* Gamma Spectrometry and Laboratory Measurements of Radium-226, October 1997 (Addendum #2)
- Effect of Environmental Variables upon *In-Situ* Gamma Spectrometry Data, December 1997 (Addendum #3)
- RTRAK Applicability Study, July 1997
- RTRAK Applicability Measurements in Locations of Elevated Radionuclide Concentrations, September 1997 (Addendum #1)

Questions and comments from the US Environmental Protection Agency (EPA), Ohio EPA (OEPA), US Department of Energy (DOE) personnel and Soil Characterization and Excavation Project (SCEP) personnel have indicated a need to bridge the gap between the primarily analytical information contained in the above reports and programmatic remediation design documents such as the Waste Acceptance Criteria Plan (WAC Plan), the Sitewide Excavation Plan (SEP), and Integrated Remedial

Design Packages(IRDPs). This document bridges that gap by providing user guidelines, data interpretation guidelines, and measurement strategies and approaches; by discussing operational and technical factors that could adversely affect data; and by delineating strengths and limitations of *in-situ* gamma spectrometry. While this document will be beneficial to anyone involved with any aspect of *in-situ* gamma spectrometry, it is primarily aimed toward FEMP project personnel who:

- plan *in-situ* gamma spectrometry data collection;
- collect *in-situ* gamma spectrometry data;
- interpret *in-situ* gamma spectrometry data;
- integrate *in-situ* gamma spectrometry data with other data sets or into engineering designs; and
- make decisions based upon *in-situ* gamma spectrometry data.

The primary users of this manual are intended to be Characterization Leads, PSP Writers, and technical personnel assisting Characterization Leads.

Figure 1.0-1 indicates the relationship between this document (hereafter referred to as the "User's Manual") and other driver documents: analytical, quality assurance, and remediation operations. To summarize Figure 1.0-1, the User's Manual contains information based upon method validation studies that has also been integrated into technical guidelines contained in the SEP. In turn, the overall approach to remediation at the FEMP as delineated in the SEP has been expressed in the form of *in-situ* gamma spectrometry measurement strategies and approaches delineated in the User's Manual. The User's Manual also contains guidance that can be incorporated into area-specific reports such as the IRDPs and certification reports. Finally, the User's Manual contains information that can be placed into PSPs in order to provide direction to field crews. Table 1.0-1 summarizes the types of information contained in the User's Manual. As implied in Figure 1.0-1 and Table 1.0-1, the User's Manual is the key document relative to incorporating *in-situ* gamma spectrometry into routine soil remediation operations.

1.2 MANDATORY VS RECOMMENDED

This manual is not meant to be overly prescriptive. Some of the guidelines and text are recommended-- to be followed or not as the professional judgement and the experience of the user dictates. Some of

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the guidelines and text are to be followed exactly, however. In this regard, the language below specifies whether a particular guidance or section of text is mandatory, recommended, or explanatory.

Shall, Will, Must: These words refer to practices and/or operations that are mandatory. The user is to follow the guidance or text exactly.

Would, Should: These words connote a recommendation to the user on how to proceed or what to do. Flexibility is implicit in these words and professional experience and judgement may suggest alternatives to be followed.

Could, Can Be, May: These words indicate that multiple possibilities exist for a particular practice, operation, or usage. They neither imply mandatoriness nor recommended guidance. Rather, they simply point out to the user that options are present.

Sometimes action verbs direct the user to perform certain operations or practices. The nature of the verb and associated adverbs will denote manditoriness or flexibility. The context of the word "ensure" is dictated by the preceding verbs: "shall" vs. "should," for example.

1.3 <u>OBJECTIVES</u>

Information relevant to carrying out *in-situ* gamma spectrometry measurements at the FEMP is contained not only in the method validation studies listed earlier, but is also derived from the scientific literature, experience of DOE personnel at other DOE institutions, and from the cumulative experience gained at the FEMP by FEMP personnel. Much of this information is discussed in the references listed in Appendix B. Information from these diverse sources has been used to achieve the following User's Manual objectives:

- Translate pertinent analytical information contained in the various method validation studies into "easy to understand" user guidelines.
- Integrate diverse technical information contained in the scientific literature with method validation information and with *in-situ* gamma spectrometry data already acquired in support of soils remediation operations to establish "easy to understand" user guidelines.
- Document "lessons learned" type information based upon the cumulative experience of FDF and DOE personnel attained in carrying out comparability studies, Area 1 Phase I (A1PI) studies, Area 1 Phase II (A1PII) studies, and Area 2 Phase I (A2PI) studies.

- Delineate strengths and limitations of the in-situ gamma spectrometry technique for use in soil remediation.

1.4 REPORT FORMAT

The general format and organization of the User's Manual are loosely patterned after "help" software programs such as those in Excel, Word Perfect, etc. The manual has several sections of related topics; each topic has a stand-alone discussion. As applicable, each topic also has a guidance section which provides rules, suggestions, and "how-to" comments. At the end of the discussion, the reader is directed to other related topics. Additionally, there is a glossary of definitions that directs the reader to various topics.

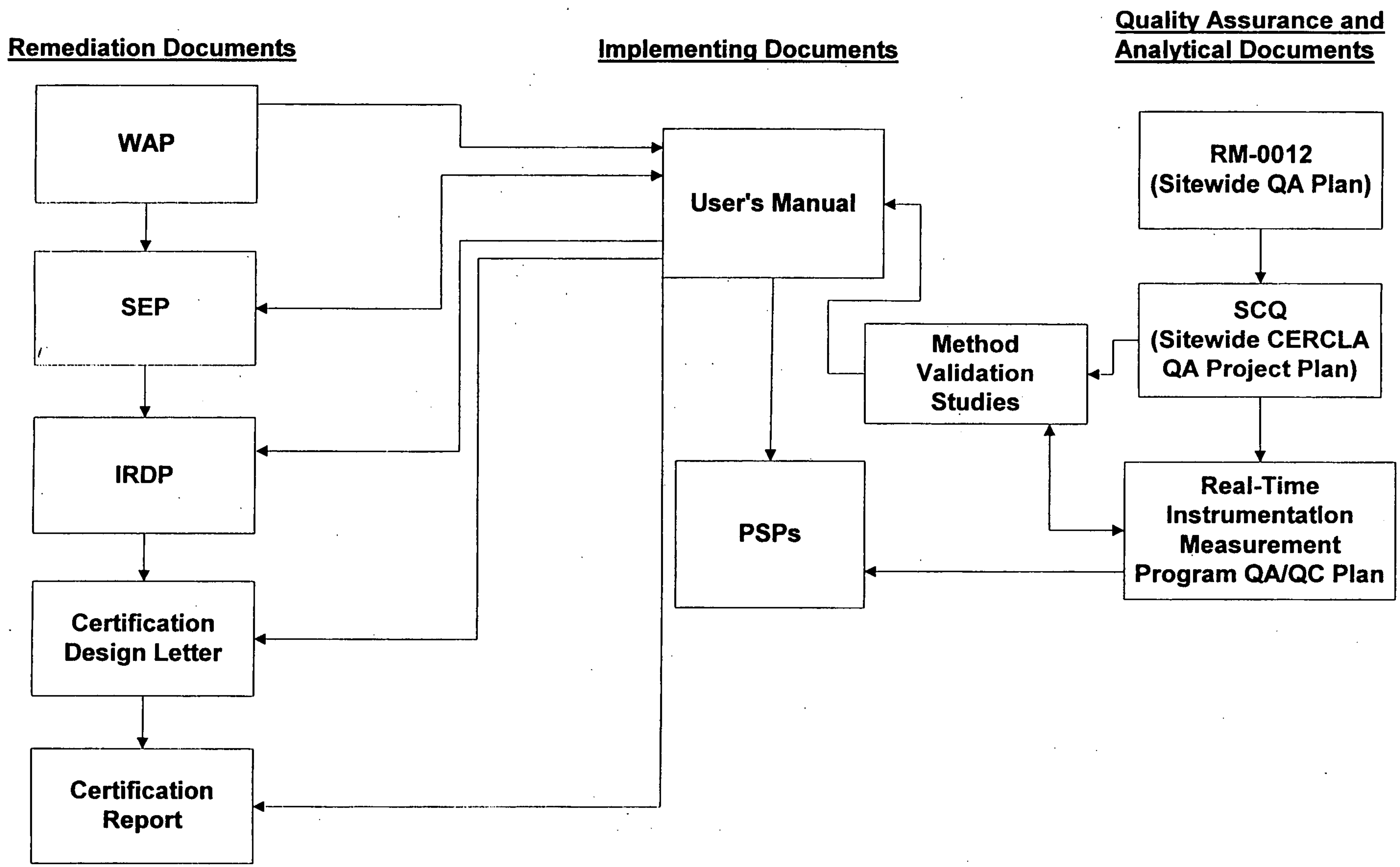
This document is divided into four general categories of topics: investigation approach/measurement strategy topics; measurement approach topics; characterization guidelines, data interpretation guidelines and operational factors topics; and technical topics. Each topic is stand-alone. It has a unique topic identifier number, unique revision number and revision date, and separate numbering scheme for figures and tables. Thus, each topic can be revised independently from the other topics without revising the entire document. Further, new topics can be added to the document without revising it entirely as experience at the FEMP with routine deployment of *in-situ* gamma spectrometry increases.

In addition, the report has two appendices and a glossary. Appendix A contains a list of procedures under which *in-situ* gamma spectrometry data are collected and processed. These include procedures unique to *in-situ* gamma spectrometry as well as relevant SCEP project, Soil and Water Division, and Site procedures. Lastly, Appendix B contains a list of references in the scientific literature, in relevant FEMP publications, and in publications produced by institutions external to the FEMP. The glossary appears before the introductory section (1.0) of the report and directs readers to topics related to a given definition.

TABLE 1.0-1
TYPES OF INFORMATION CONTAINED IN USER'S MANUAL

Type of Information	Information Used in Following Documents
Technical Guidelines	WAC, SEP, IRDP
Measurement Strategies	IRDPs, Certification Report
Measurement Approaches	IRDPs, PSPs, Certification Report
Technical Direction	PSPs
Data Interpretation Guidelines	Pre-Design Investigation Reports, IRDPs, Certification Reports
Factors Potentially Impacting Data	IRDPs, PSPs
Strengths and Limitations	IRDPs, PSPs

FIGURE 1-1
DOCUMENT RELATIONSHIPS



2.0 INVESTIGATION APPROACHES/MEASUREMENT STRATEGIES

The purpose of this section is to provide a general overview of the use of *in-situ* gamma spectrometry to support soil remediation operations, as well as an overview of approaches and measurement strategies to be used for investigations at the FEMP. More detail on general investigation approaches and issues related to individual areas are provided in the SEP. Because this document addresses the use of *in-situ* gamma spectrometry, this section provides little or no discussion of those portions of investigations that are based entirely on other analytical measurement approaches. In particular, no discussion is included related to RCRA issues, such as lead shot in the old Trap Range.

A number of potential uses for HPGe and RTRAK measurements exist in remediation operations at the FEMP. As noted in Figure 2.0-1 (Figure 1-1 of the SEP), these uses fall into four general categories: pre-design activities, soil excavtion and segregation activities, precertification activities, and certification activities. Measurement strategies and investigation approaches for each of these applications are discussed as separate topics in this section.

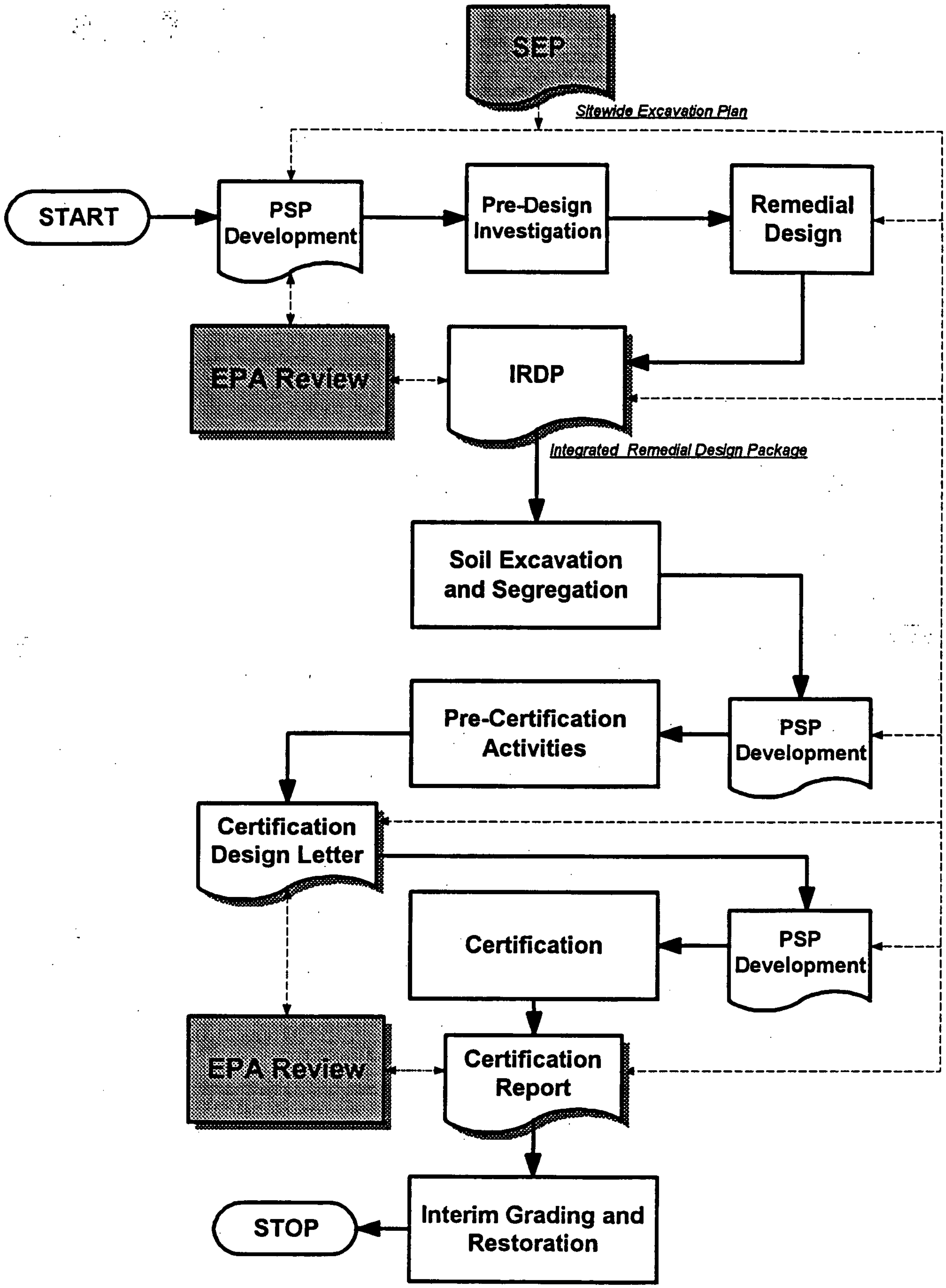


FIGURE 2.0-1 GENERAL AREA-SPECIFIC SOIL REMEDIATION PROCESS

2.1 OVERVIEW OF RTRAK AND HPGe USAGE

Both the HPGe and RTRAK systems perform *in-situ* gamma spectrometry and are used at the FEMP for data collection. However, certain situations and conditions exist which are more favorable for using one system than the other. Similarly, certain soil remediation operations require measurements which can be best provided by one or the other of the two *in-situ* gamma spectrometry systems. In order to decide which piece of equipment is more appropriate, project personnel need to know what the measurement objectives are; for this reason, the data quality objectives (DQO) and associated data quality levels must be completed in advance of actual field work. Tables 2.1-1 and 2.1-2 provide a basic overview of the possible uses of HPGe and RTRAK, and also specify the data quality levels which are likely to be required for these uses. Data quality levels have been taken from those specified for similar data measurement investigations in the A2PI and A1PII IRDPs.

The RTRAK and HPGe systems complement each other. The RTRAK is able to provide rapid, 100% coverage of an area. Its precision and detection limits are sufficient to determine the general patterns of contamination within a given area with respect to total uranium, thorium-232 and radium-226. Its data output is amenable to mapping and spatial averaging. The latter attribute makes RTRAK very useful for determining the average concentrations of soil contaminants. Finally, the RTRAK is ideal as a front-end survey tool to help focus and guide the use of HPGe. Table 2.1-2 contains specific measurement objectives and associated data quality levels for RTRAK. Unlike measurement objectives for HPGe, which may have associated data quality levels of A or B ~~or D~~, all RTRAK measurements have associated data quality levels of A. In practical terms, whether or not RTRAK can accomplish a given measurement objective depends upon whether ~~a sufficient number of measurements can be aggregated to~~ the data acquisition time, speed, and field of view can be optimized to achieve sufficiently low MDCs and system uncertainties to meet the data objectives without compromising necessary spatial resolution of the data ~~to achieve sufficiently low MDCs and system uncertainties to meet the data objectives without compromising necessary spatial resolution of the data~~.

The uses of HPGe reflect its ability to accurately quantify a variety of isotopes; its high degree of energy resolution (which makes interferences less likely), its ability to average data over a large area (wide field of view), thereby minimizing heterogeneity effects associated with sampling discrete points and maximizing data representativeness; and its capability to focus on small areas (delineate hot spot footprints or waste acceptance criteria (WAC) exceedances) by lowering the detector height. These characteristics indicate the HPGe would be useful in providing high quality data for ~~certification/verification~~ support activities to remediate soils for hot spots, WAC exceedances, and FRLs. Additionally, the ability to raise or lower the HPGe detector allows it to be used as a confirmatory tool to evaluate potential hot spot and WAC exceedance areas noted by RTRAK surveys. Table 2.1-1 delineates data quality levels expected to be associated with HPGe measurement objectives and indicates whether HPGe can currently achieve those data quality levels (i.e., can be used for the measurement objectives). **However, measurements requiring ASL D data quality levels do not appear in Table 2.1-1. Regulatory approval to use HPGe for ASL D data quality levels must be obtained separately from the approval of this User's Manual.**

2.1.1 Guidance

- HPGe measurements for total uranium and thorium-232 can be used for any investigation requiring data quality levels A or B.
- HPGe measurements for radium-226 can be used for any investigation requiring data quality levels A or B provided the measurements are corrected as explained in the "radium-226 correction" topic.
- For environmental decisions to be reviewed by the regulators, RTRAK data shall only be used for investigations requiring ASL A data quality levels. (It can be used at DOE's risk for any other investigation .)
- ~~HPGe measurements may also be used for gamma emitters that are secondary COCs, such as cesium-137. In certain situations, HPGe measurements may be used to detect thorium-230. Consult with the In-Situ Gamma Spectrometry Group in this regard.~~

2.1.2 See Also

2.2 Predesign Investigations

2.4 Precertification Investigations

~~2.5 Certification~~

3.1 Individual HPGe Measurements

3.2 RTRAK Measurements

3.3 Hot Spot Evaluations

3.4 Evaluation of Above-WAC Surface Soil

3.6 Horizontal Excavation Boundary Delineation

~~3.7 Certification Measurements~~

5.6 Strengths and Limitations

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TABLE 2.1-1
UTILIZATION OF HPGe AS A FUNCTION OF DATA QUALITY LEVEL

Possible HPGe Usage	Analyte	ASL*	Does HPGe meet ASL Criteria for Usage?
Pre-Design Investigations			
Develop a general sense of contamination patterns	Total U, Th-232, Ra-226	A	yes
Identify WAC exceedance areas	Total U	A	yes
Delineate excavation footprint of above-WAC soil	Total U	B	yes
Determine the excavation extent of below WAC (for total U) but above FRL material and determine excavation boundaries for FRL attainment, taking ALARA into consideration.	Total U, Th-232, Ra-226	B	yes
Evaluate whether soil is suitable for re-use (below FRLs)	Total U, Th-232, Ra-226	B	yes
Soil Excavation and Segregation			
Excavation of Above WAC Soil			
Verify horizontal extent of above-WAC material as identified by RTRAK as excavation proceeds	Total U	B	yes
Identify potential additional above-WAC material exposed during excavation in situations where RTRAK cannot be used	Total U	A	yes
Verify presence of above WAC material identified by RTRAK on design-based floor of excavation	Total U	B	yes
Scan design-based floor of excavation for above-WAC and above FRL material in situations where RTRAK cannot be used	Total U	A	yes

*There are no specific QC requirements for ASL A in the SCQ.

TABLE 2.1-1
(continued)

Possible HPGe Usage	Analyte	ASL*	Does HPGe meet ASL Criteria for Usage?
Below WAC - Above FRL Excavation			
Verify presence of potentially above-WAC material identified by RTRAK during excavation	Total U	A	yes
Scan lift surfaces exposed during excavation for above-WAC and above FRL material in situations where RTRAK cannot be used	Total U	A	yes
Precertification			
Confirm and evaluate potential residual hot spots identified by RTRAK	Total U, Th-232, Ra-226	B	yes
Verify residual soils no longer exceed hot spot criteria after pre-certification excavation	Total U, Th-232, Ra-226	B	yes
Verify that average activity of total U, Th-232, and Ra-226 are below FRLs where the FRL for total U is 20 ppm or less	Total U, Th-232, Ra-226	B	yes
Verify if areas identified by RTRAK as potentially exceeding FRLs actually do exceed FRLs	Total U, Th-232, Ra-226	B	yes
Certification			
Delineate size of hot spot area and determine average concentration	Total U, Th-232, Ra-226	B	yes
Delineate size of FRL exceedance area if certification unit fails certification	Total U, Th-232, Ra-226	B	yes

* There are no specific QC requirements for ASL A in the SCQ.

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TABLE 2.1-2
UTILIZATION OF RTRAK

RTRAK Measurement Objective	Analyte	ASL*	Can RTRAK Achieve Measurement Objective?
Pre-Design Investigations			
Develop a general sense of contamination patterns and radioactivity patterns	Total Activity, Total U, Th-232, Ra-226	A	Yes. Total activity can distinguish between low and high levels of contamination. Total activity can not discriminate between isotopic differences.
Identify potential WAC exceedance areas	Total Activity, Total U	A	Yes for Total U. Total activity should be confirmed by other measurement approaches
Determine the preliminary excavation extent of above FRL but below WAC (for total U) excavation boundaries, taking ALARA into consideration	Total U, Th-232, Ra-226	A	No for total U when FRLs are 10 or 20 ppm Yes when FRL is 82 ppm
Soil Excavation and Segregation			
Excavation of Above WAC Soil			
Assess horizontal and vertical removal of above WAC material as excavation proceeds	Total Activity, Total U	A	yes
Survey design-based floor of excavation to identify potential above WAC areas	Total Activity, Total U	A	yes
Below WAC - Above FRL Excavation			
Scan lift surfaces exposed during excavation for above-WAC material	Total Activity, Total U	A	yes

*There are no specific QC requirements for ASL A in the SCQ.

TABLE 2.1-2
(continued)

RTRAK Measurement Objective	Analyte	ASL*	Can RTRAK Achieve Measurement Objective?
Precertification			
Evaluate patterns of residual radioactivity on design-based excavation floor	Total Activity, Total U, Th-232, Ra-226	A	Yes, to delineate high areas from low areas, but more subtle differences may not be resolvable.
Determine average concentration for certification unit	Total U, Th-232, Ra-226	A	Yes
Identify potential hot spots in residual soils	Total U, Th-232, Ra-226	A	Yes, but total U cannot be used to identify hot spots for FRLs of 10 or 20 ppm

* There are no specific QC requirements for ASL A in the SCQ.

2.2 PRE-DESIGN INVESTIGATIONS

In many remediation areas, data generated from RI activities are not sufficiently comprehensive to prepare detailed engineering designs and excavation drawings; therefore, additional radiological surveys and sampling programs must be implemented to collect additional needed data. Real-time, field-deployable instruments have the capability to satisfy a major portion of these additional data needs, and their use will be integrated with discrete sampling and subsequent laboratory analysis to maintain quality in the remediation process.

The purpose of investigations carried out during pre-engineering design activities is to provide information on the extent of soil contaminated above FRL levels or above the ALARA goal of 50 ppm total uranium, to provide information needed for area excavation design (establish horizontal and vertical excavation boundaries) and to delineate the extent of soil contaminated with uranium above 1030 ppm, and to supply data needed to ensure compliance with the WAC for the On-Site Disposal Facility. The overall pre-design investigation approach strategy is to combine pre-existing soil characterization data from surface physical samples with supplemental data generated from *in-situ* gamma spectrometry measurements and with the laboratory analysis of soil borings at depth to establish three-dimensional boundaries of soil contaminated above FRL or WAC levels. Figure 2.2-1 (Figure 3-2 of the SEP) summarizes the general pre-design investigation process.

2.2.1 <u>Guidance</u>

- Use RTRAK (where terrain permits) preferentially to establish general patterns of contamination, to identify potential hot spots and WAC exceedance areas, and to determine above FRL but below WAC excavation boundaries.

- Use HPGe preferentially to delineate excavation footprints, to determine boundaries for FRL attainment, and to determine if soil is potentially suitable for reuse.

2.2.2 See Also:

2.1 Overview of RTRAK and HPGe Usage

3.4 Evaluation of Above-WAC Surface Soil

3.6 Horizontal Excavation Boundary Delineation

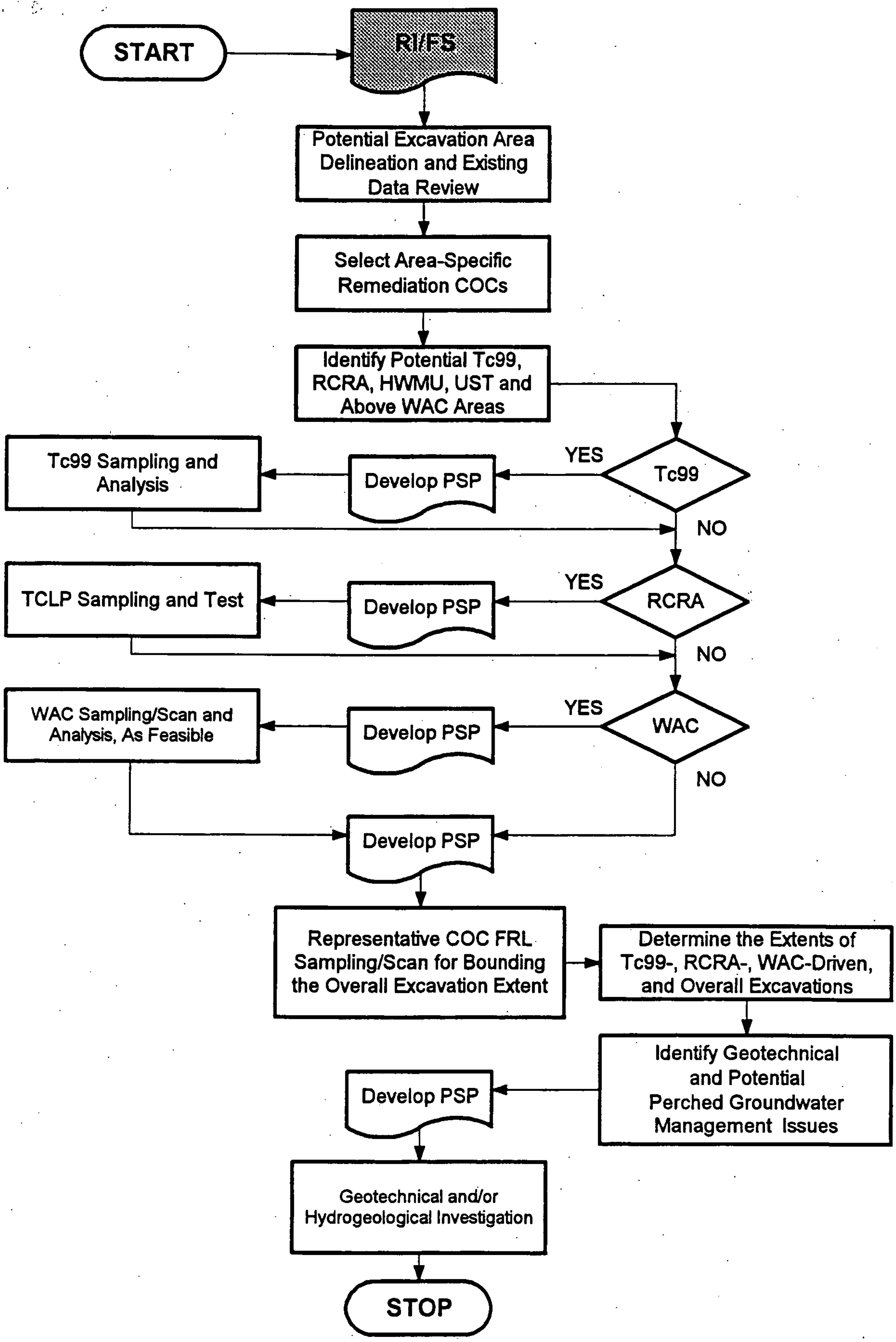

FIGURE 2.2-1 GENERAL PRE-DESIGN INVESTIGATION PROCESS

2.3 SOIL EXCAVATION AND SEGREGATION

In the remediation process, a number of different drivers control soil excavation. The soil excavation hierarchy as related to potential uses of *in-situ* gamma spectrometry is given in Figure 2.3-1 (Figure 3.4 of the SEP); the types of excavations are listed below:

- Site preparation
- WAC-driven excavation
- FRL-driven excavation
- ALARA-driven excavation

The overall analytical objective for excavation control is to provide real-time data on exposed excavation surfaces to construction personnel during the excavation process so that "dig/no dig" decisions can be made with minimal delay. *In-situ* gamma spectrometry is the primary instrument to supply this type of data for primary radionuclides.

2.3.1 Guidance

- Use RTRAK to scan exposed lift surfaces for large areas (> 0.25 acre).
- Use HPGe to scan exposed lift surfaces for small areas (< 0.25 acre) or in terrain in which RTRAK cannot operate, such as steeply sloped surfaces and trenches.
- Use HPGe for all measurements requiring verification of previously acquired data or verification of hot spot/WAC exceedance removal.

2.3.2 See Also:

2.1 Overview of RTRAK and HPGe Usage

3.5 Excavation Control For Lifts

3.6 Horizontal Excavation Boundary Delineation

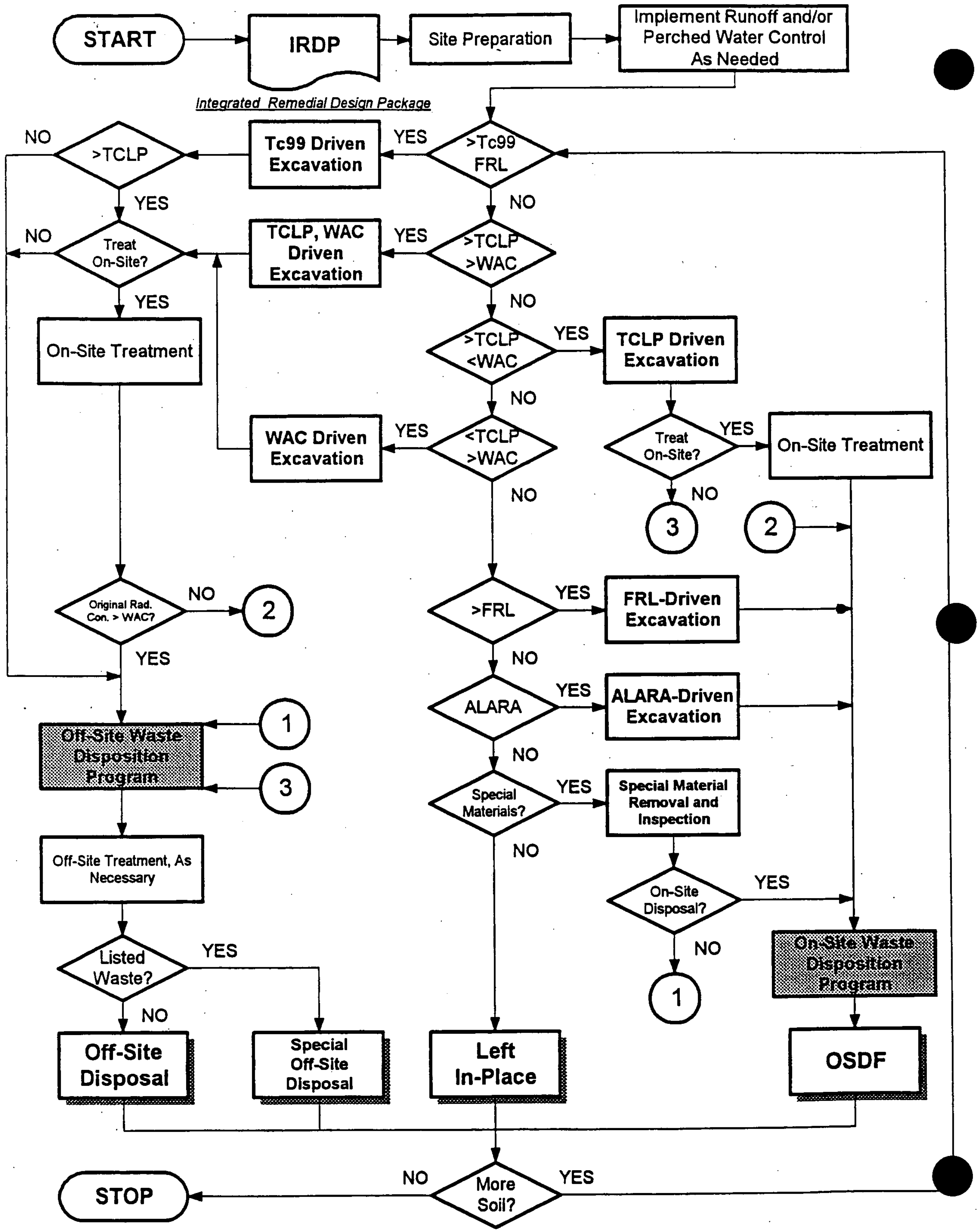

FIGURE 2.3-1 GENERAL SOIL SEGREGATION/DISPOSAL PROCESS

2.4 PRECERTIFICATION INVESTIGATIONS

The purpose of precertification is to ensure that an area is ready for certification. Therefore, measurements must be performed to delineate areas where further excavation is needed due to the average activity of primary radionuclides exceeding FRLs as well as to identify potential hot spots in residual soils. The investigation strategy for precertification measurements is to perform a complete survey of the area, generally with the RTRAK. Physical sampling may also be required if contaminants other than the primary radiological COCs determine excavation extent. On the basis of the complete survey, the general level of radiological contamination can be determined and the need for any additional remediation established. If the general level of contamination is below the FRLs for the primary radiological contaminants, the results of the RTRAK survey should be reviewed to determine if radiological hot spots are potentially present. If potential hot spots are detected, they need to be confirmed and delineated with HPGe, then removed, and surveyed again with the HPGe. Once hot spots are addressed, the overall area should be divided into certification units and the average concentrations of the primary radiological contaminants determined for each certification unit using the RTRAK results for the area. If on the basis of the RTRAK survey results, a certification unit appears likely to meet requirements for certification, the certification units should proceed through the certification process. If a CU appears unlikely to meet requirements for certification, further remediation, and/or redefinition of the CU is needed. Where FRLs for total uranium are 10 or 20 ppm, HPGe should be used to perform the area survey. Figure 2.4-1 (Figure 3-6 of the SEP) summarizes general precertification activities.

2.4.1 Guidance

- Use RTRAK (where terrain allows) preferentially to provide a general survey of the excavation floor.

- Use HPGe to provide general survey information (see Topic 4.10) where total uranium FRLs are 10 or 20 ppm.

- Use HPGe for situations in which confirmation and/or verification data are required.

2.4.2 See Also:

2.1 Overview of RTRAK and HPGe Usage

3.2 RTRAK Measurements

3.3 Hot Spot Evaluation

4.15 Mapping Conventions

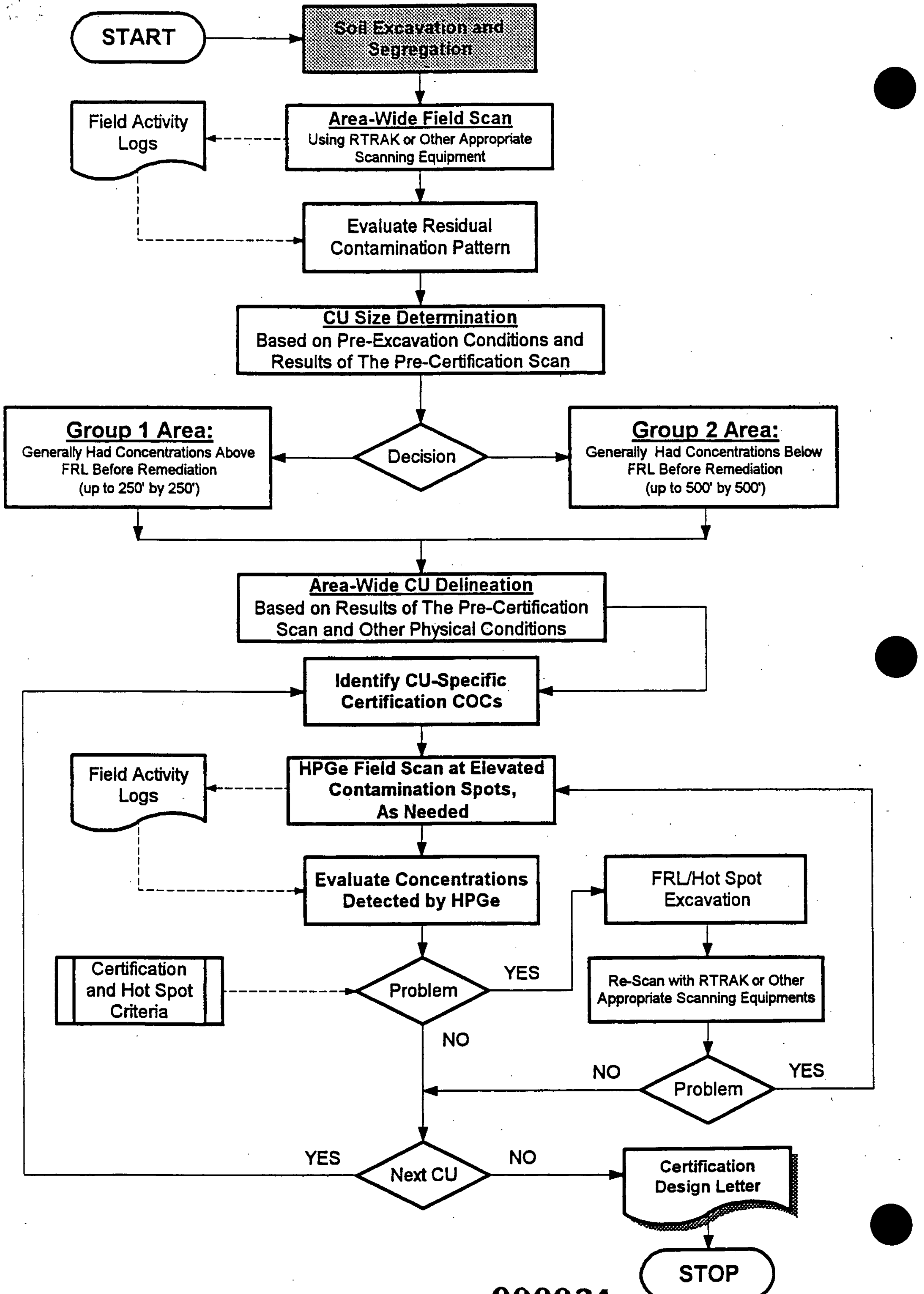

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FIGURE 2.4-1 GENERAL PRE-CERTIFICATION ACTIVITIES

2.5 CERTIFICATION

Certification consists of demonstrating for a certification unit (CU) that the residual concentrations of contaminants are below their FRLs and that no hot spots are present. Residual concentrations of a given radionuclide are determined to be below FRLs when the upper 95% confidence interval of the mean of the residual concentrations is below that radionuclide's FRL. Figures 2.5-1 and 2.5-2 (Figures 3-9 and 3-10 of the SEP) illustrate the general certification process. Confidence intervals for a certification unit are determined using 12 to 16 samples collected randomly in the certification unit. In principle, samples may be collected using either conventional methods (physical sampling and laboratory analysis) or using the HPGe instrument (*in-situ* measurement). The procedure for determining sampling locations is described in Section 3.4.2.1 of the SEP. Twelve to 16 physical samples or HPGe measurements is an adequate sample size given the expected low degree of variability in soil concentrations of contaminants following remediation. If a certification unit fails certification because the variability in sample results is too high (i.e., upper 95% confidence interval exceeds the FRL), even though the average concentrations of all contaminants are below FRLs, additional samples can be added. If the average is elevated or all or portions of the certification unit have elevated concentrations, the certification unit should be remediated further or certification unit boundaries should be revised to allow remediation to be better focused on areas with elevated levels of contamination. Details on approaches to addressing certification failures are provided in the SEP.

Hot spots generally will be addressed during precertification. However, if certification samples (either physical samples or HPGe measurements) indicate the presence of hot spots (concentrations of primary COCs at least twice the FRLs), the hot spots will be delineated (User's Manual, Section 3.3.3) and removed, and the area of the hot spots sampled again (by either physical samples or HPGe measurement).

The HPGe instrument is well suited for use in certification. It provides reproducible measurements of the primary COCs with a low degree of uncertainty. HPGe has low MDCs, and this can provide reliable data even for very low concentrations of radionuclides. HPGe measurements show good comparability with results obtained using conventional methods for uranium and thorium and for radium when empirical correction factors are used to compensate for radon disequilibrium in soil and for radon accumulation near soil surfaces. But most importantly, the *in-situ* technique provides a better average over a CU for a given number of measurements than will the same number of physical samples. This is because HPGe measures a large area within the field of view, while physical samples basically represent very small areas and soil volumes. This advantage has been demonstrated in two reports: 1) Comparability of *In-Situ* Gamma Spectrometry and Laboratory Data (DOE 1998a) and 2) Comparability of *In-Situ* Gamma Spectrometry and Laboratory Data and Decisions for Certification Units (DOE 1998b).

Both physical sample analyses and HPGe measurements shall be carried out under ASL D data quality levels as specified in the SCQ. The QA and QC program as well as ASL D specifications are detailed in the *In-Situ* Gamma Spectrometry Addendum to the SCQ (DOE 1998c).

2.5.1 Guidance

- All certification measurements performed with HPGe will be made at ASL D data quality levels. *In-situ* gamma spectrometry personnel must ensure that each detector used for ASL D measurements complies with all of the QC criteria for ASL D listed in procedure ADM-16, "*In-Situ* Gamma Spectrometry Quality Control Measurements," and also given in the *In-Situ* Gamma Spectrometry Addendum to the SCQ (DOE 1998).

- At least 10% of all ASL D data will have to be validated. Project personnel and *in-situ* gamma spectrometry personnel should check the ASL D validation checklist for data validation requirements.

- RTRAK measurements will not be used as the basis for certification of remediated areas, but will be extensively used in pre-certification measurements for hot spot detection and assessment of CU heterogeneity.

2.5.2 See Also:

2.1 Overview of RTRAK and HPGe Usage
2.4 Precertification Investigations
3.1 Individual HPGe Measurements
3.3 Hot Spot Evaluation
3.7 Certification Measurements

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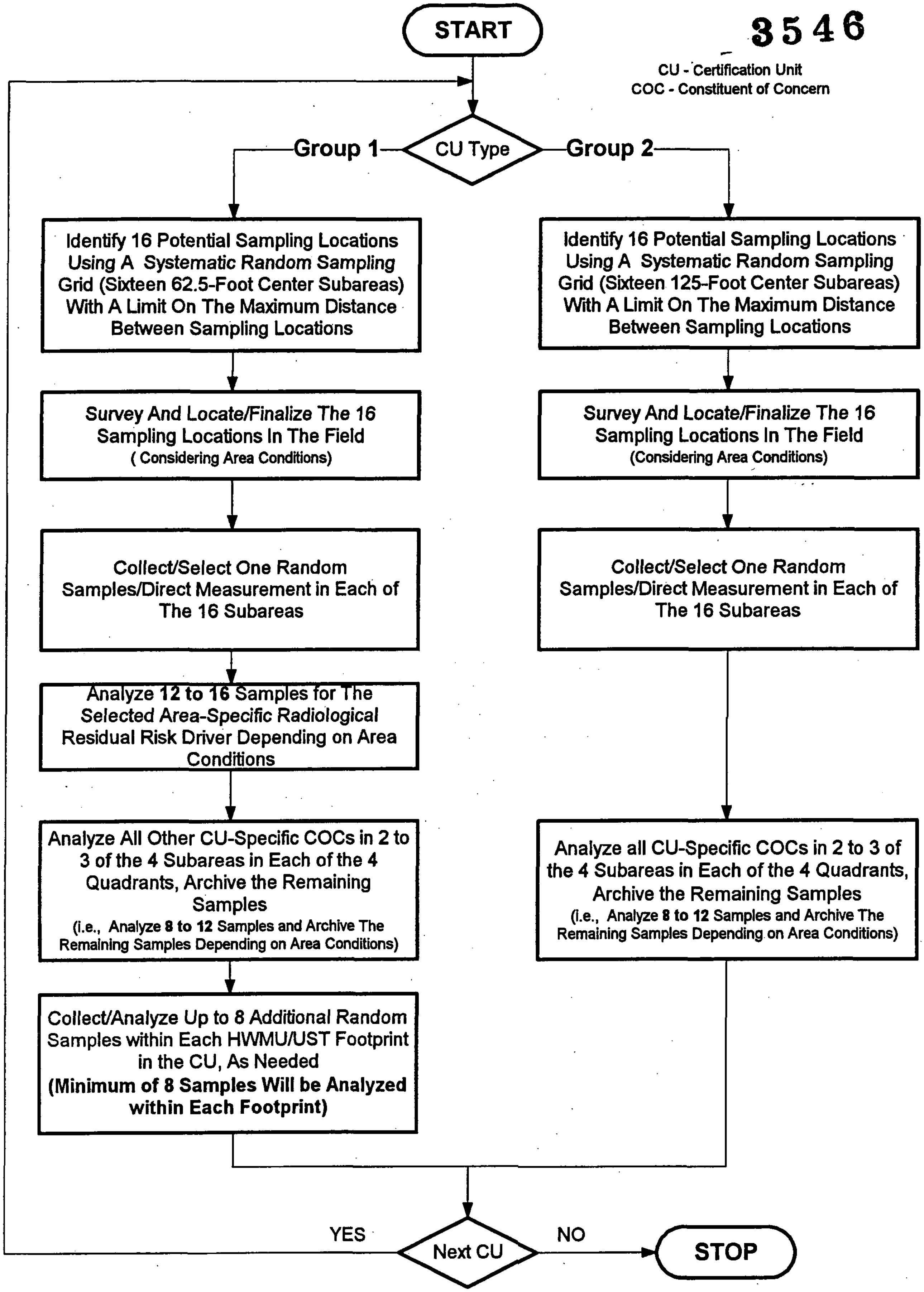

FIGURE 2.5-1 GENERAL CERTIFICATION SAMPLING STRATEGY

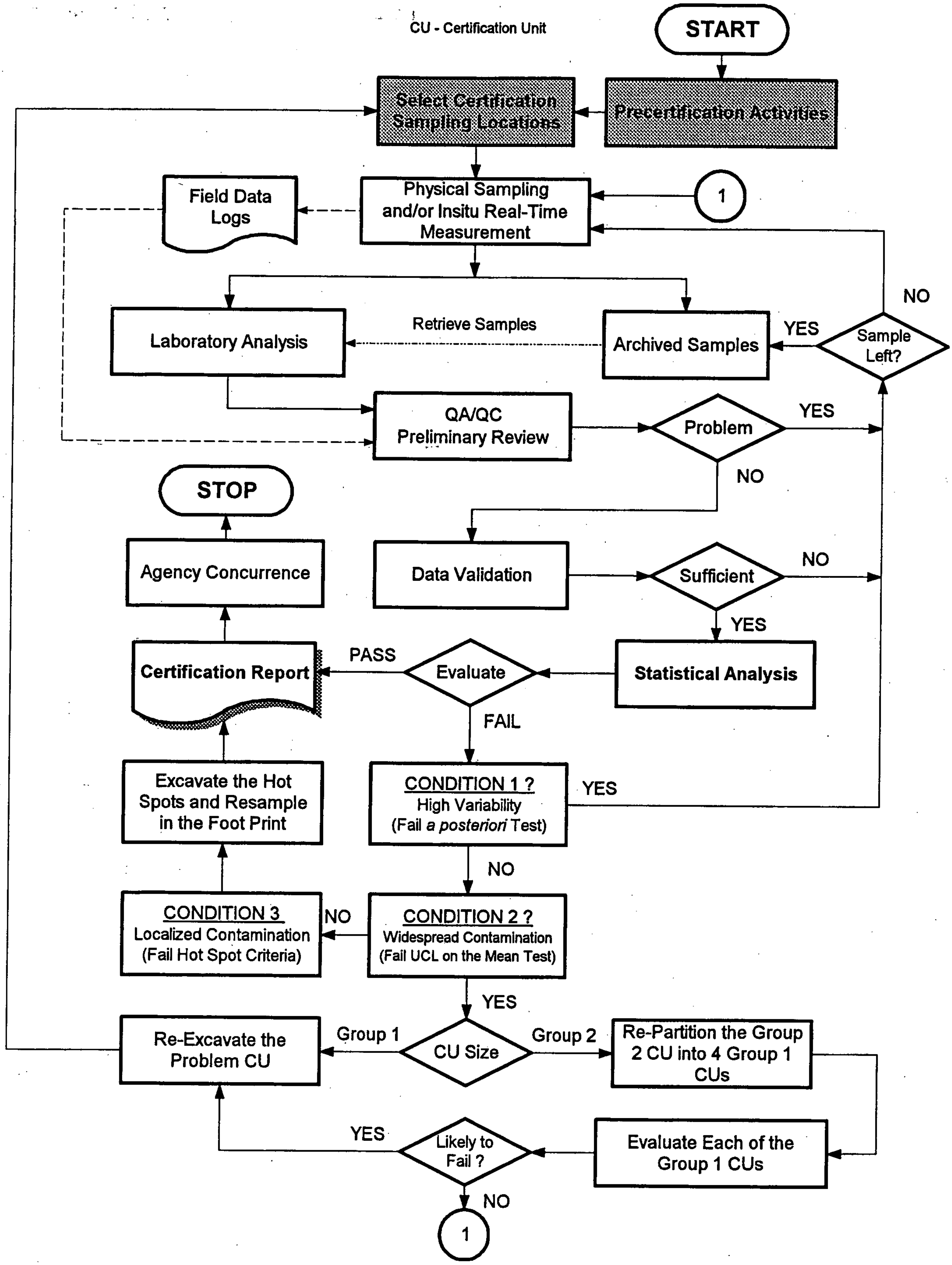

FIGURE 2.5-2 GENERAL CERTIFICATION PROCEDURE

3.0 MEASUREMENT APPROACHES

The purpose of this section is to describe the general approaches to be used for meeting specific measurement objectives. A series of measurements can be combined to carry out an activity such as certification. The strategies for certification and other activities are discussed under the "Investigation Approaches/Measurement Strategies" topic and in the SEP. Area-specific issues are discussed in the SEP and the relevant IRDPs as needed. Details on specific approaches are also provided in area-specific and activity-specific PSPs.

3.1 INDIVIDUAL HPGe MEASUREMENTS

HPGe measurements may be used for pre-certification purposes, for checking levels of contamination in an area (for excavation control, for example), for confirming other measurements, or for delineating areas that have contamination levels above FRLs, hot-spot criteria, or WAC. To achieve those measurement objectives, the HPGe instrument measures total uranium, radium-226 (with corrections as described in Section 5.3), and thorium-232 (and by assuming secular equilibrium with thorium-232, thorium-228 and radium-228 concentrations can also be inferred). Table 3.1-1 shows the gamma rays that are measured to detect and quantify concentrations of radionuclides. The general approach to all measurements is the same. Individual HPGe measurements are usually part of a program of multiple measurements carried out to achieve some objective. Some of these measurement programs are described in other topics, for example, hot-spot evaluation.

The user has control over four factors that affect HPGe measurements: the measurement location, detector height, data acquisition time, and the time of day and year of the measurement. Measurement location is determined by the context in which the measurement is made. ~~For certification, it will be specified in the Certification Design Letter.~~ For the delineation of contaminated areas, it will be determined using approaches discussed under "Hot-Spot Evaluation," "Evaluation of Above-WAC Surface Soil," and "Horizontal Excavation Boundary Delineation." Detector height is typically one meter; however, lower heights (31 cm and 15 cm) may be used, as necessary, for confirmation or delineation activities, as is discussed under "Hot-Spot Evaluation," "Evaluation of Above-WAC Surface Soil," and "Horizontal Excavation Boundary Delineation." Typical data acquisition time is 15 minutes, although shorter (5-minute) data acquisition times are sufficient for certain types of measurements such as those that provide information on WAC exceedances. The time of day or year of the measurement may affect results due to diurnal (radon-222 disequilibrium in soil, for example) or annual changes in environmental conditions (snow, rain, for example).

3.1.1 Guidance

- Project personnel must specify a data quality level for HPGe measurements.
- Ensure that all QC requirements specified in ADM-16, "*In-Situ* Gamma Spectrometry Quality Control Measurements," are met for the data quality level required for the measurement.
- Detector height and data acquisition time must be specified in PSPs

- Detector height and data acquisition time are a function of particular data objectives. Refer to Section 3.3 for detector height and data acquisition time relevant to hot spot measurements; refer to Section 3.4 for detector height and data acquisition times pertaining to evaluation of above-WAC surface soils; refer to Section 3.6 for detector height and data acquisition times for horizontal excavation boundary delineation; finally, refer to Sections 4.5, 4.10, and 5.1 for detector heights and/or data acquisition times related to trigger levels, measurement grid configurations, minimum detectable concentrations, and Section 5.4 for detector heights related to heterogeneities.

3.1.2 <u>See Also</u>:

2.1 Overview of HPGe and RTRAK Usage

4.1 HPGe Detector Field of View

4.4 HPGe Detector Height and Data Acquisition Time

4.5 Trigger Levels

4.9 Topographic Effects

4.10 HPGe Measurement Grid Configurations

4.11 Environmental Influences on *In-Situ* Gamma Spectrometry Data

4.12 Shine

4.13 Time Required for *In-Situ* Gamma Spectrometry Measurements

4.14 Seasonal Precautions

5.1 MDCs

5.2 Moisture Corrected Data

5.3 Radium-226 Corrections

5.4 Heterogeneity

5.7 Field Quality Control Considerations

5.8 Positioning and Surveying

TABLE 3.1-1
GAMMA PHOTONS USED IN HPGe MEASUREMENTS TO QUANTIFY U-238, TH-232, AND RA-226

Analyte Radionuclide	Radionuclide of Emission	Gamma Photon Energy (keV)	Gamma Photon Abundance (%)
U-238	Th-234	63.2	3.9
	Th-234	92.6	5.41
	Pa-234m	1001.0	0.845
Th-232**	Pb-212	238.6	45.0
	Tl-208	583.1	30.6*
	Ac-228	911.1	29.0
Ra-226	Pb-214	351.9	35.0
	Bi-214	609.3	43.0
	Bi-214	1120.4	17.0

* Includes 0.359 branching ratio from decay of Bi-212.

** The radionuclides of emission for determining thorium-232 are similar to those specified for gamma spectrometry analysis of thorium-232 physical samples by analytical laboratories with one exception. The gamma photon at 969.1 keV from actinium-228 is also specified for use in physical samples. Exclusion of actinium-228 (969.1 keV) leads to a result slightly higher (hence, slightly more conservative) than if that radionuclide of emission were incorporated. A weighted average thorium-232 concentration is calculated where the weighting factor is the inverse of the square of the counting error--exactly as specified for gamma spectrometry of physical samples.

3.2 RTRAK AND RSS MEASUREMENTS

3.2.1 RTRAK MEASUREMENTS

Assuming areas are accessible to the RTRAK system, results obtained with the RTRAK can be used to provide complete coverage to support pre-design investigations, excavation control for horizontal surfaces, and precertification activities. The instrument can be used to measure total uranium, radium-226 , thorium-232, and gross activity. Gamma photons used to detect and quantify these analytes are shown in Table 3.2-1. RTRAK can be used in a mobile mode to provide essentially complete coverage of an area or in a static mode to provide results for a particular location. For virtually all applications, however, it is used in the mobile mode.

The user has control over five factors that affect RTRAK measurements in the mobile mode: path followed, data acquisition time, speed, the degree of overlap between adjacent passes, and the time of day and year the measurements are made. For all RTRAK applications, the detector height is fixed at 1.0 ft (31 cm) above the ground. For the mobile mode, data acquisition time and speed are typically 4 seconds and 1 mph. Overlap is typically 0.4 m (between adjacent passes, Figure 4.3-2). The path to be followed will be specified in general terms in the appropriate PSP considering the nature of the area to be surveyed and the application, but generally the path will consist of alternate back and forth passes. The time of day and time of year during which measurements are made may affect results due to changes in environmental conditions.

~~Both thorium-232 and radium-226 emit gamma photons which interfere with the detection of gamma photons for the quantification of uranium-238. However, these interferences are compensated for in the uranium calibration equation (RTRAK Applicability Study, April 1998). Above 120 ppm of total uranium, any interference effects of thorium-232 and radium-226 on measured concentrations of total uranium are likely to be negligible. Below 50 ppm total uranium, interference effects of thorium-232 and radium-226 or measured concentrations of total uranium may be appreciable. However, whether the effect leads to falsely higher concentrations, or falsely lower concentrations, cannot be predicted.~~ The RTRAK system uses a NaI detector which has poor energy resolution in comparison to the germanium detectors typically used for gamma spectrometry. Consequently, it is not possible to readily separate peaks that are close to one another, and gamma photons with energies near those of analytes of interest can result in interferences that affect the validity of an RTRAK result. All three analytes of interest for RTRAK applications (uranium-238, thorium-232, and radium-226) can be affected by interfering gamma rays. The regions of interest for both the peaks and the backgrounds have been selected to minimize the interferences, and the calibration methodology attempts to take the interferences into account by utilizing multiple linear regression equations. However, when the activity of one or more of these analytes is significantly higher than the others, the interferences can be such that the results for the others will be inaccurate, irrespective of the compensating factors embodied in the calibration equations. The nature of gamma photon interferences are summarized in Table 3.2-2 for thorium-232, radium-226, and uranium-238.

3.2.2 RSS MEASUREMENTS

Some areas of the FEMP site cannot be accessed and measured with the RTRAK vehicle because of its size. To access such areas, a 4-inch by 4-inch by 16-inch NaI detector, signal processing electronic modules, and computer-based multichannel pulse height analysis system have been mounted on a 3-wheeled jogging stroller. All of this equipment, including the stroller, is collectively called RSS (Radiation Scanning System).

The RSS, coupled to a GPS, is pushed by hand. Portability is achieved by using a very compact, battery-operated, gamma spectrometry system called DART™ (the signal processing electronic modules referred to above) connected to a portable laptop computer loaded with a multichannel analyzer emulator and a spectrum acquisition program.

Aside from the size of the RSS jogging stroller compared to that of the RTRAK tractor, two major differences exist between the two systems. First, the RSS computer and electronics are not in an enclosed, air-conditioned cab like they are in the RTRAK. Second, in RSS, the long axis of the NaI detector is parallel to the direction of motion, whereas in the RTRAK, the long axis of the NaI detector is perpendicular to the direction of motion.

The RSS was calibrated in the same manner as the RTRAK system, that is by collecting HPGe and static sodium gamma spectra (for both RSS and RTRAK) at identical locations. Multiple linear regression analyses were performed to derive a numerical relationship between HPGe isotopic results (used as the known isotopic soil radionuclide concentrations) and isotopic net count rates derived from the RSS gamma ray spectra. These calibration equations were then verified by comparing mobile RSS results to mobile RTRAK results in repeated profile runs in the USID area and in the Drum Baling Area. These mobile calibration verification tests showed acceptable agreement between RTRAK and RSS measured concentrations. These repeated profile runs also demonstrated that the precision of the RSS system was comparable to that of the RTRAK. This conclusion was derived by splitting the repeat profile paths into smaller segments and comparing the standard deviations of RTRAK and RSS measurements within each of these segments. These comparisons were performed for each isotope measured by RTRAK and RSS. Documentation for the calibration equations appears in Revision 1.0 (1998) of the RTRAK Applicability Study.

Data acquired during the calibration of RSS indicate that the field of view of RSS is similar to that of RTRAK. This is not surprising as the dimensions of the detector crystal are identical and since the detectors are suspended 31 cm above the ground surface in both systems. Thus, all guidance and information pertaining to the field of view for RTRAK is valid for RSS as well.

3.2.2.1 Operating Conditions

Standard operating conditions of RSS are similar to those of RTRAK. These include a forward motion of approximately 1.0 mph, with a 0.4 meter overlap, a 4-second data acquisition time, and the detector suspended 31 cm from the ground. The path to be followed will be specified in general terms in the PSP considering the nature of the area to be measured, but generally will consist of alternating back and forth passes. Additional details of RSS operation are contained in procedure EQT-34 (refer to Appendix A of this report).

3.2.2.2 RSS Strengths

The strengths of RSS listed here are relative to RTRAK. Generic (or global) strengths of a mobile NaI detector system are given in Section 5.6, "Strengths and Limitations of In-Situ Gamma Spectrometry."

- RSS can make measurements in wooded terrains, sloping terrains (slopes greater than 0.5 to 1.0), and uneven terrains where RTRAK cannot maneuver.
- RSS can make measurements on wetter soils without sinking in because of its considerably lighter weight.
- RSS is inherently more maneuverable and can easily make a very dense grid of overlapping measurements over a small area to help delineate boundaries.
- The potential exists with RSS, because of ease of maneuverability and operability, to stop over suspect areas to augment moving measurements with stationery measurements at longer count times. Longer count times should improve both precision and accuracy of the individual stationary measurement.
- RSS is easier to mobilize and demobilize, thereby increasing cost effectiveness and productivity. This is a consideration for small areas (< 0.25 acre).
- RSS is potentially easier to decontaminate; thus moving it between contaminated areas should be simpler and faster.
- RSS is low maintenance and requires no fuel.

3.2.2.3 RSS Limitations

The limitations of RSS listed here are relative to RTRAK. Generic (or global) limitations of a mobile NaI detector system are given in Section 5.6, "Strengths and Limitations of In-Situ Gamma Spectrometry."

- RSS is more difficult to push at a constant and predetermined speed.
- Because the electronics and computer are not enclosed in an air-conditioned cab, RSS electronics may be more susceptible to temperature effects than RTRAK electronics. High temperatures may create problems with computer operations, thereby affecting data acquisition, manipulation, and storage.
- RTRAK is more practical than RSS for large, flat areas.
- RSS may not be practical in areas with high grass.

3.2.3 Guidance

- For general survey applications, use RTRAK wherever the areal extent of soil to be surveyed is greater than 0.25 acres. Use RSS or HPGe whenever the areal extent is less than 0.25 acre.

- For certain data usages, such as WAC exceedance detection, individual measurements should be used. For other applications, such as FRL attainment, individual measurements must be aggregated. (The process of combining a number of measurements to yield an average value). Be sure that a sufficient number of measurements are aggregated to provide acceptable MDCs (Table 5.1-3) and precision for the data usage.

- Total activity data are easy to obtain quickly since they do not require processing of gamma photon spectra and can be mapped very quickly. However, these data are more difficult to interpret and can mask real differences in spatial variations of individual radionuclides. Consult the " Total Activity" topic for interpretation guidelines for gross activity data.

- PSPs must delineate areas to be covered by RTRAK, areas to be covered by HPGe that cannot be covered by RTRAK, and areas (if any) that cannot be covered by either RTRAK or HPGe for topographic or terrain considerations.

- Use specific data review criteria listed in Table 5.4-2 to assess the impacts of gamma photon interferences on data quality.

- Unless otherwise specified in this section (Section 3.9), all references to RTRAK also apply to RSS.

- When in doubt as to the correct usage of RSS vs HPGe or RTRAK, consult the In-Situ Gamma Spectrometry Group.

3.2.4 See Also:

4.2 RTRAK Single Measurement Field of View

4.5 Trigger Levels

4.8 RTRAK Total Activity Data Interpretation

4.12 Shine

4.11 Environmental Influences on *In-Situ* Gamma Spectrometry Data

4.14 Seasonal Precautions

4.15 Mapping Conventions

5.1 MDCs

5.3 Radium-226 Corrected Data

5.4 Data Review

5.6 Strengths and Limitations of In-Situ Gamma Spectrometry

5.7 Field Quality Control Considerations

5.8 Positioning and Surveying

TABLE 3.2-1
GAMMA PHOTONS USED FOR RTRAK MEASUREMENTS

Radionuclide of Interest	Radionuclide of Emission	Gamma Photon Energy (keV)	Gamma Photon Abundance (%)	Signal Window (keV)
U-238	Pa-234m	1001.0	0.845	943.1 - 1058.9
Th-232	Tl-208	2614.44	99.8	2405.4 - 2823.8
Ra-226	Bi-214	1764.49	15.8	1699.3 - 1850.9

TABLE 3.2-2
SUMMARY OF GAMMA PHOTON INTERFERENCES

Radionuclide of Interest	Radionuclide of Emission	Energy of Gamma Photon Used for Quantification (keV)	Radionuclide Emitting Interfering Gamma Photon	Energy of Interfering Gamma Photon (keV)	Effect of Interference
Thorium-232	Thallium-208	2614	Bismuth-214 (from Ra-226 decay)	2204 2293 2448	Bias Th-232 low
Radium-226	Bismuth-214	1764	Actinium-228	1664-1666 (4 gammas) 1887	Bias Ra-226 low
Uranium-238	Protactinium-234m	1001	Thallium-208 (from Th-232 decay)	982	Bias U-238 high
				860 1093	Bias U-238 low
			Actinium-228 (from Th-232 decay)	969	Bias U-238 high
				944-1033 (7 gammas)	Bias U-238 high
				835 840 1065 1095	Bias U-238 low
			Bisumth-214 (from Ra-226 decay)	964	Bias U-238 high
				1069 1120	Bias U-238 low
			Lead-214 (from Ra-226 decay)	839	Bias U-238 low

3.3 HOT SPOT EVALUATION

Hot spots are localized areas for which levels of radiological contamination are at least twice FRLs. Formal hot spot criteria that relate the acceptable magnitude of contamination to the area of the contamination apply at the FEMP and are summarized below.

~~1) No individual location may have concentrations greater than 30 times the FRL for the three primary radionuclides.~~

1) Areas that are less than or equal to 10 m^2 in size must have average concentrations less than 3 times the FRL for the three primary radionuclides.

2) Areas that are greater than 10 m^2 in size must have average concentrations less than 2 times theFRL for the three primary radionuclides.

Evaluation of a hot spot consists of up to three steps: preliminary detection of the hot spot, confirmation of its presence (if necessary), followed by delineation of its extent and magnitude. Hot spots will be excavated and the removal of the hot spot will be verified. The evaluation of hot spots will be carried out during either precertification or certification, depending upon when the hot spot is detected. During precertification, the evaluation generally involves the use of the RTRAK and HPGe instruments in tandem. It is expected that most hot spots will be detected during precertification. However, during certification the potential exists to detect some hot spots that may have been missed during precertification. In the latter case (certification), only the HPGe will be used for evaluation of the hot spot, since the RTRAK is not used during certification. In general, during precertification, screening is carried out with the RTRAK to obtain a preliminary detection of any hot spots present and an initial estimate of their areal extent. Any detection is confirmed with the HPGe instrument, and the extent of the hot spot is then delineated using the HPGe. Before evaluation of hot spots begins, remediation should be carried out until the average soil concentrations for total uranium, thorium-232, and radium-226 are below their FRLs on the basis of RTRAK measurements. Figure 3.3-1 (Figure 3-9 in the SEP) summarizes the hot spot criteria and remediation implementation strategy.

The concentrations of hot spots measured by RTRAK and HPGe are a function of the size of the hot spot relative to the field of view of the detector. A rule of thumb is that a hot spot (i.e., location with soil concentration greater than or equal to 3xFRL) can be recognized if it is at least 2/3 (0.66) of the size of the field of view, irrespective of where it is centered within the field of view. Figure 3.3-2 shows the relationship between hot spot size and RTRAK measurement readings, and hot spot concentrations (xFRL). The line in Figure 3.3-2 represents the estimated hot spot concentration necessary for RTRAK to measure a concentration of at least 3 times the FRL for any given size hot spot. Two points are particularly salient. First, RTRAK can easily measure concentrations of hot spots at 3 times the FRL having areas less than 10 square meters, in accordance with the SEP. Second, 30 times the FRL corresponds to an approximate hot spot detectability area of 0.4 square meters.

Figure 3.3-3 shows hot spot detectability information analogous to that in Figure 3.3-2, only for HPGe at a 31 cm detector height. Because HPGe with a 31 cm detector height is used to confirm and delineate hot spots detected by RTRAK, it is important that the HPGe be able to resolve smaller hot spots. Thus, for example, as shown in Figure 2, HPGe can detect a hot spot 30 times the FRL having an area of approximately 0.04 square meters. Figure 3.3-2 assumes that the hot spot could be randomly distributed anywhere within the RTRAK field of view; this is a worst-case scenario. Conversely, Figure 3.3-3 optimizes the detectability of hot spots by HPGe by assuming the hot spot is centered directly below the detector, as would happen in the confirmation and delineation of data objectives (described below).

FRLs vary, and thus hot spot criteria vary, depending on the area being remediated. In off-property areas, the FRLs for total uranium, thorium-232, and radium-226 are somewhat lower than for most on-property areas. In the former production area and in portions of OU2, the FRL for uranium is much lower than in other areas. In the production area, the FRL for total uranium is 20 ppm, and in part of OU2 the FRL is 10 ppm .

The HPGe and RTRAK can be used for detection of radium-226 and thorium-232 hot spots in all areas; the HPGe can also be used for detection of uranium hot spots in all areas. However, the MDC for uranium for the RTRAK using a 4-second acquisition time is well above hot-spot levels (three times the FRL) for areas with an FRL for total uranium of 20 ppm or less. ~~Therefore, detection of uranium hot spots in these areas using the RTRAK is possible only if many individual measurements are aggregated.~~ Therefore, detection of uranium hot spots when uranium FRLs are less than 20 ppm would require the aggregation of many individual RTRAK measurements. However, aggregation results in the loss of spatial resolution. As a consequence, uranium hot spots may not be recognizable when uranium FRLs are 20 ppm or less.

3.3.1 Detection

Hot spots will generally be identified and removed during precertification. Following the survey of an area with the RTRAK, the data collected will be evaluated. If for any location the two-point moving average of these measurements exceeds three time the FRL for radium-226, thorium-232, or total uranium or the lowest detection limit of the system if the system cannot meet the three times the FRL limit, a hot spot may be present. For FRLs for total uranium of 10 or 20 ppm, individual measurements must be aggregated (see comment about aggregated measurements in guidance section). The possible presence of a hot spot detected during precertification shall be confirmed and, if confirmed, the area will require further delineation.

If results for radium-226, thorium-232, or total uranium obtained at any certification location from either the HPGe or from the analysis of physical samples exceed twice the relevant FRLs, soil with contaminant concentrations at or above twice the relevant FRLs will be considered to be present and further delineation will be required.

3.3.2 Confirmation

Confirmation of a potential hot spot identified by the RTRAK is necessary because of the substantial rate of false positive detections expected from the RTRAK and will be performed using the HPGe instrument. The HPGe measurement will be made at the location that yielded the maximum result for the RTRAK, using an acquisition time of 15 minutes and detector heights of both 31 cm and 1 m. Measurements should be made at two heights to minimize the potential for missing a hot spot due to any errors in determining its location during confirmation and to provide additional information on its extent. A hot spot is confirmed if an HPGe measurement exceeds twice the FRL for the relevant constituent at either height. If the hot spot is confirmed, the area generally will be further delineated using the HPGe. However, if the results exceed twice the FRL at only the 31 cm height, the hot spot will be excavated (the size of the excavation will be 20 square meters, which is the field of view at a 31 cm detector height) to a depth of 15 cm without further delineation.

3.3.3 Delineation

The process presented here represents the minimum delineation that will be done for a hot spot; in some cases more detailed delineation may be appropriate. Essentially the same process will be carried out irrespective of whether the hot spot is detected during precertification or certification. However, if the hot spot is detected during precertification and its presence is confirmed, more details on the extent of the hot spot will be available prior to delineation than if the hot spot is detected during certification. If the hot spot is detected during certification as the result of the analysis of a physical sample or a HPGe measurement taken at a 31 cm detector height, initial delineation will begin using the HPGe instrument to examine further the location where the hot spot was detected. If the hot spot was detected using the HPGe instrument, then a second measurement will be taken at the same location using a 1 m detector height. If results do not exceed twice the FRL at the 1 m height, the hot spot will be excavated (the size of the excavation will be 20 square meters which is the field of view at 31 cm detector height) to a depth of 15 cm with no further delineation. If results from the 1 m measurement exceed twice the FRL, then the general delineation approach described below will be followed. If the hot spot was detected as the result of the analysis of a physical sample, HPGe measurements will be made at the location of the physical sample at heights of 31 cm and 1 m. If results do not exceed twice the FRL for the 1 m measurement, the hot spot will be excavated (the size of the excavation will be 20 square meters which is the field view at a 31 cm detector height) to 15 cm without further delineation on the basis of the results provided by the HPGe. Otherwise, the general delineation approach given below will be followed.

The general process of delineation of hot spots uses the HPGe instrument. Four locations just outside the estimated perimeter of the hot spot (identified on the basis of detection and confirmation results) and located on perpendicular axes that pass through the center of the hot spot will be defined and HPGe measurements will be made at those locations using a detector height of 15 cm and an acquisition time of 15 minutes. If results from any measurement location are below twice the FRL for the constituent of concern, then the location defines the outer limit of the hot spot. If the result for any measurement location exceeds twice the FRL for the constituent, that measurement location will be moved 2 m farther away from the center of the hot spot and the measurement made again. This process will be repeated, as needed, until the boundary of the hot spot has been reached (i.e., until concentrations are below twice the FRLs). The hot spot then will be delineated on the basis of the four boundary locations that have been identified by constructing a smooth, continuous boundary that passes through the four locations. An example of the general process is provided in Figure 3.3-4. The soil within the boundary of the delineated hot spot will be excavated to a depth of 6 inches. If the hot spot was found during precertification, the general area of the excavated hot spot will be surveyed again with the RTRAK. If the hot spot still appears to be present, the confirmation and delineation processes will be repeated. If the hot spot was found during certification, its removal will be verified using the HPGe with complete coverage at a 31 cm detector height (see section 4.10, HPGe measurement grid configurations). (The delineation process should be refined as the relative costs of delineation versus excavation become better know.)

3.3.4 Hot Spot Mapping Requirements

Maps should be provided that indicate the extent of RTRAK data collection, and the locations of measurement aggregates that fail the hot spot trigger levels, along with an indication of which isotope presents the hot spot concern. For each location where a potential hot spot has been identified, a final set of maps should be provided that indicate the results of verification and delineation data collection efforts, the extent of hot spot removal excavation, and the results of post-hot spot removal data collection to verify that the hot spot has been removed.

3.3.5 Guidance

- A rule of thumb is that a hot spot (i.e., location with soil concentration greater than or equal to 3xFRL) can be recognized if it is at least 2/3 (0.66) of the size of the field of view, irrespective of where it is centered within the field of view.

- Hot spot definitions only apply to the primary radiological COCs.

- Hot spot definitions include two criteria: a not to exceed 3xFRL upper limit that applies to areas less than or equal to 10 square meters, and a not to exceed 2xFRL rule that applies to areas greater than 10 square meters.

- Hot spot evaluation will be performed during precertification and certification data collection activities.

- The RTRAK will be used to evaluate areas for the potential presence of hot spots. If a two-point moving average RTRAK value exceeds 3xFRL, a potential hot spot has been identified and additional action must be taken.

- Detection of total uranium hot spots when FRLs are less than 20 ppm is only possible if many individual RTRAK measurements are aggregated. While aggregation of individual RTRAK measurements can lower MDCs and improve precision to allow hot spot criteria to be met, aggregation also results in loss of spatial resolution. For example, the area represented by the aggregation of measurements may be so large compared to the size of a hot spot, that the hot spot cannot be recognized. Hot spots less than 25 square meters may not be recognizable when total uranium FRLs are 20 ppm or less.

- Refer to Table 4.3-5 using 1.0 mph with a 4-second data acquisition time and no overlap operating parameters to illustrate the guidance. Based upon this table, 972 RTRAK measurements will measure 4,291 m^2, and each measurement has an average field of view of 4.41 m^2. If, for example, it takes 40 aggregated measurements to have a sufficiently low MDC to detect low concentration hot spots, then 40 measurements will represent 176.4 m^2 (40 x 4.41 m^2). Using the first guidance bullet above, a hot spot will be recognized if it is at least 2/3 of the size of the aggregation area, or 116.4 m2 (0.66 x 176.4 m^2).

- The HPGe may be used to evaluate areas for the potential presence of hot spots if it is not practical to use the RTRAK. In this case HPGe measurements will be taken at a height of 1 foot on a triangular grid that provides 100% coverage for the area of concern.

- If any HPGe or discrete sample result is greater than 2xFRL during precertification or certification activities, a hot spot has been identified and additional action must be taken.

- Very small hot spots may be recognizable visually, such as by noticing changes in soil color, and elevated activity may be detected via hand-held survey meters.

3.3.6 <u>See Also</u>:

3.1 Individual HPGe Measurements

3.2 RTRAK Measurements

3.3 Hot Spot Evaluation

4.5 Trigger Levels

4.10 HPGe Measurement Grid Configurations

5.1 MDCs

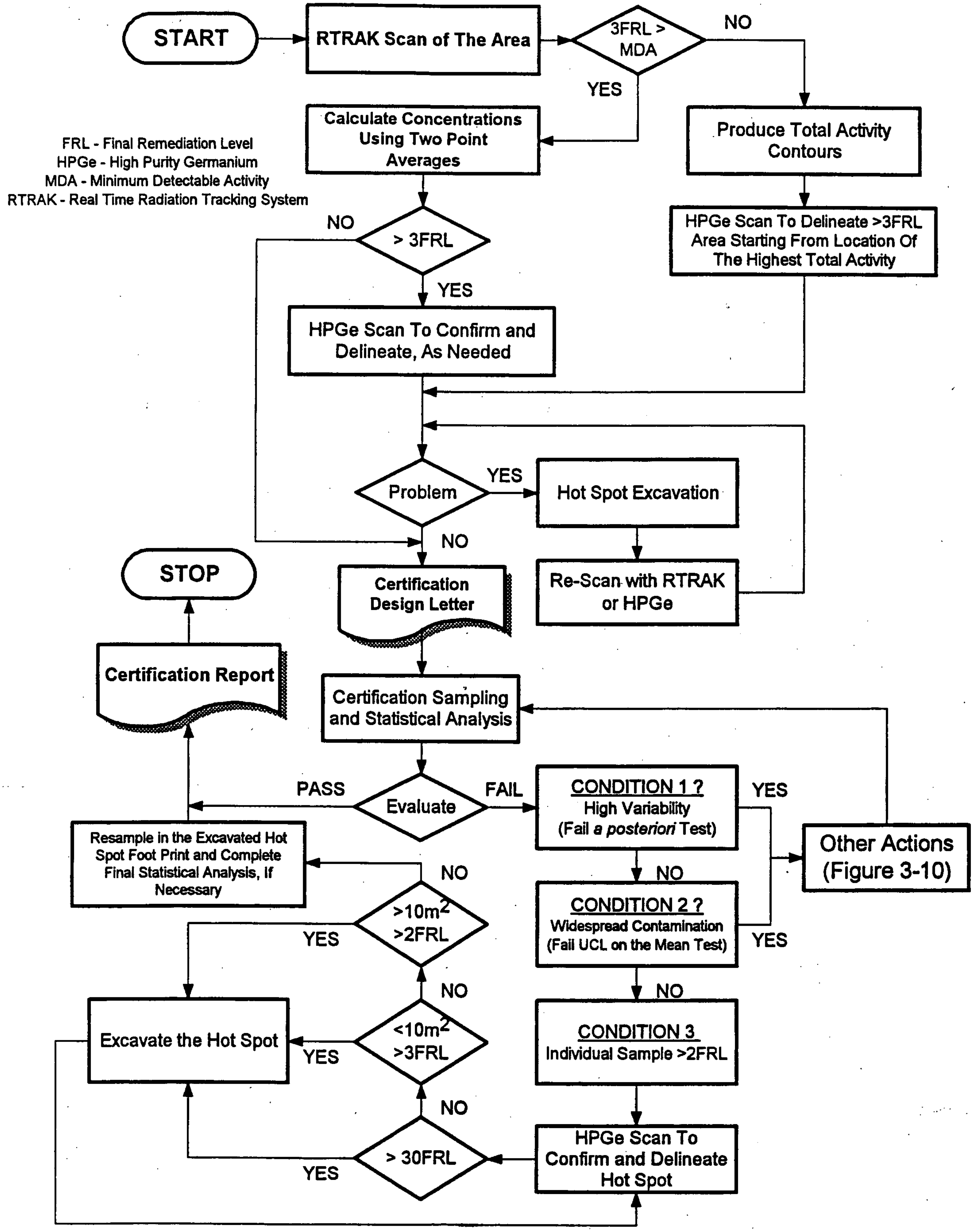

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FIGURE 3.3-1 HOT SPOT CRITERIA AND IMPLEMENTATION STRATEGY

Figure 3.3-2
Estimated Concentration of Hot Spot for RTRAK to Measure at Least Three Times FRL

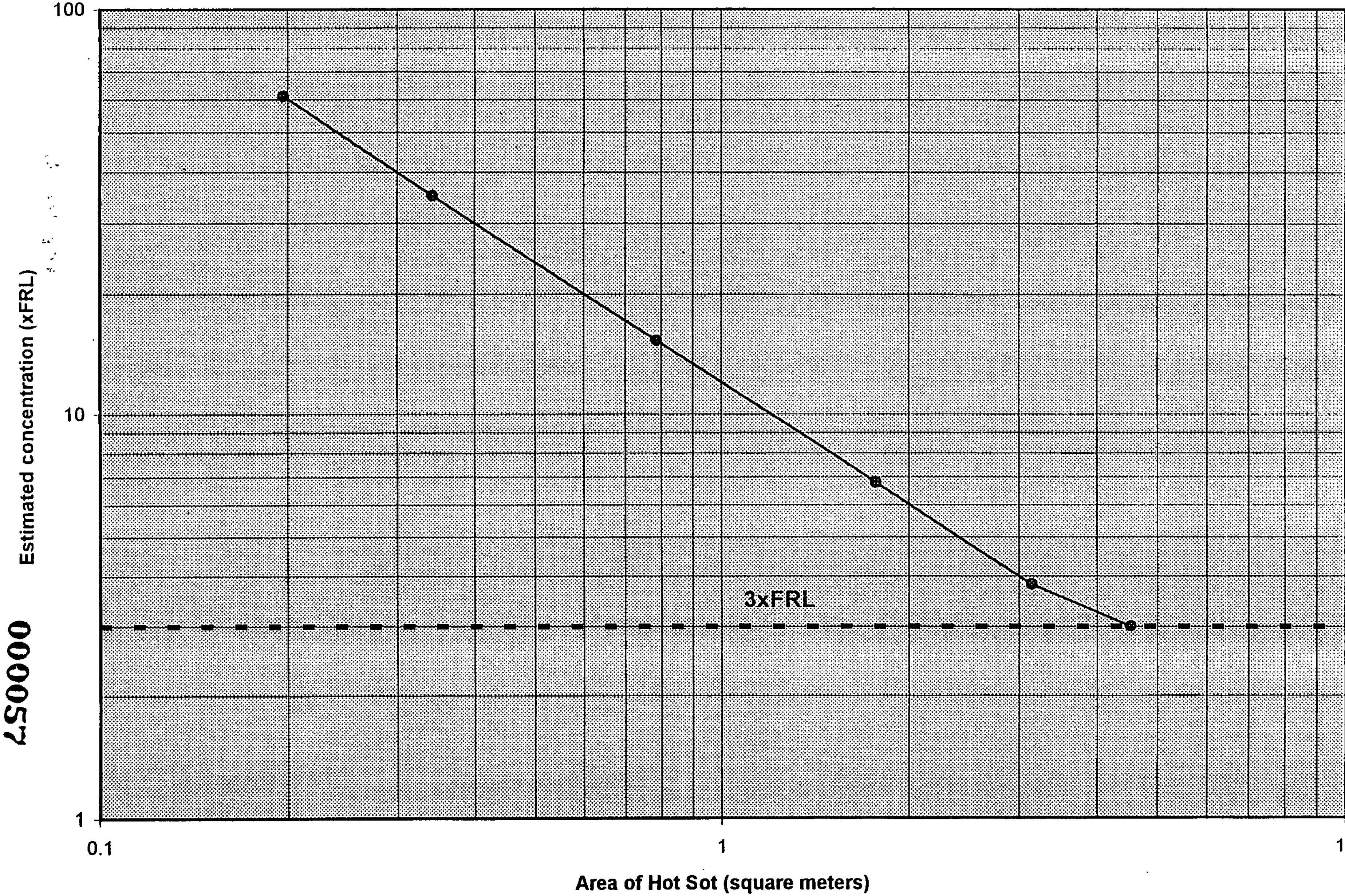

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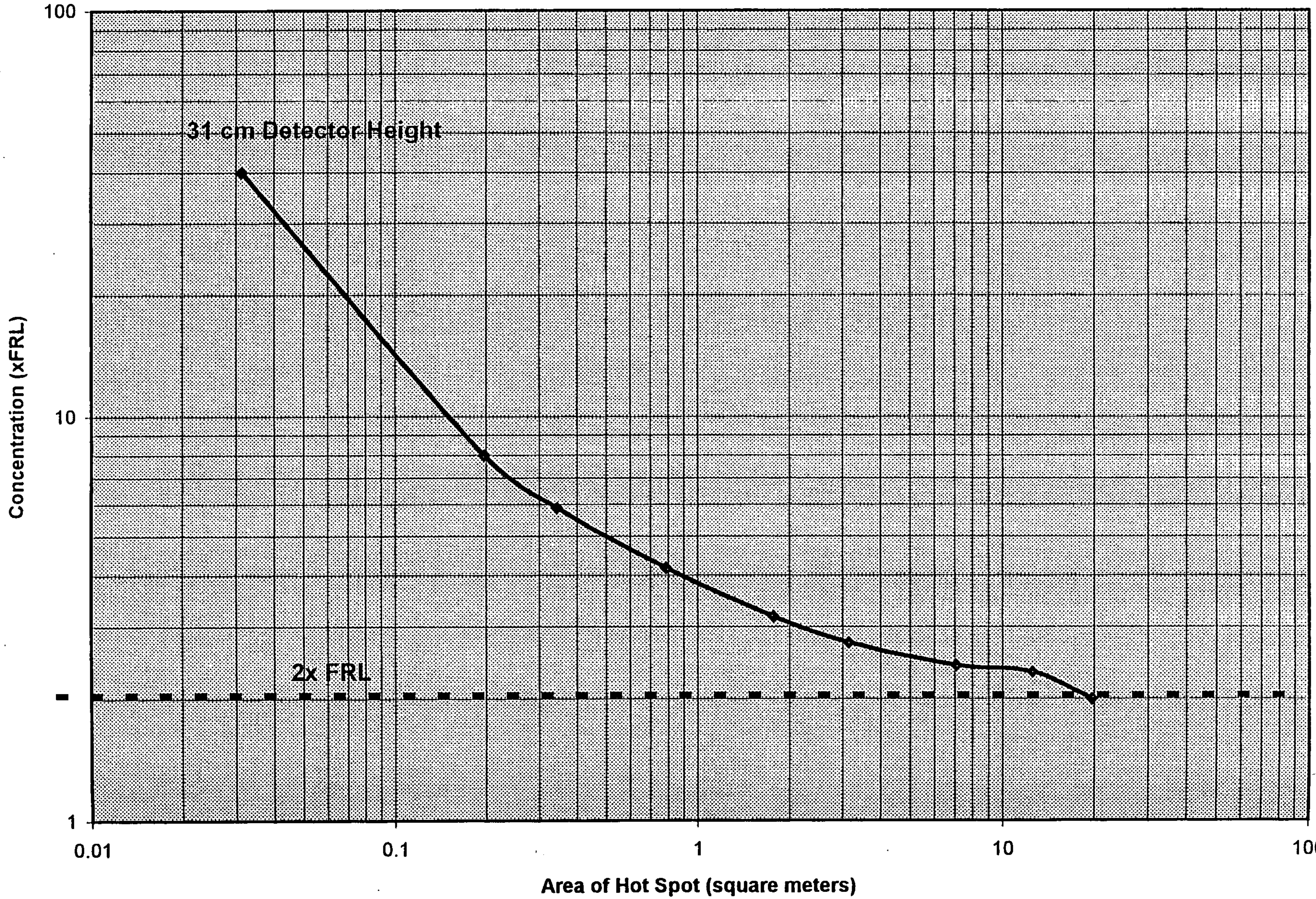
Figure 3.3-3

Estimated Concentration of Hot Spot Necessary for HPGe (31 cm Detector Height) to Measure at Least Two Times FRL



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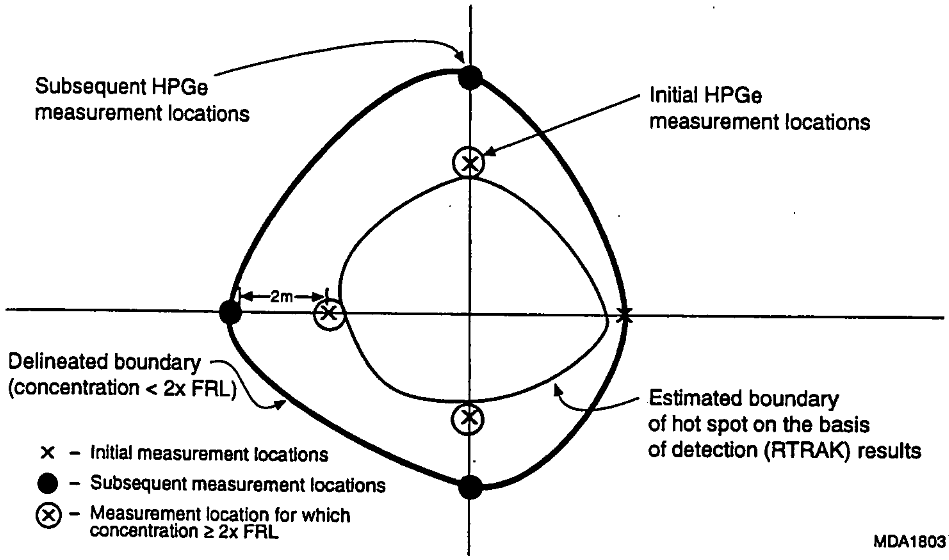

FIGURE 3.3-4 EXAMPLE OF HOT SPOT DELINEATION

3.4 EVALUATION OF ABOVE-WAC SURFACE SOIL

Evaluation of surface soil having uranium concentrations potentially above WAC levels follows an approach similar to that used for hot spots. The evaluation generally involves detection of soil with above-WAC concentrations of total uranium with the RTRAK, followed by confirmation, and then by delineation of the area with the HPGe. This evaluation will normally be done during pre-design investigations when the extent of excavation of above-WAC material will be defined.

3.4.1 Detection

Detection of soil with above-WAC concentrations of total uranium using the RTRAK does not require aggregation of measurements when the system is operated with an acquisition time of 4 sec and a speed of 1 mph. If a single measurement exceeds a trigger level for total uranium of 721 ppm, then soil with elevated uranium concentrations is present that requires confirmation to determine if those elevated uranium concentrations are actually above WAC levels. Surveys of an area using the RTRAK can identify the general extent of regions contaminated above WAC levels, but the boundary of the region should be delineated using the HPGe instrument. If above-WAC concentrations of total uranium have been detected on the basis of historic physical samples, those areas must also be confirmed by HPGe, regardless of RTRAK results.

In areas where RTRAK cannot be used, and where WAC exceedance material might reasonably be expected, HPGe will be used to perform area surveys to detect above-WAC concentrations of total uranium. A detector height of 1.0 meters, a 5-minute data acquisition time, and a triangular grid measurement system with minimal overlap (Section 4.10) will be employed. Utilizing information in Table 4.6-1, an action level of 400 ppm (WAC exceedance areas larger than 7.1 m^2 can be detected at a 1.0 meter detector height if they have a concentration greater than 400 ppm of total uranium) will be utilized to denote the existence of a possible WAC exceedance. Hand-held survey meters will be used to locate areas within the field of view giving rise to measurements greater than 400 ppm total uranium. When such areas are located, they will be confirmed with HPGe measurements at 31 cm and 15 cm as described below.

3.4.2 Confirmation

Confirmation of the presence of soil with potential above-WAC concentrations of uranium identified using the RTRAK will be performed using the HPGe instrument. Confirmation measurements will be made at the location that yielded the maximum result with the RTRAK, with the measurement location adjusted in the field using a hand-held instrument to determine the location of maximum activity. The confirmation measurement will be made using detector heights of both 31 cm and 15 cm and an acquisition time of 5 minutes. If either measurement exceeds a HPGe trigger level of 928 ppm (Table 4.5-1), then the area of the above-WAC contamination will be further delineated with the HPGe. Use of both 31 and 15 cm for the HPGe detector height provides fields of view of about 20 and 3 m^2, respectively, bracketing the 9 m^2 field of view of the RTRAK. If the HPGe trigger level of 928 ppm is not exceeded, but the HPGe results still confirm the presence of a hot spot (i.e., results exceed twice the FRL for total uranium), the identified hot spot will have to be delineated only if no excavation of the area is planned. If above WAC concentrations of total uranium were detected on the basis of results from historic physical samples, the confirmation process should be carried out to establish if above WAC concentrations are in fact present. HPGe measurements should be made at the locations where the physical samples were taken using detector heights of 31 and 15 cm, as indicated above.

3.4.3 Delineation

The HPGe instrument is used to confirm and refine the boundaries of above-WAC soil. For delineation, HPGe measurements generally should be made at a height of 15 cm with an acquisition time of 5 minutes on a 2-m triangular grid (note that the radius of the field of view is 1.0 meter for a 15 cm detector height; therefore, a two meter grid spacing has no overlap between adjacent fields of view) that covers the entire area indicated by RTRAK results or HPGe confirmation results as being above-WAC. This is consistent with the guidance given in Section 4.10, guidance bullet #1. However, if the circumscribed area appears to contain only above-WAC soil or it is not realistic to expect that soil can be segregated to minimize off-site shipment of soil, then the grid should only cover the boundary of the area identified using RTRAK or HPGe confirmation results. The trigger level for above-WAC areas for the HPGe instrument with a 5-minute acquisition time is 928 ppm. Definition of the vertical extent of the above-WAC soil will require analysis of borings. An example of the delineation process is provided in Figure 3.4-1. The soil in the delineated area should be excavated and the area surveyed again with the RTRAK. If soil with above-WAC concentrations of total uranium still appears to be present, confirmation and delineation measurements must be performed again. (The delineation procedure should be refined as more information becomes available on the relative costs of delineation and management of above-WAC soil.)

3.4.4 WAC Identification and Delineation Mapping Requirements

Maps should be provided that show the extent of RTRAK data collection, and that indicate locations where individual RTRAK readings exceeded the WAC trigger level. In the event that the RTRAK identifies potential WAC exceedance problems, for each location a final set of maps should be provided that indicate the results of verification and delineation data collection efforts, the extent of WAC mateial removal, and the results of post-WAC removal data collection to verify that the material exceeding WAC has been removed.

3.4.5 Guidance

- A rule of thumb is that WAC exceedance areas can be recognized by HPGe using the above trigger levels if that WAC exceedance area has a radius of at least 66% of the radius of the HPGe field of view for a given detector height and the concentration of total uranium is at least 1500 ppm for that WAC exceedance area.

- For WAC exceedances much smaller than the field of view of the HPGe detector, Table 4.6-1 can be used to provide guidance for WAC size, concentration, and recognizability at a given detector height.

- Use a WAC trigger level for total uranium of 928 ppm for 5-minute count times. (If 15-minute count times are used, the trigger level is 947 ppm.)

- The delineation procedure described above is intended for areas of above WAC soil of about 100 m^2 or less in size. For substantially larger areas, the approach needs to be refined and the *in-situ* gamma spectrometry group should be consulted on the most appropriate delineation approach.

3.4.6 See Also:

3.1 Individual HPGe Measurements

3.2 RTRAK Measurements

4.1 HPGe Detector Field of View

4.4 HPGe Detector Height and Data Acquisition Time

4.5 Trigger Levels

4.6 WAC Exceedance Detection

4.10 HPGe Measurement Grid Configuration

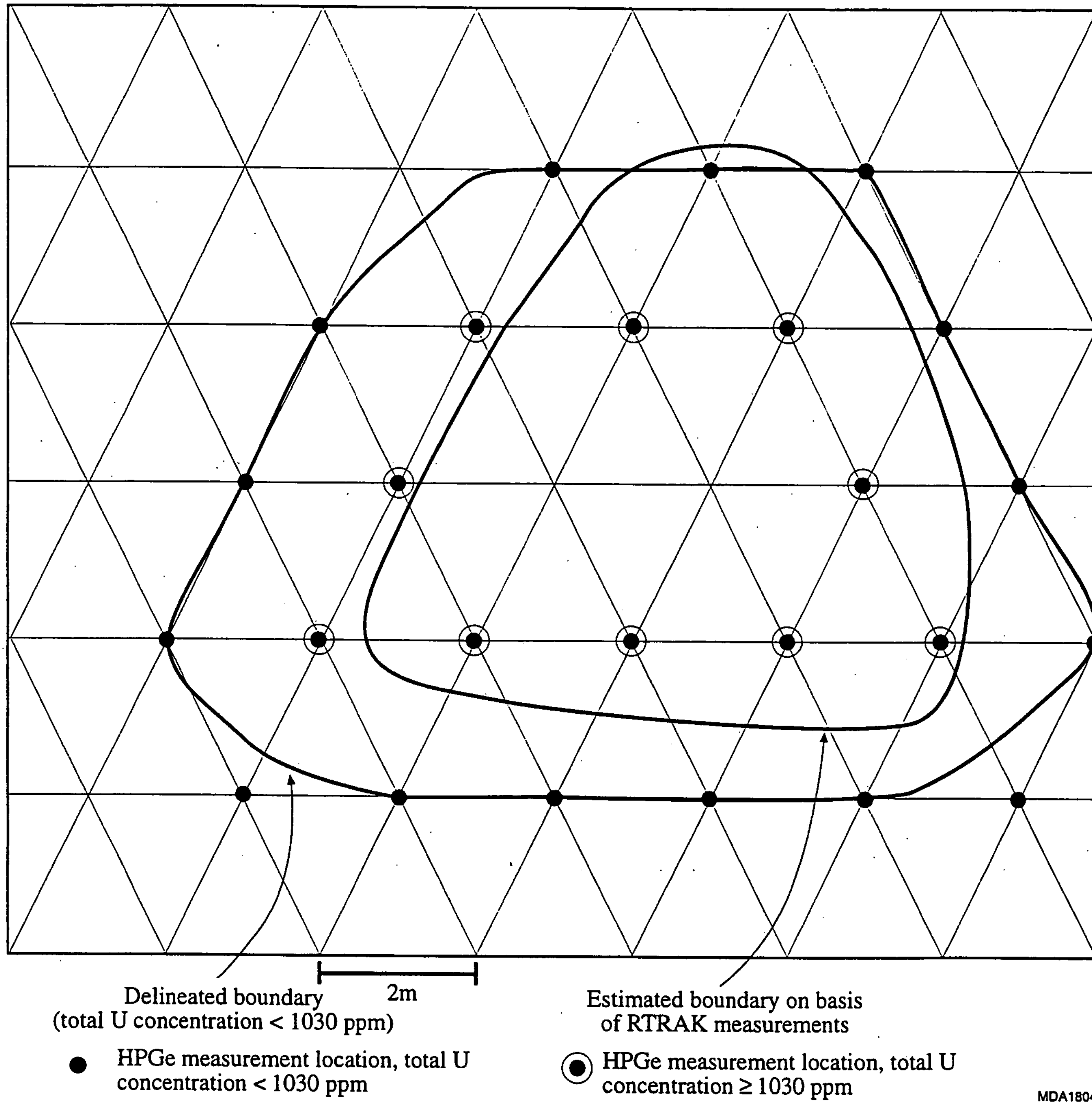

Figure 3.4-1
Example of Delineation of Above-WAC Soil

3.5 EXCAVATION CONTROL FOR LIFTS

During excavation that uses lifts, controls on excavation are required so that (1) all above-WAC soil is identified, and (2) unnecessary excavation of uncontaminated soil is not carried out. The processes to be used to define the horizontal extent of excavation and the presence of soil with uranium concentrations above WAC levels are the same as used for surface soil. After a lift is removed, the area should be surveyed with the RTRAK. If the survey indicates the presence of any above-WAC soil, the presence of the above-WAC soil will be confirmed and, if confirmed, its boundary will be delineated using the HPGe. Definition of the vertical extent of above-WAC soil may require analysis of borings. Definition of the horizontal excavation extent for soil with concentrations of contaminants above FRLs or above the ALARA goal of 50 ppm for total uranium requires the use of HPGe measurements to improve the delineation of the excavation boundary, as is done for surface soil.

3.5.1 <u>Guidance</u>:

- For confirmation and delineation of WAC exceedance areas, refer to Section 3.4, "Evaluation of Above-WAC Surface Soil."
- For identification and confirmation of very small possible WAC exceedance areas, refer to Section 4.6, "WAC Exceedance Detection."

3.5.2 <u>See Also</u>:

3.4 Excavation of Above-WAC surface soil

3.6 Horizontal Excavation Boundary Delineation

3.6 HORIZONTAL EXCAVATION BOUNDARY DELINEATION

A combination of RTRAK and HPGe measurements may be used to help establish the necessary extent of horizontal excavation. The RTRAK should be used to survey the entire area in question to identify the general extent of soil contaminated with primary radiological COCs above their FRLs. Use of the RTRAK for this purpose generally will require the aggregation of individual measurements, and therefore spatial resolution may be reduced, particularly for uranium. The RTRAK results need to be examined and the remediation area under investigation divided into three parts: (1) locations with soil concentrations that are likely above the FRL for one or more COCs, (2) locations with soil concentrations likely below FRLs for all COCs, and (3) a zone of uncertainty between (1) and (2) that may be above FRLs for one or more COCs. Trigger levels for the RTRAK for establishing results above and below FRLs are provided in Tables 3.6-1 and 3.6-2. If results are below the trigger levels in Table 3.6-1, then soil concentrations are likely below FRLs (i.e., the false negative rate is less than or equal to 5% if concentrations are actually at or above the FRL); if results are above the trigger levels in Table 3.6-2, then soil concentrations are actually at or above FRLs (i.e., the false positive rate is less than or equal to 5% if concentrations are actually at or below the FRL). RTRAK readings between the trigger levels in Tables 3.6-1 and 3.6-2 define the zone of uncertainty that must be resolved by HPGe. When available, results from the analysis of physical samples (e.g, RI/FS data) should also be used to help refine boundaries. The delineation process focuses on defining the excavation boundary, which is located in the band of uncertainty identified on the basis of RTRAK results (i.e., locations in Category #3).

A preliminary excavation boundary should be located within the zone of uncertainty identified above, using professional judgement. It would encompass all locations for which any COC has a concentration above its FRL. HPGe measurement transects would then be established at intervals along and perpendicular to the preliminary boundary. The spacing between the transects will depend on the scale of the region and the distribution of contamination in the area and should be determined using professional judgment. HPGe measurements should be made at 2-m intervals along these transects, beginning at the preliminary boundary; the measurements should be made at a height of 15 cm using an acquisition time of 15 minutes. A comparison of HPGe results with the FRL trigger levels given in Table 3.6-3 will be used as the basis for expanding or contracting the boundary along a given transect. The process of obtaining measurements at 2-m intervals along transects should be continued until all COCs are bounded (i.e., the COC that has the greatest spatial extent above its FRL along the transect).

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Analysis of physical samples may also be used to help define the excavation boundary. An example of the approach is provided in Figure 3.6-1. (The delineation procedure should be refined as more information becomes available on the relative costs of delineation and management of above-FRL soil.)

3.6.1 Horizontal Excavation Mapping Requirements

Maps should be provided that show the extent and RTRAK data collection, that plot individual RTRAK total activity readings appropriately color coded by total activity level (see Section 4.15), and that plot aggregated isotopic information for radium-226, thorium-232 and total uranium, with the aggregates color coded by their concentration. A complete discussion of aggregation techniques and requirements can be found in Section 4.15.

3.6.2 Guidance

- For the case in which contaminant concentrations decrease smoothly with distance along a transect, the boundary is established when adjacent HPGe measurements taken on the transect are above and below the relevant trigger level.

- In cases in which contaminant concentrations decrease very slowly with distance along the transect or do not consistently decrease or increase, it may be necessary to make a series of measurements to demonstrate that results are consistently below the trigger level in order to establish the boundary.

3.6.3 See Also:

3.1 Individual HPGe Measurements

3.2 RTRAK Measurements

4.5 Trigger Levels

TABLE 3.6-1
RTRAK TRIGGER LEVELS*, RESULTS BELOW FRLs (ACQUISITION TIME = 4 SEC)

Contaminant	FRL	No. Aggregated Measurements	Trigger Level
Total Uranium	82	18	58
	50**		
	20		
	10		
Thorium-232	1.5	2	1.11
	1.4		
Radium-226	1.7	5	1.22
	1.5		

* RTRAK readings between the trigger levels in Tables 3.6-1 and 3.6-2 define a zone of uncertainty that needs to be resolved by HPGe or some other means.

** The ALARA goal.

TABLE 3.6-2
RTRAK TRIGGER LEVELS*, RESULTS ABOVE FRLs (ACQUISITION TIME = 4 SEC)

Contaminant	FRL	No. Aggregated Measurements	Trigger Level
Total Uranium	82	18	106
	50**		
	20		
	10		
Thorium-232	1.5	2	1.89
	1.4		
Radium-226	1.7	5	2.18
	1.5		

* RTRAK readings between the trigger levels in Tables 3.6-1 and 3.6-2 define a zone of uncertainty that needs to be resolved by HPGe or some other means.

**The ALARA goal.

TABLE 3.6-3
HPGe TRIGGER LEVELS FOR FRLs (ACQUISITION TIME = 900 SEC)

Contaminant	FRL	Trigger Level
Total Uranium	82	75
	50*	46
	20	18
	10	9.0
Thorium-232	1.5	1.37
	1.4	1.28
Radium-226	1.7	1.48
	1.5	1.31

* The ALARA goal.

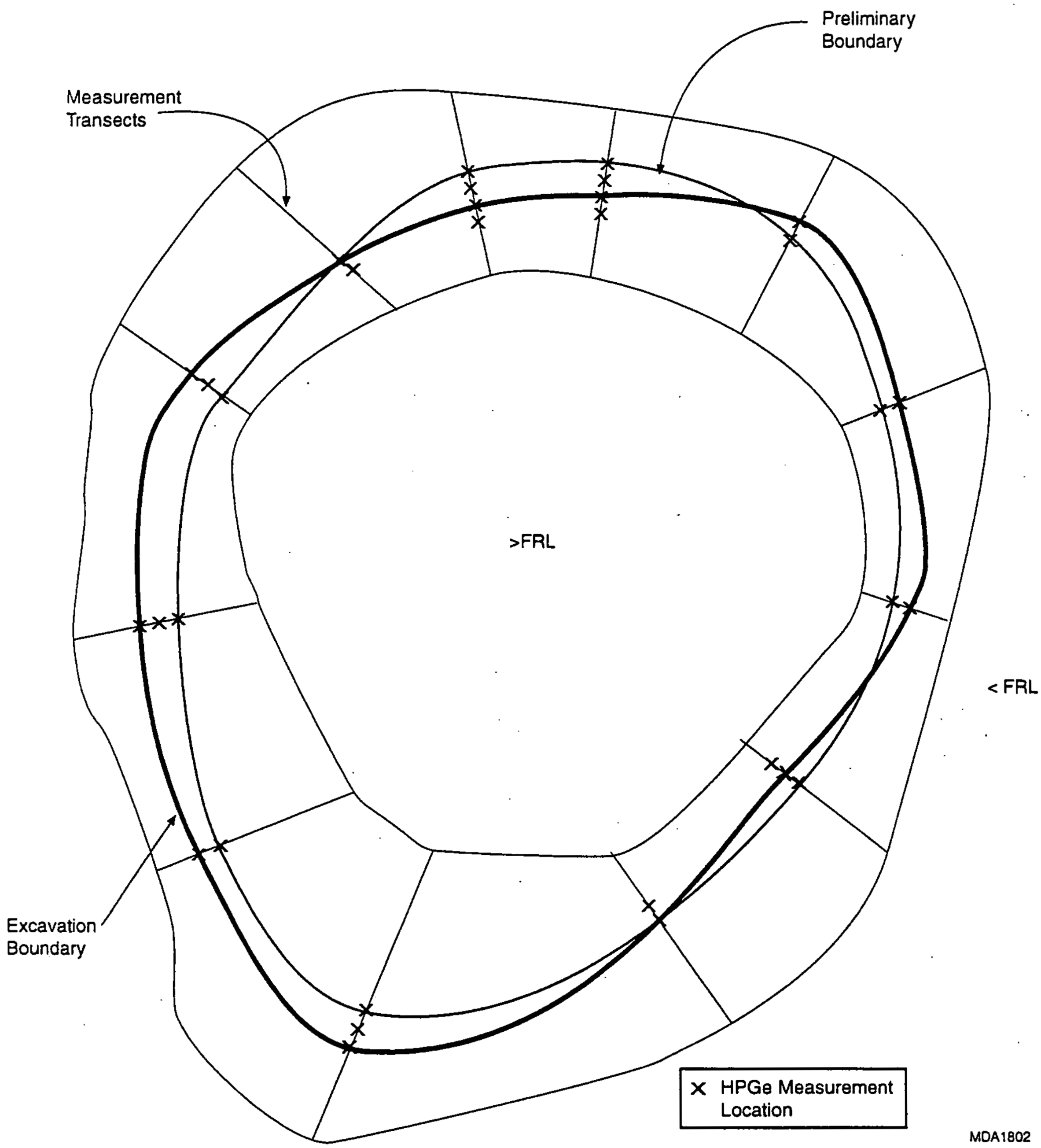


FIGURE 3.6-1 DELINEATION OF EXCAVATION BOUNDARY

3.7 CERTIFICATION MEASUREMENTS

3.7.1 Comparability of HPGe and Laboratory CU Certification Data

The report entitled "Comparability of *In-Situ* Gamma Spectrometry and Laboratory Data and Decisions for Certification Units" (DOE 1998b) demonstrates that:

1. The same decisions with respect to CU certification will be made for total uranium, thorium-232, and radium-226 (with occasional exceptions; see Section 3.7.4 below) regardless of whether HPGe or laboratory data are used.

2. HPGe certification data are very comparable to laboratory certification data for total uranium, thorium-232, and radium-226.

3. HPGe data generally have smaller percent relative standard deviations than laboratory data, they are based on a larger "sample" size, and hence are more representative for certification purposes.

Accordingly, the FEMP will use HPGe as the principal analytical instrument for certification measurements of primary radionuclide contaminants of concern (total uranium, thorium-232 and radium-226). Certification for certain secondary radionuclide contaminants of concern, such as technetium-99, cannot be accomplished with the HPGe.

3.7.2 Pre-Certification Measurements

The key to successfully using HPGe for certification is the precertification investigation (Section 2.4). Pre-certification involves 100 percent scan of all CUs by RTRAK/RSS to demonstrate that contamination is below the FRL for each radiological COC and that no potential hot spots exist. With regard to hot spots, if for any reason the two point moving average of RTRAK/RSS measurements exceeds thee times the FRL for radium-226, thorium-232 or total uranium, a hot spot may be present (Section 3.3.1). The location in each CU of the highest RTRAK total activity reading is also measured by HPGe to confirm that the highest total activity measurement does not correspond to a hot spot. If remediation has been successful, pre-certification measurements will demonstrate an absence of elevated contamination areas and a relatively homogeneous residual contamination distribution.

3.7.3 Certification Approach

The overall approach to certification using HPGe will be similar to the approach used for physical samples with respect to sample locations and statistical interpretation of data. The procedure for determining sample locations is described in Section 3.4.2.1 of the SEP. Sixteen HPGe measurements will be performed in randomly selected locations irrespective of CU classification. To prevent clumping of measurement locations in one small area of the CU, the two criteria for selecting measurement locations described in Section 3.4.2.1 of the SEP will be followed. Physical samples will serve as QC checks on HPGe measurements. One physical sample will be taken per CU at the highest HPGe reading that was obtained during certification measurements.

Sixteen HPGe measurements is an adequate sample size given the expected low degree of variability in soil concentrations of primary radionuclides following remediation. A statistical analysis of the HPGe measurements will be conducted with the validated HPGe data as described in Sections 3.4.3, 3.4.4, and Appendix G of the SEP. Table 3.7-1 presents certification data (means and standard deviations) for individual radiological COCs averaged from all CUs in A1PI, A1PII, A1PI sediment traps, and A8PI. Both laboratory and HPGe means are all well below FRLs, and the small standard deviations attest to relative homogeneity. Similar results are expected for future areas to be certified.

Similar to laboratory analysis of physical samples, HPGe measurements will be performed at ASL D for certification. Further, all measurements will be carried out under the auspices of a QA/QC program that is in full compliance with the SCQ. The *In-Situ* Gamma Spectrometry Addendum to the SCQ (DOE 1998c) contains a complete description of the QA and QC programs that will govern HPGe measurements as described in procedures ADM-16 and 20300-PL-0002 listed in Appendix A. The QC requirements to perform ASL D HPGe measurements are specified in ADM-16. Finally, HPGe measurement data will be validated independently of the *in-situ* gamma spectrometry group performing the measurements.

3.7.4 Radium-226 Certification Measurements

Radium-226 measurements must be conducted in strict accordance with Sections 5.3.1.1 and 5.3.3.3 in order to compensate for radon-222 disequilibrium in soil and radon-222 accumulation near the ground surface. Radon monitors (Section 5.3.2) must be employed to address the second effect. Despite the use of radon monitors, they occasionally are unable to properly compensate for radon buildups near the ground surface. This may happen when the normal cycle of ground surface warming and cooling is interrupted or when atmospheric inversions occur and last throughout the day. When these situations arise, radium-226 data will be biased high. Typically, such occasions can be recognized in two ways: 1) the radon monitor consistently yields radium-226 concentrations above 0.90 pCi/g (wet weight) throughout the day, and 2) measured radium-226 concentrations are consistently considerably higher than those measured on preceding or succeeding days. As shown in the 1998 Certification Comparability Report, anomalously high radium-226 concentrations may cause a CU to fail certification. When radon monitors cannot properly compensate for radon accumulations near the ground surface and the CU subsequently fails certification, the CU will be remeasured using physical samples as the basis for certification.

3.7.5 Guidance

- Sixteen HPGe measurements will be taken per CU at a 31 cm detector height and a 15-minute count time. A 31 cm detector height was chosen because the field of view is approximately 20 m^2. Given the size of the field of view and given hot spot criteria in Section 3.3, a 31 cm detector height is well suited to provide relevant information pertaining to the presence of hot spots, should any be present within the field of view of the detector during certification measurements.

- All data will be reviewed within 24 hours of being collected. Any measurement that is greater than the 95% UCL or lower than the 95% LCL for the CU and is more than 50% greater than the CU mean or is less than 50% of the CU mean will be remeasured for accuracy. If the second measurement agrees with the first (less than 20% RPD), the average of the two measurements will be used for the measurement location. If the second measurement does not agree with the first (greater than 20% RPD), a third measurement will be taken and the average of the two measurements in closest agreement will be used for the measurement location.

- If the radon monitor consistently yields radium-226 concentrations greater than 0.90 pCi/g (wet weight) and calculated radium-226 concentrations at CU locations are considerably higher than those calculated on succeeding or preceding days and the CU fails certification for radium-226, physical samples shall be used as the basis for certification.

- One physical sample will be taken per CU at the location of the highest HPGe reading that was obtained during certification measurements. The sample location will be based upon the highest ratio of measured concentration to the FRL irrespective of analyte.

- The higher value of either the HPGe or laboratory measurement will be used in the statistical analysis for certification decisions.

- If laboratory analytical data from the physical sample are greater than 2 x FRL for a primary radionuclide COC, then a hot spot will have been detected. The hot spot will be delineated per Section 3.3.3.

- If an HPGe measurement (31 cm) performed during certification exceeds 2xFRL for a primary radionuclide COC, then a hot spot will have been detected. The hot spot will be delineated per Section 3.3.3.

- One duplicate HPGe measurement per CU will be taken. This duplicate measurement will not be taken back to back with the original measurement.

- The QC requirements to support an ASL D program are specified in ADM-16 and must be met to ensure an ASL D compliant program for certification measurements.

3.7.6 <u>See Also</u>:

2.4 Precertification
2.5 Certification
3.3 Hot Spot Evaluation
5.3 Radium-226 Corrections
5.6 Strengths and Limitations

TABLE 3.7-1
AVERAGES AND STANDARD DEVIATIONS FOR CERTIFICATION DATA FROM A1PI, A1PII, A8PI, AND A1PI SEDIMENT TRAPS

DATA	Total Uranium (ppm)		Thorium-232 (pCi/g)		Radium-226 (pCi/g)	
TYPE	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Laboratory Data*	13.0	11.6	1.05**	0.16**	1.21	0.23
HPGe Data*	16.4	6.8	0.95	0.15	1.23	0.26

*Means and standard deviations are weighted based upon the number of measurements in each of the four certification areas.

**Laboratory thorium-232 excludes data from A1PI because those data are biased anomalously high per the certification comparability study discussed in Section 3.7.1.

3.8 FIELD MOISTURE MEASUREMENTS

The following general directions will govern the collection of moisture data in the field. Area-specific instructions, if any, will be found in area-specific PSPs. Surface Troxler measurements will be obtained at each HPGe measurement point and at a minimum of two locations per acre for RTRAK measurements. The Project Characterization Lead may increase the number of Troxler measurements based on the visual variability of soil conditions at the time of the measurement. Troxler measurements will be conducted within eight hours (as soon as possible, but not to fall outside the working day) of the HPGe and/or RTRAK measurements if environmental/weather conditions have not changed. If environmental/weather conditions have changed (i.e., rain or snow), see guidance below. Technicians cannot perform moisture measurements simultaneously with, and in the same vicinity as (within 75 meters of HPGe or RTRAK), RTRAK or HPGe measurements, because internal radioactive sources contained in the Troxler moisture gauge can interfere with the HPGe or RTRAK measurements.

3.8.1 Guidance

- Surface Troxler measurements will be obtained at the center point of each HPGe measurement, and a minimum of two Troxler measurements per acre will be taken for RTRAK measurements.

- If surface soil conditions are unsuitable for Troxler moisture measurements, a 4-inch depth core sample will be collected at each planned Troxler measurement location and submitted to the on-site laboratory for moisture determination.

- If physical samples were not collected per above, soil moisture data will be estimated based upon Troxler measurements and/or physical sample analyses made on days closest to those on which *in-situ* gamma spectrometry measurements were performed and in areas closest to that which *in-situ* gamma spectrometry runs were made (provided that no rainfall has occurred in the intervening time period).

- If differences in weather conditions preclude the use of moisture data obtained on other days and in other areas, a default value of 20% soil moisture will be utilized. The default value will overcorrect (i.e., yield higher values) *in-situ* gamma spectrometry data in dry conditions, and will undercorrect (i.e., yield lower values) *in-situ* gamma spectrometry data in wet conditions.

- Do not take measurements immediately after a heavy rainfall in which the soil may be completely saturated with water. Even dry weight concentrations may be anomalously low, necessitating rework. The same situation applies for days in which snow has accumulated on the ground surface. Measurements should not be taken the same day following a heavy rain; measurements should not be taken on a muddy surface, and measurements should not be taken if standing water is present within the field of view.

3.8.2 See Also:

5.2 Moisture Corrected Data

4.0 CHARACTERIZATION, DATA INTERPRETATION, AND OPERATIONAL GUIDELINES

This section contains practical information needed by project personnel who 1) plan *in-situ* gamma spectrometry measurements, 2) interpret *in-situ* gamma spectrometry data, 3) integrate *in-situ* gamma spectrometry data with other data sets or into engineering designs, and 4) make decisions based upon *in-situ* gamma spectrometry data. In particular, Characterization Leads should be familiar with this section.

The information in this section is derived from multiple sources: the various comparability studies referenced in Section 1, the scientific literature (including DOE in-house publications), and previously unpublished calculations/interpretations based upon FEMP *in-situ* gamma spectrometry data. Where information is derived from FEMP comparability studies or from the scientific literature, the reader is directed to the appropriate publication for supporting documentation, justification, and background. Where data, interpretations, or facts are unpublished, sufficient supporting documentation to justify assertions is included in the topic text.

4.1 HPGe DETECTOR FIELD OF VIEW

The field of view of an *in-situ* gamma spectrometry detector is defined as *the surface area that corresponds to the volume of earth from which 85 to 90% of the detected gamma photons originate.* For a HPGe detector, the field of view primarily depends on the height of the detector above the ground surface and the energy of the gamma photon. Detectors farther from the ground surface will have larger fields of view than detectors closer to the ground surface. Because higher energy gamma photons are less attenuated by soil and air than lower energy gamma photons, the field of view is larger for higher energy photons than for lower energy photons (Miller et al., 1994, Figure 1).

Table 4.1-1 gives conventions that have been adopted at the FEMP for the HPGe field of view. Because the field of view is dependent upon gamma photon energy, the numbers in Table 4.1-1 represent an approximate average of all gamma photons; however, the field of view will be somewhat larger or smaller for higher or lower energy gamma photons, respectively (Miller, et. al., 1994).

TABLE 4.1-1
HPGe FIELDS OF VIEW AT DIFFERENT DETECTOR HEIGHTS

Detector Height	Radius(m) of Field of View	Area(square meters) of Field of View
1.0(m)	6.0	113
31 (cm)	2.5	19.6
15 (cm)	1.0	3.1

Figures 4.1-1 and 4.1-2 provide additional quantitative perspective on the HPGe field of view. Figure 4.1-1 (see Miller et al., 1994, Figure 1 for more information on photon fluence) plots the cumulative uncollided photon fluence (% of total photons impinging upon the detector) vs distance from a point under the detector (1.0 meter height above the ground) for 100 and 1000 keV gamma photons. About 30% of the gamma photons impinging on the detector originate in the soil within 1.0 meter of the detector; about 56% originate within 2.0 meters of the detector; and about 86% originate within 6.0 meters (the field of view) of the detector. Figure 4.1-2 adds insight relative to photon fluence as a function of soil depth. Each cell in Figure 4.1-2 in a vertical or horizontal sequence represents 1.0% of the total uncollided gamma photon fluence. (Each cell actually represents a three-dimensional circular tube of soil surrounding the HPGe detector, and the "cells" in Figure 4.1-2 actually represent

cross sections of those tubes.) The practical significance of Figure 4.1-2 is that a HPGe detector can effectively detect gamma photons only to a depth of about 10 to 15 cm., and this depth range is limited to within 2 meters of the detector. Both Figures 4.1-1 and 4.1-2 are for fields of view at a 1.0 meter detector height.

4.1.1 Guidance

- For general survey measurements a 1.0 meter detector height should be used.
- For boundary delineation measurements, particularly for small hot spots or WAC exceedance areas, a 31 cm or 15 cm detector height should be used.
- In areas where contamination is homogeneous, very similar results will be obtained at different detector heights.
- In areas where contamination is very heterogeneous, different results may be obtained at different detector heights.
- Refer to Section 5.5 (Heterogeneity) generally and Tables 5.5-1 through 5.5-3 specifically for a discussion of detector height as related to degree of heterogeneity.

4.1.2 See Also:

4.2 RTRAK Single Measurement Field of View

4.4 Detector Height and Data Acquisition Time

4.10 HPGe Measurement Grid Configuration

Figure 4.1-1 Cumulative Fluence of 100 and 1000 keV Photons at 1.0 m detector height
(Assumes a Homogeneous Distribution with Depth)

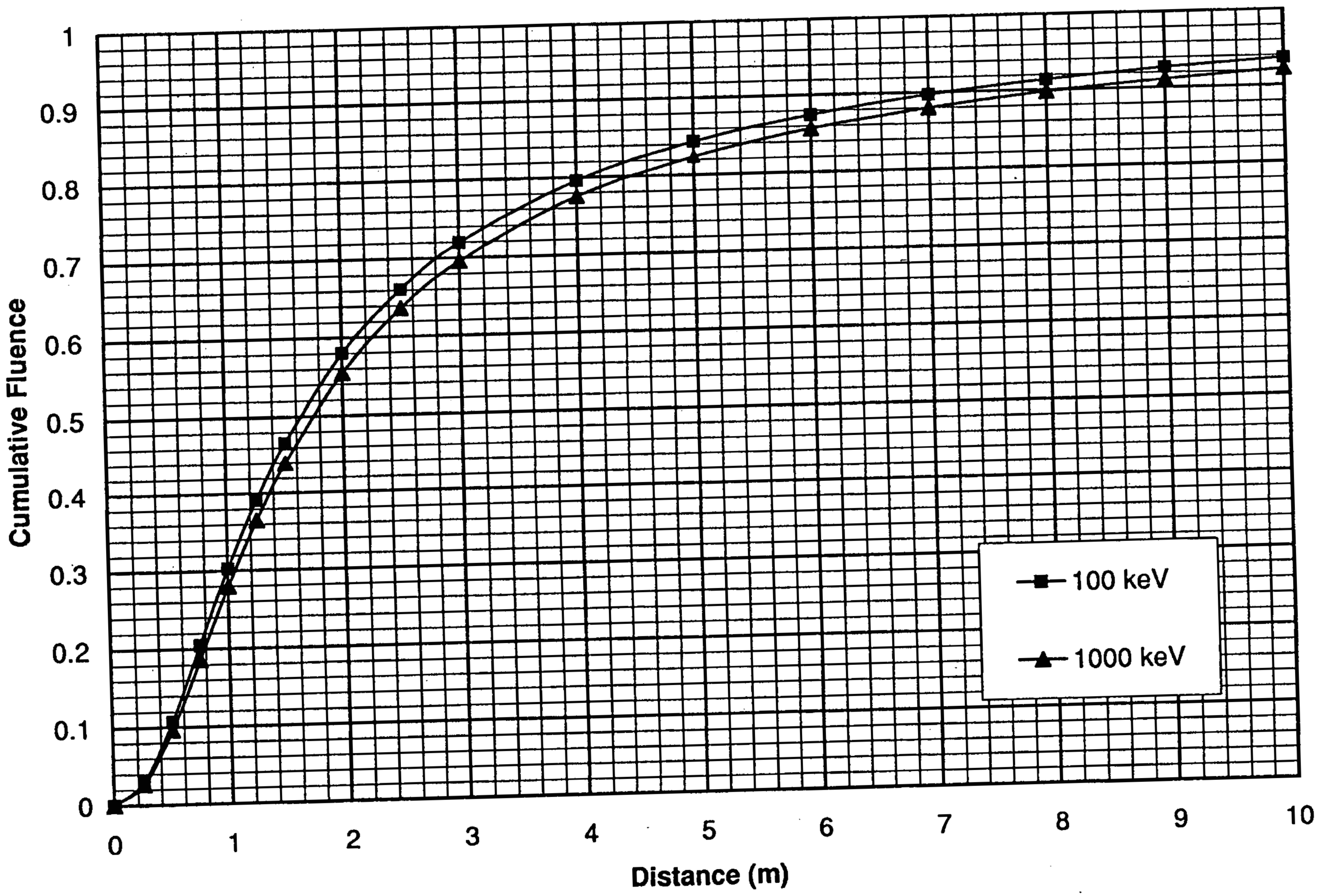
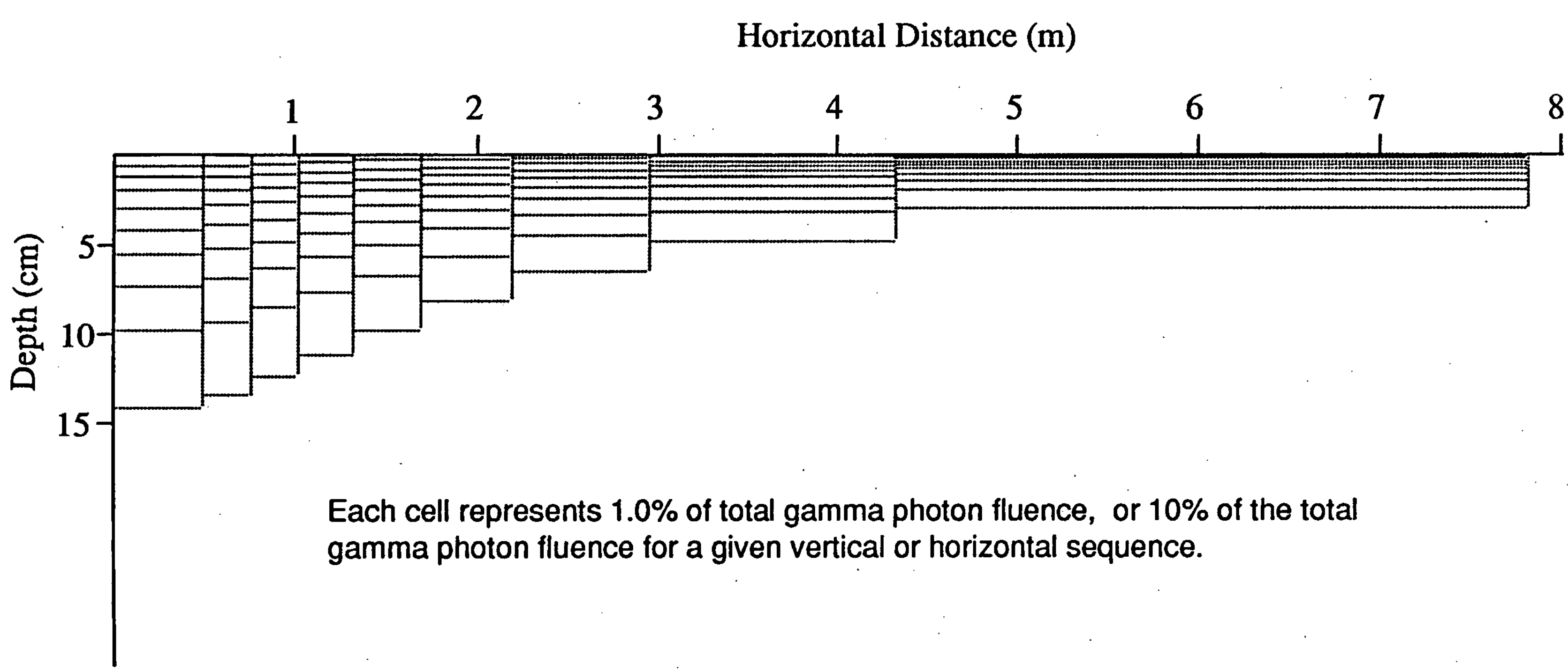


FIGURE 4.1-2
Fluence of 500 keV Gamma Photons As a Function of Soil Depth and Horizontal Distance from a Detector at a 1.0 meter height.



4.2 RTRAK SINGLE MEASUREMENT FIELD OF VIEW

In addition to gamma photon energy, the single measurement RTRAK field of view also depends upon the forward speed of the tractor and the data acquisition time. The RTRAK single measurement field of view as a function of speed and data acquisition time is shown in Table 4.2-1. A 1.2 meter radius (radius of field of view when RTRAK is stationary) is used to calculate the areal extent of the field of view. Although the field of view depends upon detector height, the RTRAK detector remains a fixed distance above the ground (1.0 ft). Using operating parameters of 1.0 mph with a 4 second data acquisition time, the RTRAK single measurement field of view is 8.8 square meters. (Although 0.5 mph gives a smaller field of view which may be desirable in some situations, tractor speed control at 0.5 mph is very difficult.) Figure 4.2-1 shows how the field of view is calculated for 1.0 mph with a 4 second data acquisition time.

TABLE 4.2-1
RTRAK FIELD OF VIEW
AS A FUNCTION OF SPEED AND DATA ACQUISITION TIME

Speed(mph)	Data Acquisition Time		
	2 Seconds	4 seconds	8 seconds
0.5	5.6*	6.7	8.8
1.0	6.7	8.8	13.1
2.0	8.8	13.1	21.7

* Numbers represent the area of the field of view in square meters.

4.2.1 Guidance

- Whereas the HPGe field of view is circular, the RTRAK, because it moves, sweeps out a field of view that resembles an elongated ellipse.
- The fields of view in Table 4.2-1 should not be used if static RTRAK measurements are made. The static RTRAK field of view is approximately 4.5 square meters (see below).
- In reality, single measurement RTRAK fields of view are somewhat smaller than indicated in Table 4.2-1 because of the shielding effect of the tractor tires. That shielding effect is very difficult to quantify, however.

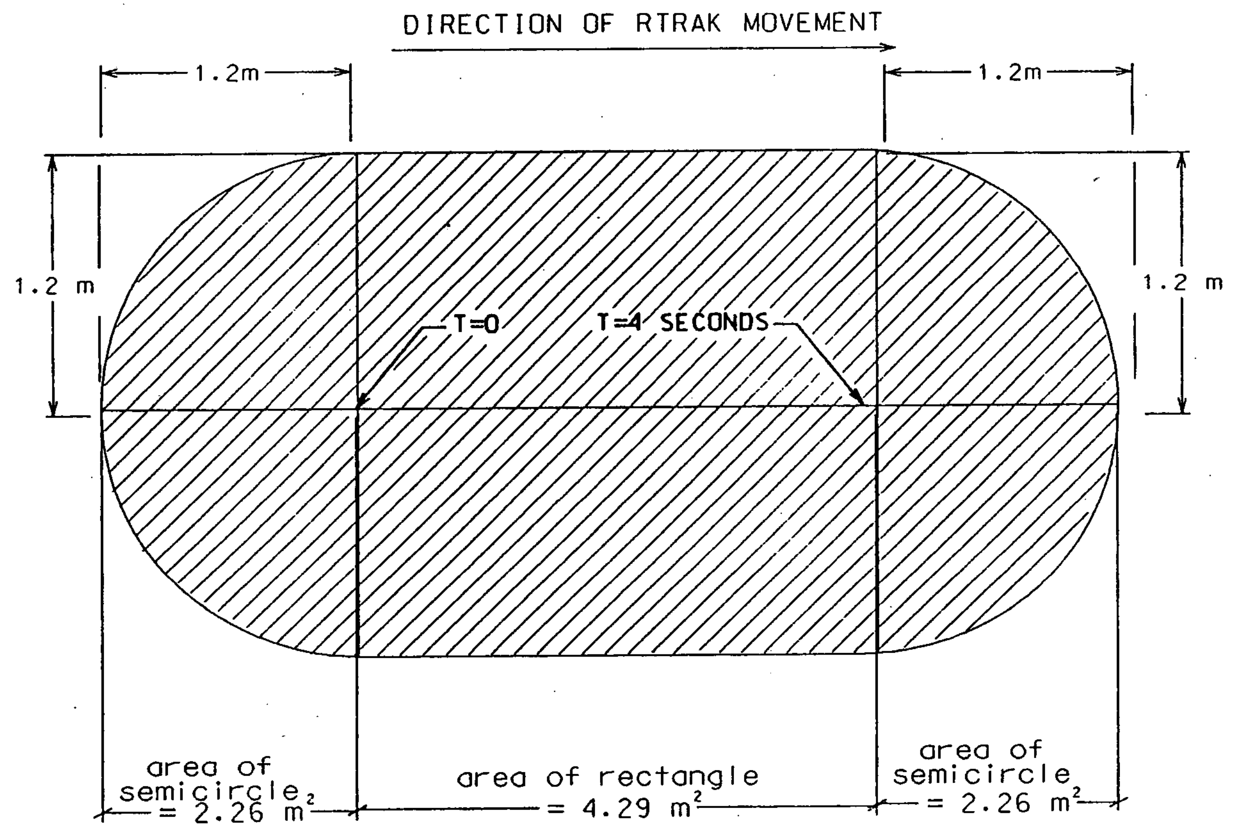
4.2.2 See Also:

4.1 HPGe Detector Field of View

4.3 RTRAK Multiple Measurement Field of View

FIGURE 4.2-1.

FIELD OF VIEW OF A SINGLE RTRAK MEASUREMENT AT 1.0 MPH WITH A 4.0 SECOND DATA ACQUISITION TIME



FIELD OF VIEW
= 2.26 + 4.29 + 2.26
= 8.81 M

RTRAK STARTS AT T=0 AND MEASUREMENT ENDS AT T=4 SECONDS. 1.0 MPH = 0.447 M/SEC. IN 4.0 SECONDS THE RTRAK TRAVELS 1.787 METERS.

000083

v:+5cra3+dgn+bmp+calc-005.dgn

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4.3 RTRAK MULTIPLE MEASUREMENT FIELD OF VIEW

The general approach to RTRAK measurements consists of alternating, adjacent, back and forth passes. A pass is defined as a series of consecutive measurements made in a single direction. The determination of the total field of view taking into account overlap of successive fields of view is more complicated for RTRAK than for HPGe. Figures 4.3-1 and 4.3-2 depict cumulative (or total) fields of view, the amount of overlap between consecutive measurements in a single pass, and the amount of overlap between two measurements in adjacent passes.

An equation has been developed which estimates the total field of view for any given number of measurements in a single pass and for any given number of passes.

$$\text{Total Field of View } (m^2) = k(0.8941nrvt + 3.1416\, r^2) - [(k-1)((0.4471nvLt) + L^2)] \qquad [1]$$

and

$$\text{Average Field of View } (m^2) = \text{Total Field of View}/kn \qquad [2]$$

where:

n =	number of measurements in a pass
k =	number of passes (each pass is assumed to have the same number of measurements)
r =	radius of the field of view in meters (1.2 for the RTRAK as currently configured)
v =	RTRAK speed in miles per hour
t =	data acquisition time in seconds
L =	Amount of overlap in meters between adjacent passes
kn =	total number of measurements

Tables 4.3-1 through 4.3-3 show total fields of view and average fields of view per measurement calculated from Equations 1 and 2 for typical RTRAK operating conditions (1.0 mph and 4.0 second data acquisition time). Table 4.3-4 represents RTRAK operating conditions in which the RTRAK is moving at 1.0 mph with a 2.0 second data acquisition time and in which each moving pair of 2.0 second measurements is combined as a moving average of four second count times. These operating conditions are equivalent to 0.5 mph with a 8.0 second data acquisition time. Table 4.3-4 is included because it simulates operating conditions which effectively result in a denser measurement grid without sacrificing speed or reducing data acquisition time.

Several aspects about RTRAK operating conditions are quite evident from Tables 4.3-1 to 4.3-4. First, with increasing amount of overlap between adjacent passes, the total field of view for a given number of measurements decreases significantly. Thus, for 10,000 measurements (k=100, n=100), the total field of view for no overlap (43,369 m^2) is nearly double that for a 1.0 meter overlap (25, 565 m^2). Second, the effective coverage significantly increases as the amount of overlap increases. Effective coverage is defined as the field of view for a single measurement (8.81 m^2) divided by the average field of view per measurement. For no overlap between adjacent passes, the effective coverages vary between 100 and 200%, while for a 1.0 meter overlap, the effective coverage varies between 100 and 300%. ~~Third, increasing the effective measurement density per the operating conditions represented by Table 4.3-4 results in a significantly increased effective coverage of up to nearly 500% without sacrificing speed.~~

Table 4.3-5 puts the above discussion into perspective relative to measuring one acre of soil with RTRAK. (The fact that the total field of view is somewhat larger than an acre (4,047 m^2) results from rounding off fractional measurements and using the next highest number.)

4.3.1 Guidance

- Unless special circumstances dictate otherwise, use 0.4 meter overlap on all adjacent passes. Such an overlap corresponds to a separation of the center line of the passes of 2 m. The need for overlap is desirable because of the decreased photon fluence from areas distant from the detector. An overlap of 0.4 m is tolerable as it will not leave either major areas without coverage or major areas with over coverage.

- Shielding effects of tires are diminished or minimized by alternating back and forth passes with overlap.

- Data in Table 4.3-5 can be used to calculate the theoretical area represented by a given number of aggregated measurements. For example, suppose that at 1.0 mph, a 4-second data acquisition time and a 0.4 meter overlap, 100 measurements are aggregated for mapping purposes. The area represented by 100 aggregated measurements is 100 x (4283/1152) = 372 m^2.

- In reality, the area represented by an aggregated number of measurements could be significantly greater or smaller than the area calculated above, depending upon driver skill in driving straight lines with the exact degree of overlap on all passes, terrain obstructions, and topographic features.

4.3.2 See Also:

4.2 RTRAK Single Measurement Field of View

4.15 Mapping Conventions

TABLE 4.3-1
RTRAK FIELD OF VIEW AT 1.0 MPH, 4.0 SECOND DATA ACQUISITION TIME, AND 0.0 METER OVERLAP BETWEEN PASSES

Number of RTRAK Passes	Number of Measurements per RTRAK Pass									
	1		2		4		10		100	
	Total Field of View (m^2)	Field of View per Measurement (m^2)	Total Field of View (m^2)	Field of View per Measurement (m^2)	Total Field of View (m^2)	Field of View per Measurement (m^2)	Total Field of View (m^2)	Field of View per Measurement (m^2)	Total Field of View (m^2)	Field of View per Measurement (m^2)
1	8.82	8.82	13.1	6.55	21.7	5.42	47.4	4.74	434	4.34
2	17.6	8.82	26.2	6.55	43.4	5.42	94.9	4.74	867	4.34
4	35.3	8.82	52.4	6.55	86.8	5.42	190	4.74	1735	4.34
10	88.2	8.82	131	6.55	217	5.42	474	4.74	4337	4.34
100	882	8.82	1311	6.55	2169	5.42	4744	4.74	43369	4.34

TABLE 4.3-2
RTRAK FIELD OF VIEW AT 1.0 MPH, 4.0 SECOND DATA ACQUISITION TIME, AND 0.4 METER OVERLAP BETWEEN PASSES

Number of RTRAK Passes	Number of Measurements per RTRAK Pass									
	1		2		4		10		100	
	Total Field of View (m^2)	Field of View per Measurement (m^2)	Total Field of View (m^2)	Field of View per Measurement (m^2)	Total Field of View (m^2)	Field of View per Measurement (m^2)	Total Field of View (m^2)	Field of View per Measurement (m^2)	Total Field of View (m^2)	Field of View per Measurement (m^2)
1	8.82	8.82	13.1	6.55	21.7	5.42	47.4	4.74	434	4.34
2	16.8	8.38	24.6	6.16	40.4	5.04	87.6	4.38	796	3.98
4	32.6	8.16	47.7	5.96	77.7	4.8 6	168	4.20	1520	3.80
10	80.3	8.03	117	5.84	190	4.74	409	4.09	3692	3.69
100	795	7.95	1153	5.77	1870	4.67	4020	4.02	36271	3.63

3546

TABLE 4.3-3
RTRAK FIELD OF VIEW AT 1.0 MPH, 4.0 SECOND DATA ACQUISITION TIME, AND 1.0 METER OVERLAP BETWEEN PASSES

Number of RTRAK Passes	Number of Measurements per RTRAK Pass									
	1		2		4		10		100	
	Total Field of View (m^2)	Field of View per Measurement (m^2)	Total Field of View (m^2)	Field of View per Measurement (m^2)	Total Field of View (m^2)	Field of View per Measurement (m^2)	Total Field of View (m^2)	Field of View per Measurement (m^2)	Total Field of View (m^2)	Field of View per Measurement (m^2)
1	8.82	8.82	13.1	6.55	21.7	5.42	47.4	4.74	434	4.34
2	14.8	7.42	21.6	5.41	35.2	4.40	76.0	3.80	688	3.44
4	26.9	6.72	38.7	4.84	62.3	3.89	133	3.33	1195	2.99
10	63.1	6.3 1	89.9	4.49	144	3.59	304	3.04	2718	2.72
100	606	6.06	858	4.29	1362	3.40	2875	2.87	25565	2.56

TABLE 4.3-4
RTRAK FIELD OF VIEW AT 0.5 MPH, 8.0 SECOND DATA ACQUISITION TIME, AND 0.4 METER OVERLAP BETWEEN PASSES

Number of RTRAK Passes	Number of Measurements per RTRAK Pass									
	1		2		4		10		100	
	Total Field of View (m^2)	Field of View per Measurement (m^2)	Total Field of View (m^2)	Field of View per Measurement (m^2)	Total Field of View (m^2)	Field of View per Measurement (m^2)	Total Field of View (m^2)	Field of View per Measurement (m^2)	Total Field of View (m^2)	Field of View per Measurement (m^2)
1	8.82	8.82	13.1	6.55	21.7	5.42	47.4	4.74	434	4.34
2	16.8	8.38	24.6	6.16	40.4	5.04	87.6	4.38	796	3.98
4	32.6	8.16	47.7	5.96	77.7	4.86	168	4.20	1520	3.80
10	80.3	8.03	117	5.84	190	4.74	409	4.09	3692	3.69
100	795	7.95	1153	5.77	1870	4.67	4020	4.02	36,271	3.63

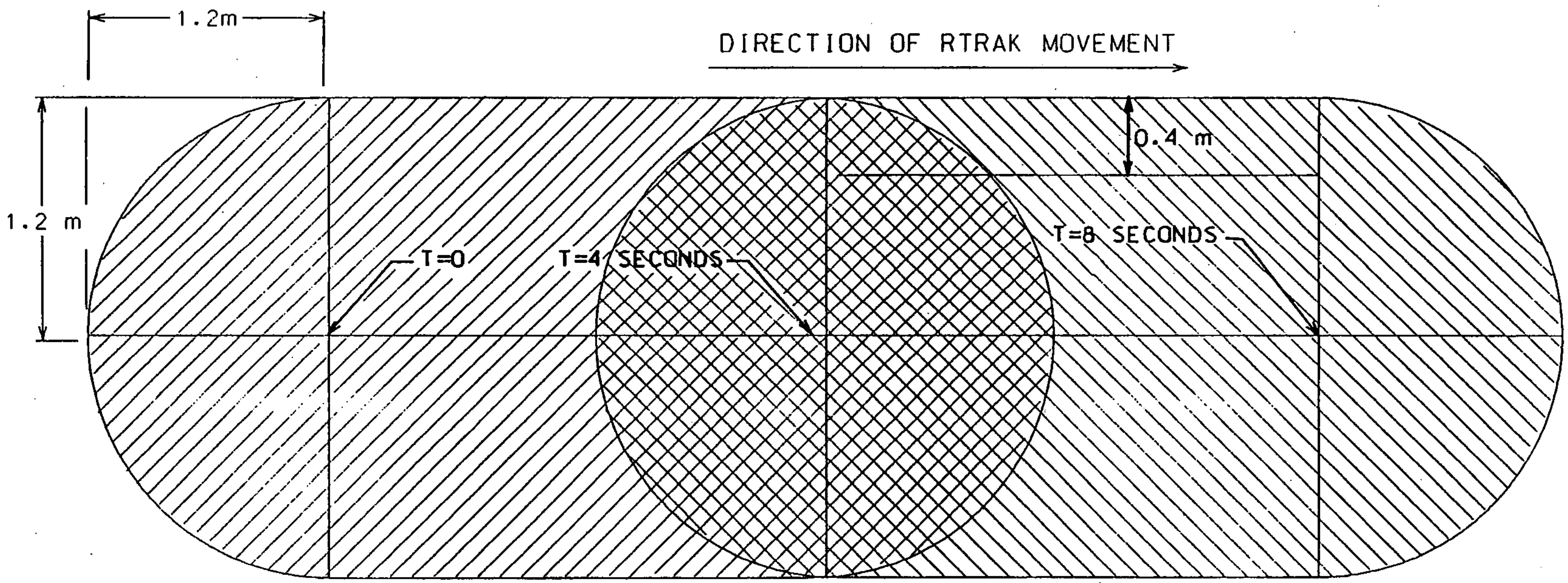
000089

TABLE 4.3-5
NUMBER OF RTRAK MEASUREMENTS PER ACRE OF GROUND AS A FUNCTION OF OPERATING CONDITIONS

Parameter	Operating Conditions			
	1.0 mph, 4.0 Second Data Acquisition Time, No Overlap Between Adjacent Passes	1.0 mph, 4.0 Second Data Acquisition Time, 0.4 meter Overlap Between Adjacent Passes	1.0 mph, 4.0 Second Data Acquisition Time, 1.0 meter Overlap Between Adjacent Passes	0.5 mph, 8.0 Second Data Acquisition Time, 0.4 meter Overlap Between Adjacent Passes
Number of Measurements per Pass	36	36	36	36
Number of Passes	27	32	46	32
Total Measurements	972	1152	1656	1152
Total Field of View (m^2)	4,291	4283	4370	4284
Average Field of View per Measurement (m^2)	4.41	3.72	2.64	3.72

FIGURE 4.3-1

FIELDS OF VIEW OF TWO CONSECUTIVE RTRAK MEASUREMENTS IN A SINGLE PASS



RTRAK STARTS AT T=0 AND FIRST MEASUREMENT ENDS AT T=4 SECONDS. MEASUREMENT 2 STARTS AT T=4 SECONDS AND ENDS AT T=8 SECONDS. IN THIS EXAMPLE RTRAK MOVES AT 1.0 mph WITH A 4 SECOND DATA ACQUISITION TIME.

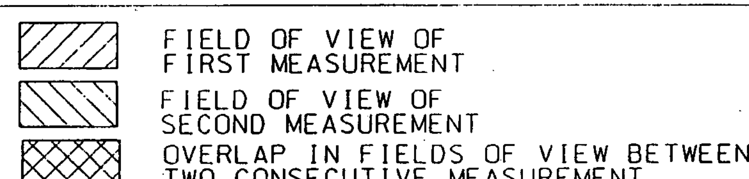
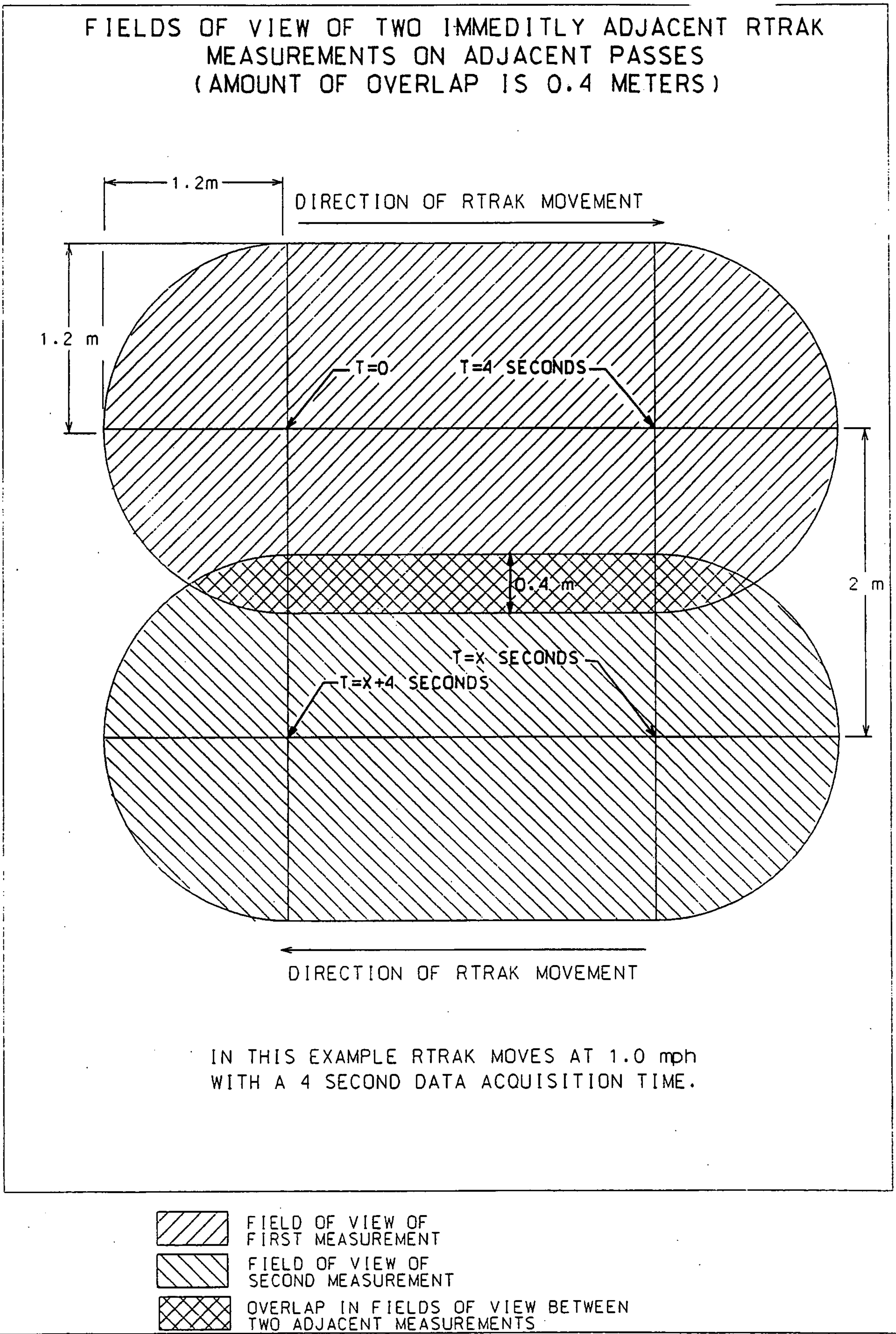


FIGURE 4.3-2

3546



v:45cro3#dgn#omp#colc-004.dgn

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4.4 HPGe DETECTOR HEIGHT AND DATA ACQUISITION TIME

In order to detect very small WAC exceedance areas (Section 4.6, WAC Exceedance Detection), or to closely delineate excavation boundaries, it may be necessary to lower the HPGe detector to within six inches of the ground surface. Further, when measuring areas of high total uranium concentration, such as WAC exceedance concentrations, a reduced data acquisition time will result in more HPGe measurements per day without compromising the validity of the data. The discussion below documents that 5-minute data acquisition times and a 6-inch HPGe detector height yield very similar measurements to those taken at greater detector heights and longer count times. These data are presented in this document because they have not appeared in any comparability study to date.

Table 4.4-1 presents ten sets of measurements taken at the FEMP Field Quality Control Station (FCS) over a six-day period in November, 1997. Each set of measurements consisted of 900-second (15 minutes) and 300-second (5 minutes) count times at detector heights of 1.0 meters, 31 cm (1.0 ft), and 15 cm (6.0 inches).

Table 4.4-1 summarizes the results of the above measurements and demonstrates that:

1) There is little difference between the means of 300-second and 900-second data for a given isotope at a given detector height for total uranium, thorium-232, radium-226 and potassium-40.

2) There is little difference between the means of 15 cm and 31 cm data for a given isotope at a given count time for total uranium, thorium-232, radium-226 and potassium-40.

3) Although 100 cm data tend to be slightly lower than 15 cm and 31 cm data, the difference is less than 10% for total uranium, less than 5% for thorium-232 and potassium-40, and less than 3% for radium-226. The FCS is an area with elevated uranium relative to immediately surrounding areas; therefore, the field of view when HPGe is 15 cm or 31 cm does not include areas of lower total uranium concentration that are in the 1.0 meter field of view.

4) Generally, the standard deviations are larger for shorter count times than for longer count times. This is not surprising. However, these standard deviations should not be used to calculate system uncertainties for trigger level purposes for 5-minute count times. The uncertainties used to calculate trigger levels for 15-minute count times (Section 4.5) are based upon six months of data collected at the FCS under a variety of weather and climate conditions.

4.4.1 Guidance

- A 5-minute count time and 15 cm detector height may be employed with confidence using the HPGe where field measurement objectives require such conditions. Sections 3.3 and 3.4 indicate that 15 cm HPGe detector height shall be used for hot spot and above-WAC delineation.

- Five-minute count times at any detector height may be used for detecting, confirming, and delineating WAC exceedances. The number of HPGe measurements per day will increase (greater productivity and less cost per measurement).

- 31 cm and 15 cm detector heights will increase the number of measurements required to scan a given area (at 100% coverage) with an attendant increase in measurement cost per unit area (cost per measurement depends upon count time).

- Use a lower trigger level for total uranium for WAC investigations measured with a 5-minute count time (928 ppm) than with a 15-minute count time (947 ppm). This is supported by the data in Table 4.4-1 which show larger standard deviations for 5-minute count times than for 15-minute count times. See Table 4.5-1 for HPGe trigger level values.

4.4.2 See Also:

4.1 HPGe Detector Field of View

4.6 WAC Exceedance Detection

TABLE 4.4-1
HPGe MEASUREMENTS AT DETECTOR HEIGHTS OF 15 AND 31 CM AND 300 AND 900 SECOND COUNT TIMES

Detector Height (cm)	Data Count Time (sec.)	Statistical Parameters	Analytes			
			Total Uranium (ppm)	Thorium-232 (pCi/g)	Potassium-40 (pCi/g)	Radium-226 (pCi/g)
15	300	Number *	10	10	10	10
		Mean	71.2	0.89	10.3	0.98
		Std. Dev.	2.99	0.03	0.27	0.16
15	900	Number	10	10	10	10
		Mean	71.3	0.86	10.3	0.98
		Std. Dev.	1.61	0.02	0.24	0.15
31	300	Number	10	10	10	10
		Mean	70.2	0.87	10.3	1.04
		Std. Dev.	3.04	0.03	0.42	0.16
31	900	Number	10	10	10	10
		Mean	69.5	0.85	10.3	1.01
		Std. Dev.	1.98	0.03	0.24	0.15
100	300	Number	10	10	10	10
		Mean	66.8	0.83	10.0	1.01
		Std. Dev.	3.35	0.04	0.29	0.20
100	900	Number	10	10	10	10
		Mean	65.9	0.83	10.1	0.99
		Std. Dev.	2.35	0.02	0.18	0.18

* Number of measurements.

4.5 TRIGGER LEVELS

This section establishes trigger levels that can be used to aid in decision making. A trigger level is defined as *a specified radionuclide concentration that, if exceeded by a HPGe or RTRAK measurement, provides the basis for some subsequent action to be taken.* This action could be excavation of soil, additional *in-situ* gamma spectrometry measurements, or collection and analysis of physical samples, for example. The general approach described below can be applied to any analytical method/data set, but the tables provided are specific to the HPGe and RTRAK instruments as configured and used at the FEMP. In practice, FEMP trigger levels are associated with regulatory limits such as FRLs and WAC exceedance concentrations. The advantage of using a trigger level is that it provides a single value against which data can be quickly compared to screen a location relative to some limiting criterion.

Because every HPGe or RTRAK measurement has some corresponding uncertainty, trigger levels are typically set below the actual regulatory level to reduce the chance of mistakenly classifying soil as meeting the limit when it actually does not. The difference between the regulatory limit and the trigger level is a function of the precision (total system uncertainty) of the measurement being performed and the required level of confidence that a measurement at or below the trigger level will not exceed the regulatory limit. Because the precision of a measurement method is radionuclide specific, the trigger level will also be radionuclide specific. The trigger level is defined as:

$$\text{Trigger} = L - k\sigma_{limit} \qquad [1]$$

where:

- L = the magnitude of the limiting criterion such as the FRL, hot spot criterion, or WAC
- k = the standard normal variate; a statistical factor related to the acceptable confidence level of the measurement. At the 95% confidence level, k is equal to 1.645 for a single-tailed distribution.
- σ_{limit} = the standard deviation assumed for measurements of soil concentrations that are numerically equal to the limit

Several factors are particularly important in establishing trigger levels for HPGe and RTRAK. First, a 95% confidence level for a one-sided distribution ensures that the regulatory limit will not likely be exceeded. Second, from a practical perspective, a trigger level cannot be less than or nearly equal to either the typical background concentration of a given radionuclide or to the detection limit of a given radionuclide in order to prevent the trigger level from being frequently exceeded even though elevated activity is not actually present. *Third, the trigger levels presented below are most applicable when the size of the potential WAC exceedance area or FRL exceedance area is approximately the same size as,* *or larger than, the field of view of the detector*. The trigger levels presented below become less applicable if the potential regulatory exceedance area is smaller (particularly, much smaller) than the field of view of the detector. This situation is discussed in the WAC Exceedance Detection topic (Section 4.6).

4.5.1 HPGe Trigger Levels

HPGe trigger levels for a data acquisition time of 15 minutes are shown in Table 4.5-1 and have been calculated using Equation 1. The standard deviation representing overall HPGe precision is taken from information in Tables 2 and 3 in the December, 1997 report entitled "Effect of Environmental Variables Upon *In-Situ* Gamma Spectrometry Data." Data in Tables 2 and 3 of that report indicate that the overall HPGe system uncertainty for 15-minute count times expressed as the relative standard deviation based upon measurements at the Field Quality Control Station is 4.88% for total uranium, 5.42% for thorium-232, and 7.84% for radium-226 (afternoon measurements). The assumption is made that these estimates of the total HPGe system uncertainty as a percentage of the mean are also valid at more elevated concentrations than were measured at the Field Quality Control Station (this is a conservative assumption as the counting error will decrease in a relative sense as the concentration increases). Conversely, the assumption is also made that the total uranium numbers for uncertainty as a percentage of the mean are also valid at lower concentrations than were measured at the Field Quality Control Station. This assumption probably underestimates the standard deviation at 10 and 20 ppm. By multiplying the regulatory limit by the relative standard deviation for the total system, standard deviations for measurements at regulatory limits can be calculated for use in Equation 1.

Most of the trigger levels in Table 4.5-1 are based upon data acquired for 15-minute count times. For WAC measurements, however, 5-minute count times are adequate. Table 4.5-1 also shows a trigger level for total uranium for 5-minute count times.

4.5.2 RTRAK Trigger Levels

As noted in the topic on MDCs (Section 5.1), at low analyte concentrations (near the FRLs) of various isotopes the single measurement MDC may be higher than the FRL. Similarly, the July 1997 RTRAK Applicability Report noted that single measurements at low analyte concentrations yielded large standard deviations. Both the large standard deviation and high MDCs complicate the use of trigger levels for single measurement data. As stressed in the July 1997 RTRAK Applicability Study, both

MDCs and measurement standard deviations (precision) can be reduced by aggregating a number of measurements and using the aggregate as the basis for calculating a standard deviation and MDC.

The use of aggregate measurements complicates establishing a trigger level because Equation 1 can no longer be used. Instead, a practical approach to setting a trigger level is to arbitrarily define a minimum acceptable trigger level as a percentage of the applicable regulatory limit. This percentage must be a value such that the trigger level is well above the detection limit and is also well above the radionuclide background concentration in soils. Equation 2, below, can then be solved for the corresponding number of measurements that must be aggregated in order for the standard deviation to be acceptably reduced.

$$\text{Minimum Acceptable Trigger} = L - k\sigma_{limit}/(n)^{1/2} \qquad [2]$$

where:

- L = the magnitude of the limiting criterion such as the FRL, hot spot criterion, or WAC
- k = the standard normal variate, a statistical factor related to the acceptable confidence level of the measurement. At the 95% confidence level, k is equal to 1.645 for a single-tailed distribution.
- σ_{limit} = the standard deviation assumed for RTRAK measurements of soil concentrations numerically equal to the limit
- n = the number of measurements that are aggregated

For the purposes of this discussion, the minimum acceptable RTRAK trigger level is set at 70% of the applicable regulatory limit. This is not based on a rigorous statistical or quantitative evaluation, but was chosen in part because at 70% of the limit, acceptable trigger levels can be achieved with single measurements for uranium WAC exceedances. Using single measurements simplifies the use of the trigger level concept. In addition, the Real-Time Working Group concluded that a trigger level lower than 750 ppm would be acceptable for the uranium WAC; 70% of the WAC is 721 ppm.

The trigger levels and the number of measurements that must be aggregated (calculated using Equation 2) to achieve these levels are presented in Tables 4.5-2 through 4.5-6. Tables 4.5-2 through 4.5-4 are for total uranium at FRLs of 10, 20, and 82 ppm respectively. Tables 4.5-5 and 4.5-6 are for thorium-232 and radium-226, respectively. Each table lists trigger levels for the FRL and WAC (total uranium only) at acquisition times of 2, 4, and 8 seconds.

The tables can be interpreted as follows:

1. The first and second columns define the applicable limiting criterion.

2. The third column is the minimum acceptable trigger level calculated as 70% of the limiting criterion.

3. Subsequent columns provide trigger level information for the three acquisition times.

4. The following information is provided for each acquisition time:

   a. The column labeled "Single Measurement Trigger" shows the trigger level that would be calculated for a single measurement using Equation 1. The column is annotated to indicate whether this satisfies the requirement to exceed the minimum acceptable trigger level. The notation "marginal" indicates that the single measurement trigger level is less than 10% lower than the minimum acceptable trigger level.

   b. The column labeled "No. Aggregated Measurements (Trigger)" shows the number of measurements that must be aggregated in order to reduce the uncertainty to achieve the minimum acceptable trigger level. This number is calculated using Equation 2 and rounded up to the next whole measurement. Underneath the number of measurements, in parentheses, is the actual calculated trigger level that would be obtained for the aggregated measurements.

4.5.3 Guidance

- A rule of thumb is that WAC exceedance areas can be recognized by HPGe using the above trigger levels if the WAC exceedance area has a radius at least 66% of the radius of the field of view of the HPGe detector at a given height and the concentration of total uranium is at least 1500 ppm for the WAC exceedance area.

- For WAC exceednces much smaller than the field of view of the HPGe detector, Table 4.6-1 can be used to provide guidance for WAC size, concentration, and recognizability at a given detector height.

- The trigger levels for FRL attainment are valid for all circumstances and situations.

- Care must be taken when aggregating RTRAK measurements to ascertain that the area represented by the aggregated measurements is not significantly larger than the hot spot of interest. This can be a practical limitation to the use of RTRAK to detect hot spots. Section 4.3-1 gives a method to determine the approximate size of an area represented by a number of aggregated measurements.

4.5.4 See Also

3.4 Evaluation of Above-WAC Surface Soil

3.5 Excavation Control for Lifts

3.6 Horizontal Excavation Boundary Delineation

4.6 WAC Exceedance Detection

TABLE 4.5-1
HPGe TRIGGER LEVELS FOR FRL AND WAC EXCEEDANCES
(15-MINUTE COUNT TIME)

Radionuclide	Regulatory Application	Regulatory Limit	Trigger Level
Total Uranium (ppm)	FRL	82	75
	FRL	20	18
	FRL	10	9.0
Total Uranium (ppm)	WAC	1030	947 (928*)
Thorium-232 (pCi/g)	FRL	1.50	1.37
Radium-226 (pCi/g)	FRL	1.70	1.48

* Trigger level for a 5-minute count time

TABLE 4.5-2
TOTAL URANIUM RTRAK TRIGGER LEVELS (FRL = 10 ppm)

Application	Limit (ppm)	Minimum Acceptable Trigger (ppm)	2 sec Acquisition Time		4 sec Acquisition Time		8 sec Acquisition Time	
			Single Measurement Trigger (ppm)	No. Aggregated Measurements (Trigger, ppm)	Single Measurement Trigger (ppm)	No. Aggregated Measurements (Trigger, ppm)	Single Measurement Trigger (ppm)	No. Aggregated Measurements (Trigger, ppm)
FRL	10	7	-122 unacceptable	1925 (7)	-90 unacceptable	1119 (7)	-62 unacceptable	583 (7)
WAC	1030	721	695 marginal	2 (793)	787 acceptable	1 (787)	860 acceptable	1 (860)

TABLE 4.5-3
TOTAL URANIUM RTRAK TRIGGER LEVELS (FRL = 20 ppm)

Application	Limit (ppm)	Minimum Acceptable Trigger (ppm)	2 sec Acquisition Time		4 sec Acquisition Time		8 sec Acquisition Time	
			Single Measurement Trigger (ppm)	No. Aggregated Measurements (Trigger, ppm)	Single Measurement Trigger (ppm)	No. Aggregated Measurements (Trigger, ppm)	Single Measurement Trigger (ppm)	No. Aggregated Measurements (Trigger, ppm)
FRL	20	14	-112 unacceptable	481 (14)	-80 unacceptable	280 (14)	-52 unacceptable	146 (14)
WAC	1030	721	695 marginal	2 (793)	787 acceptable	1 (787)	860 acceptable	1 (860)

000101

TABLE 4.5-4
TOTAL URANIUM RTRAK TRIGGER LEVELS (FRL = 82 ppm)

			2 sec Acquisition Time		4 sec Acquisition Time		8 sec Acquisition Time	
Application	Limit (ppm)	Minimum Acceptable Trigger (ppm)	Single Measurement Trigger (ppm)	No. Aggregated Measurements (Trigger, ppm)	Single Measurement Trigger (ppm)	No. Aggregated Measurements (Trigger, ppm)	Single Measurement Trigger (ppm)	No. Aggregated Measurements (Trigger, ppm)
FRL	82	57	-51 unacceptable	30 (58)	-21 unacceptable	18 (58)	8 unacceptable	9 (57)
WAC	1030	721	695 marginal	2 (793)	787 acceptable	1 (787)	860 acceptable	1 (860)

TABLE 4.5-5
THORIUM-232 RTRAK TRIGGER LEVELS IN pCi/g

			2 sec Acquisition Time		4 sec Acquisition Time		8 sec Acquisition Time	
Application	Limit (pCi/g)	Minimum Acceptable Trigger (pCi/g)	Single Measurement Trigger (pCi/g)	No. Aggregated Measurements (Trigger, pCi/g)	Single Measurement Trigger (pCi/g)	No. Aggregated Measurements (Trigger, pCi/g)	Single Measurement Trigger (pCi/g)	No. Aggregated Measurements (Trigger, pCi/g)
FRL	1.5	1.05	0.87 unacceptable	2 (1.05)	0.95 marginal	2 (1.11)	1.01 marginal	2 (1.15)
WAC	na	na	na	na	na	na	na	na

TABLE 4.5-6
RADIUM-226 RTRAK TRIGGER LEVELS IN pCi/g

Application	Limit (pCi/g)	Minimum Acceptable Trigger (pCi/g)	2 sec Acquisition Time		4 sec Acquisition Time		8 sec Acquisition Time	
			Single Measurement Trigger (pCi/g)	No. Aggregated Measurements (Trigger, pCi/g)	Single Measurement Trigger (pCi/g)	No. Aggregated Measurements (Trigger, pCi/g)	Single Measurement Trigger (pCi/g)	No. Aggregated Measurements (Trigger, pCi/g)
FRL	1.7	1.2	0.34 unacceptable	8 (1.22)	0.63 unacceptable	5 (1.22)	0.82 unacceptable	3 (1.19)
WAC	na	na	na	na	na	na	na	na

000103

4.6 WAC EXCEEDANCE DETECTION

WAC exceedance trigger levels, as presented in the "Trigger Level" topic (Section 4.5), are designed to detect areas of elevated contamination whose size approaches or exceeds the field of view area of either the HPGe detector or the RTRAK detector. However, experience in carrying out both the HPGe and RTRAK Comparability Studies and the remediation operations in the South Field has shown that areas of very elevated contamination can be considerably smaller than the field of view of the detector. In fact some areas of elevated contamination may be no more than several inches in diameter. Table 4.6-1 shows action levels for total uranium as a function of hypothetical WAC exceedance size, and detector height. *Action level is defined here as the highest concentration that, if exceeded by a HPGe measurement for an area in question, indicates the need for further evaluation.*

Table 4.6-1 is solely for the convenience of the Characterization Lead to help detect small WAC exceedances. The action levels in the Table 4.6-1 are calculated based upon the percentage of photons impinging upon the detector as shown in Miller et al. (1994, Figure 1). These calculations assume the hypothetical WAC exceedance area is centered directly below the detector and that all soil surrounding the WAC exceedance area has zero total uranium concentration. Thus, the action level will reflect only the photon fluence coming from the WAC material. In this case, the action level is simply the percentage photon fluence (as determined from Figure 1 in the paper by Miller et. al. using the uniform depth distribution model) times the total uranium concentration of the hypothetical WAC material. (For the values in Table 4.6-1, 1030 ppm was used as the concentration of above WAC material.) (Fluence rates for a 15 cm detector height are based upon a thoretical curve parallel to the 3.0 meter, uniform distribution curve in Figure 1 of the paper by Miller et. al. (1994). This curve was constructed such that it has a 87.5% cumulative fluence at a 1.0 meter distance from the detector.) The action levels in Table 4.6-1 have been rounded downward to the nearest 100 for simplicity of use and to build in extra conservatism.

The action levels in Table 4.6-1 are meant to be used to confirm and to delineate suspected WAC exceedances smaller than the field of view of the HPGe at a given detector height. Typically these suspected WAC exceedances will have been identified by some other means; for example, by visual recognition of exposed product, construction rubble, soil discoloration, or by frisking with a hand-held survey meter.

An alternative use of Table 4.6-1 is for detecting for WAC exceedances by HPGe when RTRAK cannot be used for some reason. Section 3.4-1 ("Hot Spot Detection") describes the use of the action level of 400 ppm for a 1.0 meter detector height when searching for WAC exceedance areas with HPGe.

4.6.1 Guidance

- Suspect objects or soil spots shall be checked with a hand-held GM survey meter for gross beta/gamma activity.
- Frisk the suspect area with a hand-held GM survey meter to delineate the area of elevated activity.
- Center the HPGe detector over the area of elevated activity.
- Use Table 4.6-1 to choose concentration levels that are representative of the suspect WAC exceedance areas when searching for WAC exceedance areas smaller in size than 66% of the field of view. For example, suppose a hand-held survey meter indicated an area of elevated activity having a radius of 0.5 meters. If a HPGe measurement at a detector height of 31 cm yielded a total uranium concentration greater than 400 ppm, a WAC exceedance is possible. If a HPGe measurement at a 15 cm detector height yielded a total uranium concentration greater than 700 ppm, a WAC exceedance is probable.
- Consult the *In-Situ* Gamma Spectrometry Group if different size WAC exceedances than those in Table 4.6-1 are to be detected for a given detector height.
- It is not realistic to expect to detect single small (several inches or less in diameter) areas of radioactive material exceeding WAC with HPGe or RTRAK. Note that the chances of collecting such material with physical samples is also extremely problematic.

4.6.2 See Also:

3.4 Evaluation of Above WAC Surface Soil

4.7 Use of Hand-Held Survey Meters

TABLE 4.6-1

ACTION LEVELS FOR TOTAL URANIUM

HPGe Detector Height	Radius (m) of WAC Exceedance Area to be Detected				
	0.2	0.5	1.25	1.5	3.0
1.0 m	*	--	--	400**	700
31 cm		400	800	--	--
15 cm	300	700	--	--	--

* Action levels not calculated.

** Action level (ppm) for WAC exceedance area to be detected.

4.7 USE OF HAND-HELD SURVEY METERS

Hand-held survey meters, some versions of which are commonly called friskers, can be useful tools for measuring radiation and radioactivity levels to support measurements of soils at the FEMP. Like their more sophisticated spectrometer counterparts, they can be used in the field in real time. The advantages of a hand-held survey meter include low cost, ruggedness, small size, and ease of use. This type of instrument is effective for quickly assessing the general contamination level in an area or of objects or small areas of concern such as discolored soil.

The limiting factor for the application for the typical survey meters used at the FEMP is that they only measure gross radiation or radioactivity levels. Thus, one generally cannot make a distinction between the principal contaminants of concern, i.e., uranium isotopes, thorium-232 series nuclides, and radium-226 nuclides. Not only are these instruments non-radionuclide specific, but their response can vary widely for the various radiations emitted by different radionuclides. Thus, the same meter reading could translate to different concentrations depending upon the mix of radionuclides present.

Despite the above limitations, a simple survey meter provides a reasonable overall measure of contamination. Where a reading is observed to be in excess of the normal background, it points to elevated radionuclide levels with the potential for a WAC~~, FRL,~~ or hot spot criteria exceedance. Given some knowledge of the contaminant mix, a rough conversion from count rate to concentration can be determined. At sufficiently elevated radionuclide levels, survey meters are quite sensitive and capable of delineating the area of contamination when used in a scanning mode.

Two hand-held instruments that can be used to support real time soil measurements are the Bicron MICRO-REM meter and a Ludlum GM probe and rate meter. Their description and uses are described in more detail in the following two sections.

4.7.1 <u>MICRO-REM Meter</u>

The MICRO-REM meter employs a tissue equivalent scintillator as a detector element. This meter ahd a fairly flat energy response to gamma radiation and reasonable sensitivity at background levels. It provides a reading of the external dose rate (which is closely related to the exposeure rate for environemtnal radiation fields) from all gamma-emitting sources present. When held at waist height, it essentially sees the same radiation field as a HPGe at one meter above the ground. It responds to both primary and scattered radiation so its radiation so its reading is generally proportional to the total count rate (peaks + continuum) in a HPGe or NaI spectrum. It is used in two ways to support the real time instrument program:

- to identify external radiation source interferences when using *in situ* spectrometers, as in the cab of the RTRAK;
- to serve as a quality control measurement to confirm the relative radiation intensity at a spectrum measurement location.

4.7.2 <u>GM Survey Meter</u>

The GM survey meter consists of a nominal 2" diameter Geiger-Muller pancake probe and a rate meter. This probe responds to typical beta radiation with an approximate efficiency of 10% (at the FEMP, the efficiency is 3% for beta particles emitted from protactinium-234) and to gamma radiation with an approximate efficiency of 1%. The probe can be held in the hand or attached to a pole to access areas that cannot be reached at arms length. Because of its sensitivity to beta radiation, it is most effective when held close to a measurement point (approximately one half inch). It can be passed over the surface using a scan rate of about 1 to 2 inches per second. Areas with surface activity of 1000 disintegrations per minute (dpm) per 100 cm^2 are readily measurable with this instrument. To support real time spectrometric measurements, the GM survey meter can be used for the following:

- to locate the highest reading in an elevated area (potential hot spot or WAC exceedance) to guide the "centering" of an HPGe or RTRAK measurement;
- to investigate objects or small areas that are picked up visually as suspicious;
- to scan cores or sections of soil sampled with devices such as the Geoprobe
- to scan areas that are inaccessible with either the RTRAK or HPGe such as steeply sloped surfaces or the bottoms of very narrow trenches.

4.7.3 <u>Calibation of GM Survey Meter</u>

The Gm survey meter has been used extensively to screen soil cores extracted from Area 2 Phase I in the vicinity of suspected WAC area SWU-5. As part of this activity, 260 soil samples from screened core intervals were analyzed for total uranium. The results from this work indicate that the GM survey meter can provide a good qualitative indication of the presence or absence of total uranium at or above WAC levels. In general, GM survey readings that provided corrected counts per minute (ccpm) less than 450 indicate that uranium concentrations are below WAC concern. GM survey readings that are above 1000 ccpm almost always indicate total uranium concentrations above WAC levels. GM survey readings between 450 and 1000 ccpm indicate the potential for WAC problems. Part of the uncertainty associated with interpreting GM survey meter readings for the presence of WAC material is a result of the contributions from thorium-232 and radium-226 when these are at levels elevated above background.

With this 450/1000 rule of thumb, the GM survey meter can be used for screening small areas for WAC concerns (i.e. soil cores or surface areas where there is visual evidence of contamination), and also can be used for providing a rough estimate of the lateral extent of above WAC surficial soils, particularly when the above WAC locations have a lateral extent smaller than the viewing window of the HPGe at a height of one meter or the RTRAK. For areas where GM results are ambiguous and WAC material is a potential concern, the use of the GM survey meter should be supported either with discrete sampling or with the HPGe. For isotopic levels between FRLs and hot spot levels (2 or 3x FRL), there is at present insufficient experience to support the use ofthe GM survey meter as a method for identifying material that would be of hot spot or FRL concern, or for estimating the approximate lateral extent of such material. This may change as more experience is gained using the GM survey meter to support soils characterization and excavation work at the FEMP.

4.7.4 <u>Guidance</u>

- Use the GM survey meters as a quick check of the radioactivity level of an object, a sample, or a soil core to determine the presence or absence of WAC material. Use the 450/1000 ccpm rule as a guide (<450, no WAC concerns; 450-1000, potential for WAC concerns; >1000, definitely WAC concerns).

- Although no specific corrected counts per minute guidelines can be provided for recognition of FRL or hot spot exceedance using the GM survey meter, field personnel may request a HPGe measurement for any suspicious area which has elevated activity characteristics.

- Use the GM survey meter to help center HPGe, RTRAK, or discrete soil sample collection over isolates areas of concern (i.e., WAC or hot spot).

- Use the GM survey meter to provide a rough boundary for above WAC material, particularly when it is believed that the above WAC area is of a size less than the viewing window of the RTRAK or of the HPGe at a height of one meter.

- If a rough concentration value is desired, a calibration (correlation) based on source or reference material of known activity and radionuclide mix should be performed. Remember that a survey meter does not provide a definitive measurement, particularly if the radionuclide mix is different from the calibration source. Consult with the *In-Situ* Gamma Spectromety Group with respect to calibration.

- Resort to a spectrometric or other radionuclide-specific measurement if a clear interpretation of the survey meter measurement cannot be made or there are doubts as to the actual radionuclide mix.

- Use the MICRO-RHEM meter in conjunction with the RTRAK and HPGe systems to screen for possible shine effects, and to assist in evaluating anomalies in the gamma spectrum information provided by RTRAK and HPGe.

4.7.5 See Also

3.3 Hot Spot Evaluation

3.4 Evaluation of Above-WAC Surface Soil

4.6 WAC Exceedance Detection

5.5 Heterogeneity

4.8 RTRAK TOTAL ACTIVITY DATA INTERPRETATION

Total activity data (or gross counts) are obtained by simply summing all of the counts in the RTRAK gamma spectrum. Based upon data presented in the July 1997 RTRAK Applicability Study (DOE 1997b), the following conclusions concerning total activity data were drawn.

- Total activity measurements exhibit a high degree of precision.
- The counting uncertainty is relatively low.
- Total activity measurements can be effective in defining general patterns of elevated activity.
- Total activity measurements do not provide radionuclide-specific information.

Data in Table 4.8-1 demonstrates the third conclusion above. These data are derived from Tables 1-4 of the September 1997 addendum to the July 1997 RTRAK Applicability Study, entitled "RTRAK Applicability Measurements in Locations of Elevated Radionuclide Concentrations." Elevated concentrations of uranium, thorium-232, and radium-226 are reflected in an increased number of gross counts.

Because both thorium-232 and radium-226 have relatively high gamma ray intensities, total activity is affected much more by their presence at elevated levels in the soil as compared to total uranium which has low gamma intensities. A doubling of the thorium-232 or radium-226 concentration above background will have a marked effect on total activity whereas doubling background uranium would produce no measurable effect. Only where uranium concentrations are in the range of hundreds of ppm will total activity be affected.

The data in Table 4.8-1 show a danger in interpreting total activity data. The total activity in the South Field is about 17% higher than that in the USID area. However, the uranium-238 concentration in the South Field is approximately half the concentration of uranium-238 in the USID area. Conversely, the radium-226 concentration in the South Field is approximately 1.75 times higher than in the USID area. Thus, although the total activity is approximately 400 cps greater for the

South Field area than for the USID area, the concentrations of individual isotopes in both areas are low and isotopic concentration differences between the two areas are not readily correlative with the difference in total activity between the two areas.

Additional perspectives on interpreting total activity data can be garnered by examination of Figure 4.8-1. Based upon RTRAK measurements collected in the drum baling area (where total uranium concentrations range from low to very high), Figure 4.8-1 displays a trend of increasing RTRAK total activity with increasing RTRAK total uranium concentrations. Bounding the data by upper and lower 95% confidence intervals, a trigger level of 18,000 cps can be assigned for WAC exceedances.

4.8.1 Guidance

In consideration of the data in Table 4.8-1, data displayed on Figure 4.8-1, and data in the RTRAK Applicability Study (DOE 1997b), the following guidance for using total activity data is presented.

- Total activity less than 3000 cps likely indicates that total uranium, thorium-232, and radium-226 do not exceed their FRLs. This guidance is for a uranium FRL of 82 ppm; it does not hold for uranium FRLs of 10 or 20 ppm.

- Total activity between 5000 and 15,000 cps likely indicates that one or more of the following analytes--total uranium, thorium-232, or radium-226--exceed their FRLs, and may indicate a hot spot exceedance.

- Total activity above 18,000 cps may indicate a WAC exceedance. Areas with total activity in excess of 18,000 Cps should be confirmed by HPGe.

- In a given area, a range of 50% increase (in high total activity relative to low total activity) may indicate a significant increase in concentration for one or more isotopes.

- Total activity data are primarily designed for field use to guide additional RTRAK or HPGe measurements. Total uranium, thorium-232 and radium-226 data should be used for final interpretation of contamination patterns.

4.8.2 See Also:

2.1 Overview of HPGe and RTRAK Usage

4.5 Trigger Levels

4.6 WAC Exceedance Detection

4.12 Shine

TABLE 4.8-1

COMPARISON OF RTRAK GROSS ACTIVITY DATA TO RTRAK ISOTOPIC DATA AT 0.5 MPH WITH AN EIGHT SECOND DATA ACQUISITION TIME

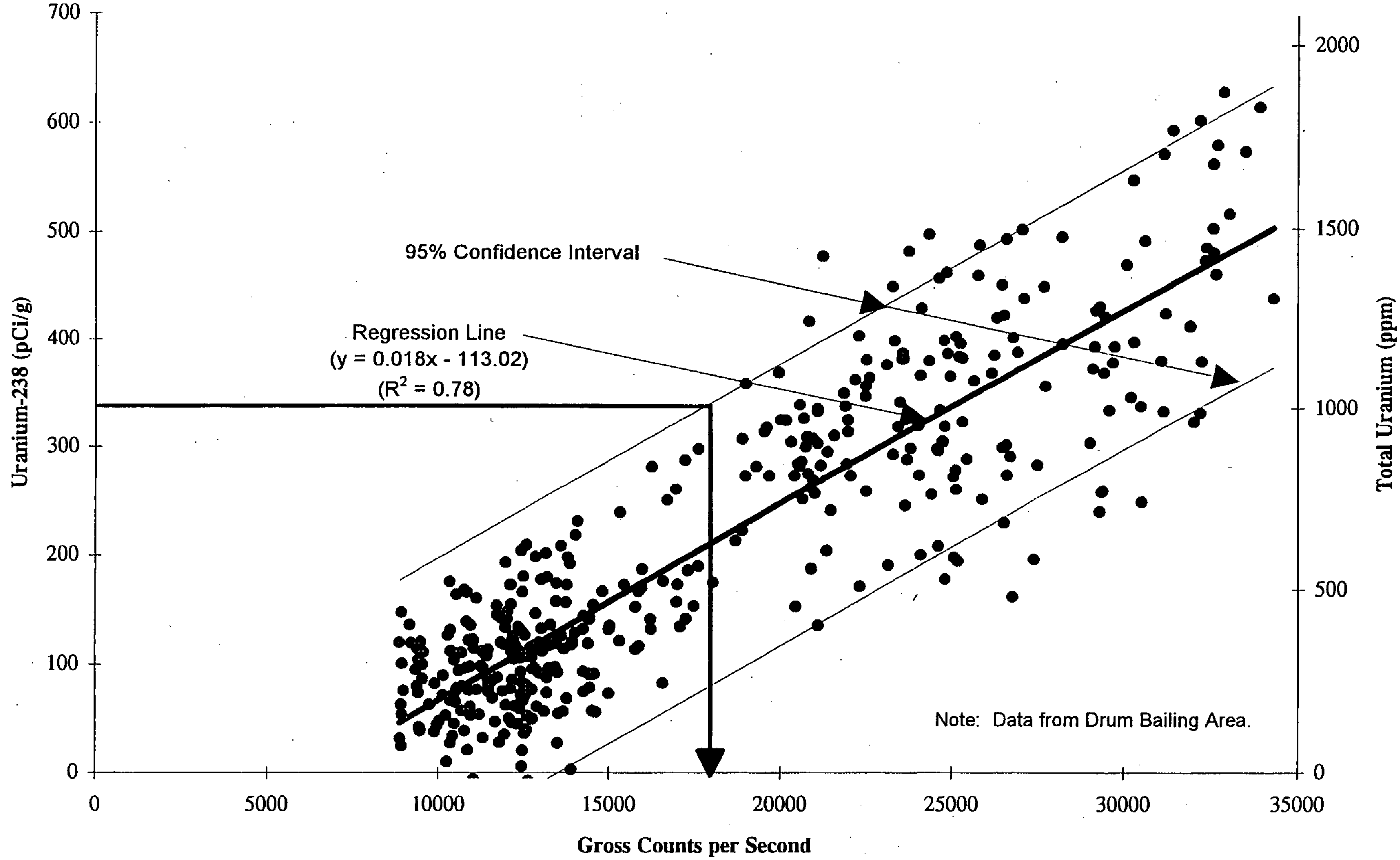
Area	Uranium-238 (pCi/g)		Thorium-232 (pCi/g)		Radium-226 (pCi/g)		Gross Counts (cps)	
	Area Mean	Area Std. Dev.	Area Mean	Area Std. Dev.	Area Mean	Area Std. Dev.	Area Mean	Area Std. Dev.
USID	17.2	14.1	0.75	0.19	0.81	0.40	2456	176
South Field	9.71	14.3	0.83	0.22	1.38	0.47	2883	180
Drum Baling	209	69.8	3.83	0.78	8.46	2.44	15,703	2,298

3546

000114

Figure 4.8-1

Uranium Concentrations vs Gross Counts



4.9 TOPOGRAPHIC EFFECTS

Topographic effects need to be assessed to determine the appropriateness of using standard field calibration factors for real-time spectrometry measurements. An *in-situ* spectrometer, such as the HPGe or RTRAK, responds to the incidence of photons per unit area per unit time (fluence rate) at its position, and this quantity can be directly related to the amount of radioactivity (concentration or activity per unit mass) in the volume of soil being measured. Calibration factors derived for *in-situ* gamma spectrometry measurements utilize the concept of an infinite half-space; that is, a volume of soil that extends infinitely deep below a detector and out to the horizon. This can be considered analogous to the standard counting geometry employed for laboratory gamma spectrometry measurements, except that with *in-situ* gamma spectrometry the "sample" can be considered very large while the detector is a point instead of vice-versa as in the laboratory. Due to the effect of soil and air attenuation on the photons, the amount of soil being measured in the field is, practically speaking, finite in size and the detector response varies principally with the detector height above the ground. The following sections will address potential departures from this idealized half-space geometry (principally deviations from an idealized flat soil surface, i.e., topographic effects) as they relate to producing bias in the results of measurements.

4.9.1 Surface Cover

One of the most important topographic factors to consider is surface cover; that is, matter that could shield the underlying soil and thus attenuate the photon fluence arriving at the detector. Surface cover would bias results low. Grass or similar vegetation is a common surface cover at many ground areas at the FEMP. ~~While this factor must be taken into account for measuring surface source distributions, it becomes less important for deeply distributed sources, i.e., radioactive contamination that can be approximated as homogeneous with depth, as is the usual case for soils at the FEMP. Tall, uncut grass (knee high) can be expected to have a wet mass per unit area on the order of 0.1 to 0.3 g/cm^2. As a worst case scenario, a 0.3 g/cm^2 mass thickness would result in a decrease (i.e, concentrations will be biased low) in the fluence rate of about 18 percent for 100 keV photons and about 9 percent for 1000 keV photons for source profiles that are uniform with depth. Where these types of mass loadings are present, correction factors can be applied to data based on measurements of wet weight per unit area. To avoid making these type of corrections, measurements can be performed over clipped grass, where the attenuation correction is negligible (1% or less).~~

To ascertain the attenuating effect of grass on gamma photons, an experiment was carried out whereby HPGe measurements were performed in grass of different heights. More specifically, HPGe measurements were taken at detector heights of 1.0 m and 31 cm at a location covered by 41.5-inch high grass (average grass height within the field of view of the detector). Subsequent to the measurements in the 41.5-inch high grass, the grass was cut to a 3-inch height, and the cut grass was removed from the field of view of the HPGe detector. Additional HPGe measurements (1.0 m and 31 cm detector height) were taken at the exact location as described above, only with 3-inch high grass within the field of view.

Results of this study are shown in Tables 4.9-1 and 4.9-2. Data in Table 4.9-1 indicate that on average, waist high (41.5 inches tall) grass results in a decrease in measured concentration of about 5.4% for a 1.0 meter detector height, while a decrease in measured concentrations of about 3.6% is observed for a 31 cm detector height. In looking at the relative attenuation of low vs high energy gamma photons (Table 4.9-2) used to quantify uranium-238 (total uranium), the attenuation of low energy photons is not significant. The 63.2 keV photon does appear to be somewhat attenuated by grass, but the 92.6 keV photon does not. In this respect, the attenuating effect of 41.5" high grass is fairly minor. (The relative attenuation of low energy gamma photons to high energy gamma photons is inferred from data in columns 7 and 9 in Table 4.9-2.)

Finally, based upon measured values of the wet and dry weight of grass within the detector field of view, the theoretical attenuation of gamma photons was calculated for uranium-238. The calculated attenuation for the mass loading (wet grass between the 3" and 41.5" heights) within the field of view of a 1-meter high detector is 4.1, 3.8, and 1.9% for energies of 63, 93, and 1001 keV respectively. The calculated attenuation effect is small and is on the same order as the measured reduction observed. The conclusion is that grass, at least as tall as waist height, has a mass per unit area that is insufficient to substantially affect *in-situ* gamma spectrometer readings, even at the lowest energy measured. The second bullet in Section 4.9.7 provides guidance as to HPGe measurements vis-a-vis grass height based upon the results of the experiment described above.

Rubble, such as loose stones or man-made debris that might cover the surface of the ground, is of greater potential concern. Because the density of these objects is much greater than that of grass, corrections would be required if a significant fraction of the surface was covered. It should be noted that stones do not represent a pure attenuating layer, in as much as they may contain concentrations of radionuclides similar to those found in the soil. However, where contamination is associated with the underlying soil at concentrations well above those associated with natural background radioactivity in the stones, they can be treated as an attenuation layer, and the net effect is to decrease the gamma photon fluence rate at the detector from the contaminated soil (i.e., concentrations biased low).

Snow or ice cover and standing water (puddles) also represent an attenuating layer which would bias measurements low. In the case of snow, it is the water equivalent (again, in terms of mass per unit area) that is the fundamental controlling parameter. A 10 cm snow layer with a water equivalent of 1 cm (1 g/cm^2 surface layer) would bias results low by 33 percent at 100 keV and 19 percent at 1000 keV.

A puddle (or any other surface object such as a rock) off to the side of a detector may not unduly influence a measurement. Figure 4.9-1 can be used to roughly estimate the fluence rate contribution at the detector for various ground areas. Clearly, objects a few meters away, even though they may be several square meters in size, would block only a very small fraction of the half space and could be ignored. Smaller objects closer in can also be tolerated. An example evaluation of shielding effects by objects is provided at the end of this section.

4.9.2 Density

Although soil density is not usually considered a topographical effect, density variations do not measurably affect the results of *in-situ* spectrometry when radioactivity concentrations in soil are being measured. This is true because the detector calibration factor incorporates terms which convert count rate to activity per unit mass of soil with the density terms canceling out. Consideration should be given to density effects if comparisons are being made between *in-situ* measurements and physical soil samples. Sampling depths may need to be adjusted proportionately as an *in-situ* detector sees deeper into the soil for light soils and shallower for dense soils. For calculations of depth of view at the FEMP, a default density of 1.5 g/cm^3 has been used.

4.9.3 Slope of Ground Surface

Measurements can be performed on a sloped surface since this does not fundamentally change the assumed source geometry, only the frame of reference. A detector can be inclined at the same angle as the slope to keep the detector-source geometry the same (i.e., the cylinder axis of the HPGe detector is perpendicular to the ground). However, if necessary to maintain physical stability, a tripod mounted detector can be adjusted to incline at a different angle than that of the ground slope without producing undue bias. Any difference in count rate that might arise would result from the angular response of the detector. This response is measured at various energies during an in-situ calibration so that the effect can be estimated. The difference between a measurement performed at some inclination angle and that of the normal position would be bounded by the range in the relative angular response of the detector and could be either positive or negative depending upon the dimensions of the detector crystal. Experiments with a HPGe detector having a relatively large variation in angular response have shown that for a full 90 degree tilt (axis of Ge crystal parallel to the ground instead of perpendicular to the ground as is the normal case), the effect is only on the order of 5 to 10 percent. It can be expected that for more typical coaxial Ge crystals, the effect would be negligible for small tilt angles. (Note that this is not an issue for RTRAK.)

4.9.4 Ground Roughness

In a recent publication (Laedermann et al, 1998), the effects of ground roughness on in-situ spectrometry results were examined using a model that incorporated closely spaced bumps in the terrain in place of a smooth surface. It was concluded in this study that bumps of up to 20 cm in height (the largest studied) were negligible for sources that were well aged, i.e., deeply distributed or uniform radionuclide concentrations with depth in the soil (such as occurs at the FEMP). The effect is pronounced only in cases where the activity is on or close to the surface, such as immediately after deposition. This is because the field of view is rather large (on the order of 100 m^2 area) for a surface or near surface deposit and the outer edges of the field are shielded by the bumps.

Substituting single large bumps in place of numerous small bumps also has a minimal effect. Calculations performed for this guidance document show that a mound of soil 50 cm high and 1 meter wide at a distance of 1 meter from the detector and circling the detector half way around (a crescent shaped mound) would result in biasing a measurement performed at a height of 1 meter by less than a half percent.

4.9.5 Other Topographic Deviations

The results discussed above clearly indicate the robustness of the *in-situ* technique for concentration measurements of deeply distributed sources. However, the question arises as to the effect of major departures from the model of flat, open-ground areas. This would include geometries that could be modeled as cones with the detector at the apex (the top of a hill or mound), and geometries such as wells with the detector at the bottom (pits with walls extending up to and even above the detector height). In the following discussion the contaminant distribution in soil with topographic features is assumed to be the same as in soil with flat surfaces; that is, the contaminants have a uniform, vertical distribution with depth into the soil.

The cone geometry represents a case where there is less fluence rate than from flat ground, and results will be biased low if the standard calibration factors are used. For situations where the cone is infinitely wide, as a rough rule of thumb, each percent in the slope of the cone (i.e. the grade leading down from the top of the hill) would result in a 1% loss in the amount of fluence reaching the detector. For a more realistic geometry, one can consider a cone with finite dimensions superimposed over flat ground. Figures 4.9-2 to 4.9-4 give the results of calculations for a number of different size and shape cones. The calculated values are indicated as points in these figures, and a smooth curve has been drawn to fit them. The values are relative to the fluence for flat ground. It can be seen that the effect is a few percent or less for these cases. In the limit, the result of positioning a detector at the apex of a finite-size cone geometry is equivalent to performing the measurement at a greater height above the ground as the cone width becomes vanishingly small.

The well geometry, in effect, represents a ground half space that has had its outer regions folded up into walls. In this situation the results of a measurement would be biased high as more fluence would reach the detector for a given concentration in the soil. Figures 4.9-5 and 4.9-6 show the results of calculations for a well geometry. As can be seen, where the height of the wall does not exceed the height of the detector (Figure 4.9-5), there is less than a 5 percent effect. The effect is small because the fraction of the horizontal ground area not seen is replaced by the wall. (The horizontal surface normally viewed is simply brought closer to, and at a more beneficial angle to, the detector.) However, as the wall extends above the height of the detector (Figure 4.9-6), the situation increasingly begins to approach that of a situation in which the detector is surrounded by the source. The increased fluence rate for a very deep well can thus be double (or somewhat more so due to less air attenuation) than that of the flat ground geometry.

In situations where the wall of a pit is close (within 3 meters) to a detector position, and thus represents a significant fraction (more than 10 percent) of the half space, one must take into account whether the wall contains the radionuclide being measured. As in the case of loose stones on the soil surface, a pit wall may or may not be considered part of the source geometry. If it is not, then a correction factor based on the fraction of missing ground must be applied in order to avoid biasing the measurements low. If the pit wall does contain the radionuclide being measured, then no correction is necessary. If the pit wall is higher than the height of the detector, results will be biased high by an amount that depends upon the relative proximity of the wall and its height.

Source geometries such as a cone or pit will affect not only the total fluence arriving at the detector but also the areas from where the fluence originates. In the case of a cone geometry, a higher fraction will be incident at angles close to the normal detector face as opposed to flat ground. For the situation of a pit, and in particular a pit with a small radius and high walls, a larger fraction will be incident to the sidewall of the detector. Normally, a coaxial HPGe detector does not require a correction for source geometries deviating from an idealized flat surface for medium and high energy photons. For energies below 200 keV, corrections may become necessary for source geometries that are very different from those of flat ground.

Other source geometries may arise in the course of FEMP remediation activities. These may include, for instance, trenches. Photon fluence calculations will be performed for these situations where needed on a project specific basis. In the case of trenches, detectors that are positioned at the top level of the trench would not require any modification of the normal half space calibration factor. Intuitively, this can be understood because a trench geometry is like that of a pit. The photon fluence from ground areas at far distances is replaced by the contribution from the walls of the trench. There will not be a significant overestimate as long as the detector is not placed below the trench top.

4.9.6 Example of Topographic Corrections

As an example of a measurement location where one should consider the need for corrections to the results of measurements, consider a case where there is a puddle of water, a large tree trunk, and a pile of excavated clean soil (a wall, in effect) near a measurement point. Assume that the natural background content of the soil in the excavation wall is well below that of the contaminated area to be measured. All three "objects" block out some fraction of the full ground area normally seen by the detector. The characteristics of these objects are given below.

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Object	Nature	Shape	Dimensions (m)	Closest Distance (m)
Excavation Wall	no source	rectangular	30 x 50	3
Water Puddle	no source	irregular	2 x 3.5	1.5
Tree	obstruction	circle	1 (diameter)	2

Offhand, the above information might be grounds to disqualify this measurement as not appropriate for the assumed detector calibration geometry. However, mapping these objects and overlaying the fluence rate cell chart from Figure 4.9-1 allows for a realistic evaluation. Figure 4.9-7 shows the results. For easy visual computation while maintaining adequate accuracy, the percent fluence rate deficit for each cell is rounded to the nearest half percent. As a conservative estimate, the water in the puddle is considered to be deep enough to essentially block all of the photons originating in the soil beneath it. The following table summarizes the fluence rate deficit for all objects, broken down according to the rings in which they fall. Note that the tree not only blocks the part of the cell it covers but also shadows the same fraction of each cell beyond it in the outer rings.

Approximate Percent Deficit of Fluence Rate for Measurement Location in Figure 4.9-7

Object	Ring Number					Total
	6	7	8	9	>9	
Excavation Wall	0	0	2	3.5	4	9.5
Water Puddle	1	1.5	1	0	0	3.5
Tree	0	0.5	0.5	0.5	0.5	2
All Objects	1.0	2	3.5	4	4.5	15

The total deficit is seen to be 15 percent, which is not unduly large. The multiplicative correction that should then be applied to the radionuclide concentration that is measured at this location would be 1/(1.0-.15) or 1.18.

As previously pointed out, the radionuclide being measured and whether it is contained within the objects in the detector field of view must be considered. For instance, if the Th-232 series is being measured, the soil in the excavation wall could be considered as a source if the measurement is being performed near natural background concentrations. Under these circumstances, it would not be appropriate to eliminate it as part of the source geometry. If the radionuclide concentration of any particular "background" soil within the field of view of the detector is known, then the following generalized equation can be applied to correct any measured concentration:

$$C_c = (C_m - xC_b)/(1-x) \qquad [1]$$

where C_c is the concentration in the contaminated portion in the detector field of view C_m is the measured concentration, C_b is the background concentration, and x if the fraction of the fluence rate at the detector associated with the background area.

4.9.7 Guidance

- Site conditions should be optimized (mowing grass, picking up debris, etc.) whenever practicable prior to in-situ gamma spectrometry measurements to avoid subsequent data correction factors. Further, whenever remediation schedules will permit in-situ gamma spectrometry to be delayed until adverse weather factors (snow, standing water, etc.) have been alleviated, the measurements will not be performed until conditions have become more normal.

- ~~Vegetative cover should not exceed a mass loading of 0.1 gram per cm^2.~~ Grass clipped to an average height not to exceed 3 inches is ideal for *in-situ* gamma spectrometry measurements. Waist high grass may result in measurements that are low by approximately 5%. Measurements shall not be performed in grass taller than waist height, and should be performed in grass less than knee high whenever possible.

- Soil areas must be cleared of loose debris within 6 meters of a detector mounted at a height of 1 meter. Measurements cannot be performed where surface rubble exceeds 10 percent of the ground cover. For detector heights less than 1.0 meter, smaller cleared areas are permissible (i.e., 2.5 meters for a 31 cm detector height and 1.0 meter for a 15 cm detector height).

- No measurements will be performed with 100% snow cover. If snow patches, standing water or other objects block more than 10 percent of the fluence arriving at the detector (using Figure 4.9-1 as a guide), corrections will be made. See also bullet #2 in Section 4.11.1, "Environmental Influences on In-Situ Gamma Spectrometry Data."

- Measurements may be performed with the horizontal plane (face) of the detector inclined at an angle to the plane of the ground not to exceed 20 degrees. Angles of inclination greater than 20° may incur errors of 5% to 10%.

- For a 1 m high detector within 3 meters of a vertical soil wall surface, measurements using the standard calibration factor can be performed if the height of the wall does not exceed 1 meter.

- Variations of more than 20 percent in the detector response across the range of photon incident angles for a given source geometry other than that of the normal soil half space shall be cause to evaluate the necessity of an angular correction factor.

- For unusual/special topographic situation or geometries, consult the In-Situ Gamma Spectrometry Group for guidance prior to making measurements. Such situations could include the following:
  * Pits
  * Trenches
  * Steep slopes
  * Measurements next to buildings
  * Measurements next to excavation side walls
  * Measurements in wooded terrain
  * Measurements in rocky soil
  * Measurements in gravel

4.9.8 <u>See Also</u>:

4.1 HPGe Detector Field of View

4.10 HPGe Measurement Grid Configuration

5.4 Data Review

TABLE 4.9-1
EFFECT OF GRASS ON IN-SITU GAMMA SPECTROMETRY MEASUREMENTS

Analyte (Units)	Detector Height (cm)	Dry Weight Concentration in Soil with 41.5" Grass	Dry Weight Concentration in Soil with 3" Grass	% Decrease(-) or Increase(+) in Concentration
Total Uranium (ppm)	100	67.0 ± 2.3**	70.8 ± 2.2	-5.37*
	31	67.9 ± 2.3	72.0 ± 2.2	-5.69
Thorium-232 (pCi/g)	100	0.99 ± 0.03	1.17 ± 0.03	-15.4
	31	1.13 ± 0.03	1.20 ± 0.03	-5.83
Potassium-40 (pCi/g)	100	13.8 ± 0.3	13.3 ± 0.2	+4.51
	31	14.2 ± 0.3	14.1 ± 0.3	+0.71

* % Decrease or increase= (1.0-(41.5"concentration/3" concentration))*100
** ± One standard deviation counting error
Average Difference in Concentration for 100 cm Detector Height=-5.42 %
Average Difference in Concentration for 31 cm Detector Height=-3.60%

TABLE 4.9-2
EFFECT OF GRASS ON ATTENUATION OF GAMMA PHOTONS USED TO QUANTIFY URANIUM-238

Detector Ht. (Cm)	Grass Ht. (in)	U-238 from 63.2 keV (pCi/g)	U-238 from 92.6 keV (pCi/g)	U-238 from 1001.1 keV (pCi/g)	Ratio of 63.2 to 1001.1 keV Concs.	Ratio 41.5" Grass Data to 3" Grass Data*	Ratio of 92.6 to 1001.1 keV Concs.	Ratio 41.5" Grass Data to 3" Grass Data**
100	41.5	16	15	14	1.14	0.87	1.07	1.01
100	3	21	17	16	1.31		1.06	
31	41.5	16	14	16	1.00	0.95	0.88	0.98
31	3	20	17	19	1.05		0.90	

* Ratio of 63.2 to 1001.1 keV concentrations for 41.5" grass divided by the same ratio for 3" grass
** Ratio of 92.6 to 1001.1 keV concentrations for 41.5" grass divided by the same ratio for 3" grass

Figure 4.9-1 Individual ground cells that contribute 1% to the fluence rate measured by a detector at a height of 1 m. Each ten cell ring contributes 10% . Region beyond outermost ring depicted contributes 10%.

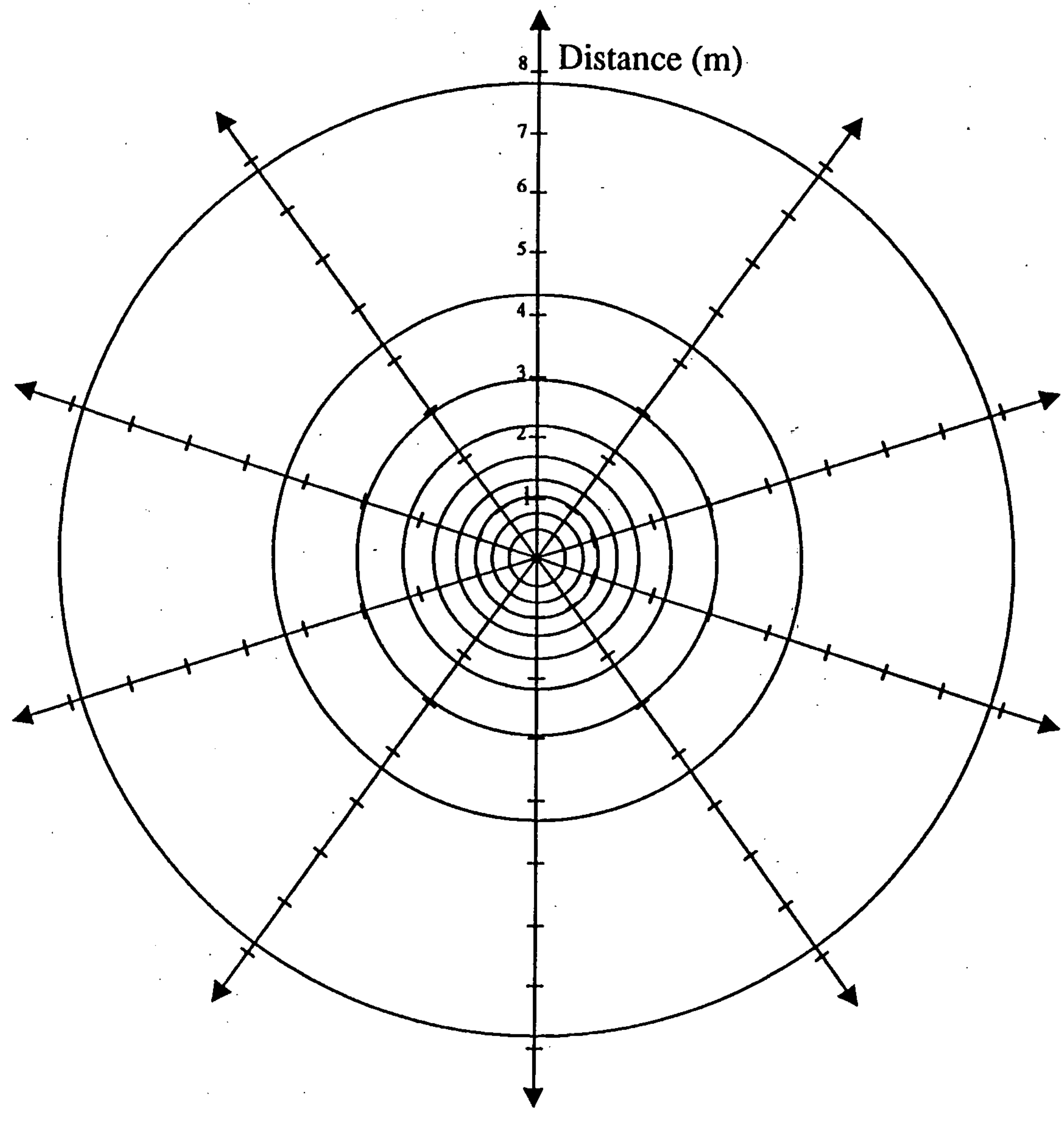
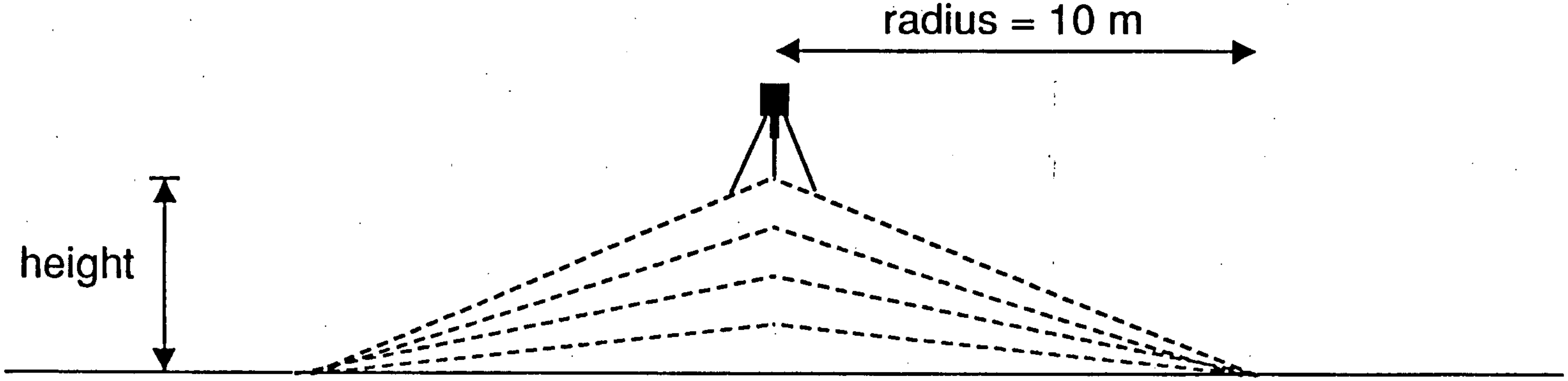


Figure 4.9-2 Relative fluence rate as a function of height for a cone with a base radius of 10 m.



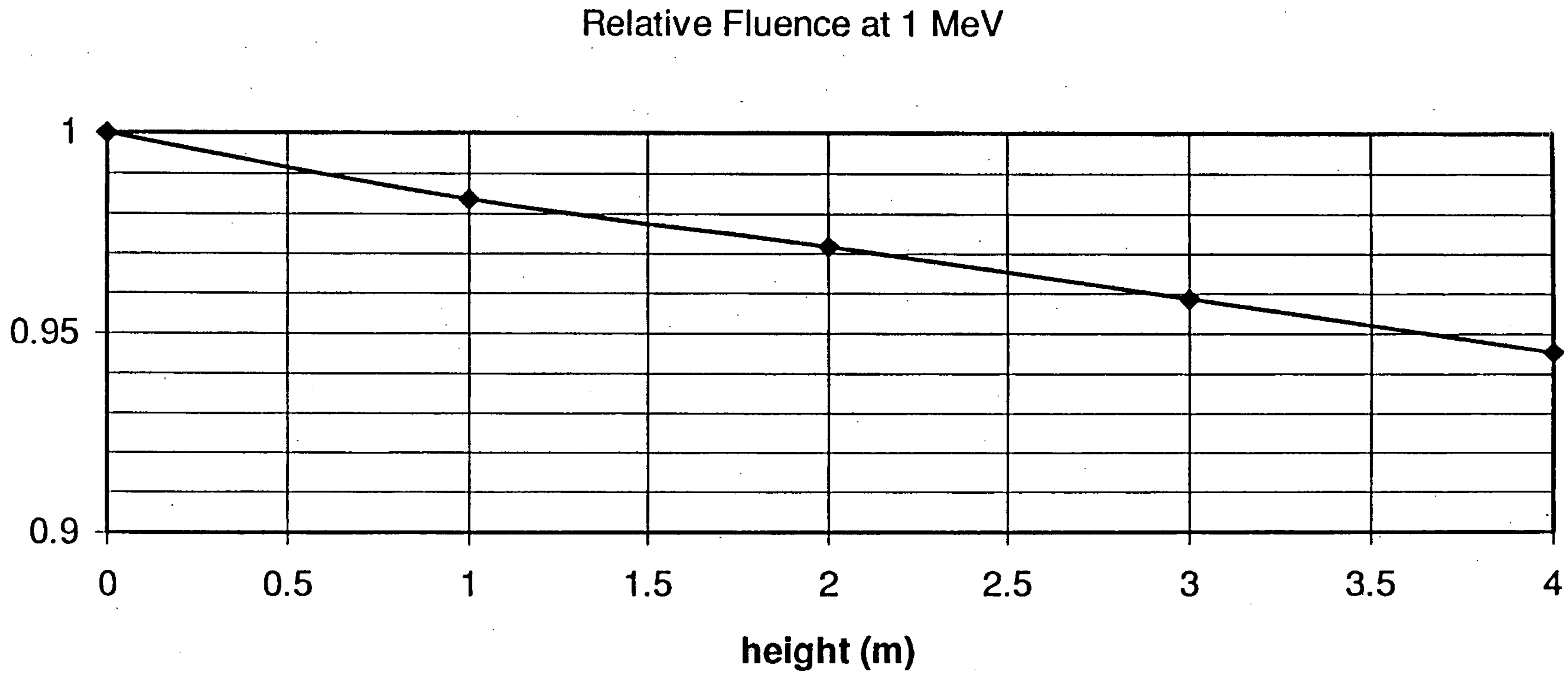


Figure 4.9-3 Relative fluence rate as a function of radius of base for a cone with a height of 1 m.

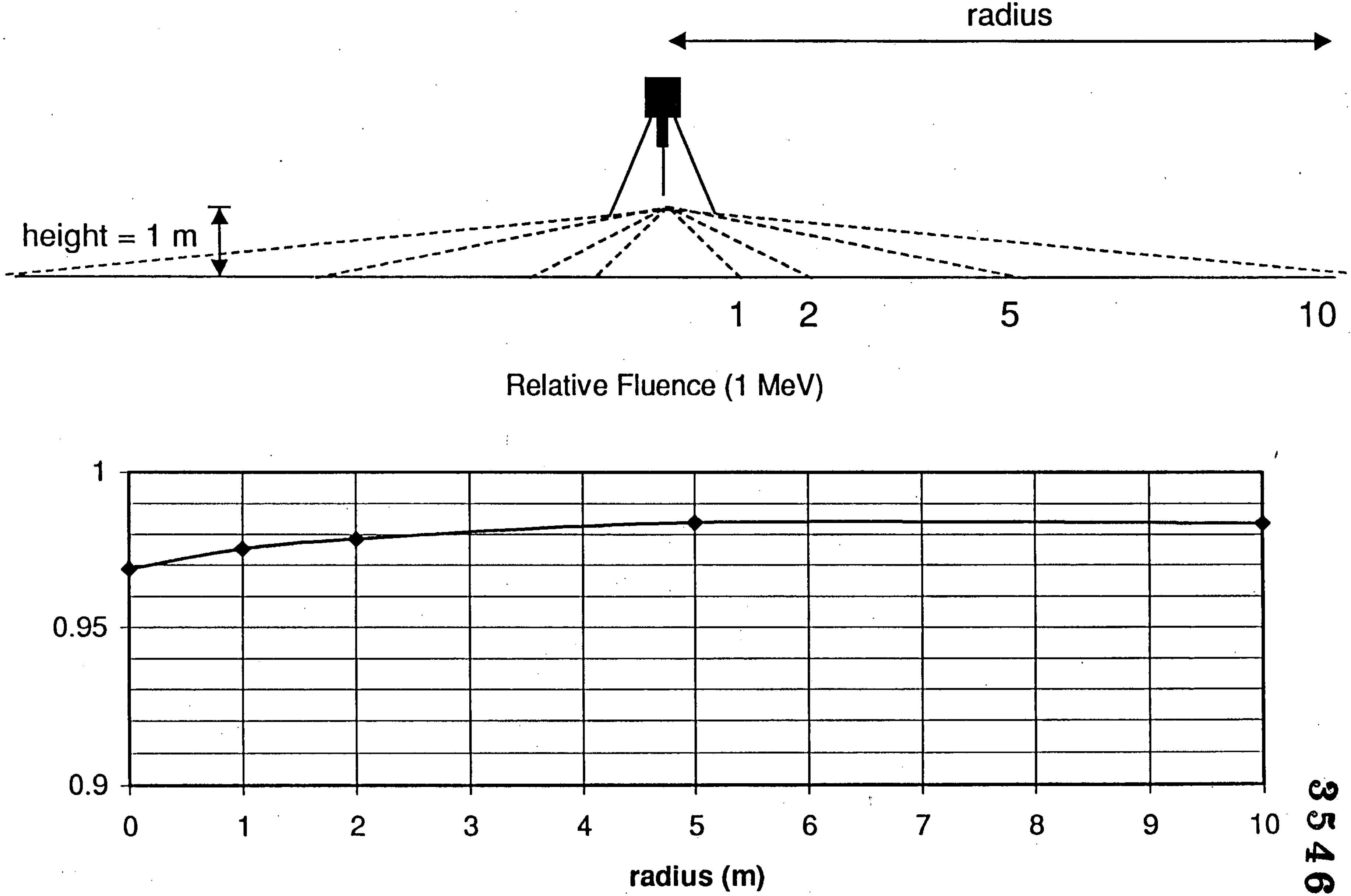
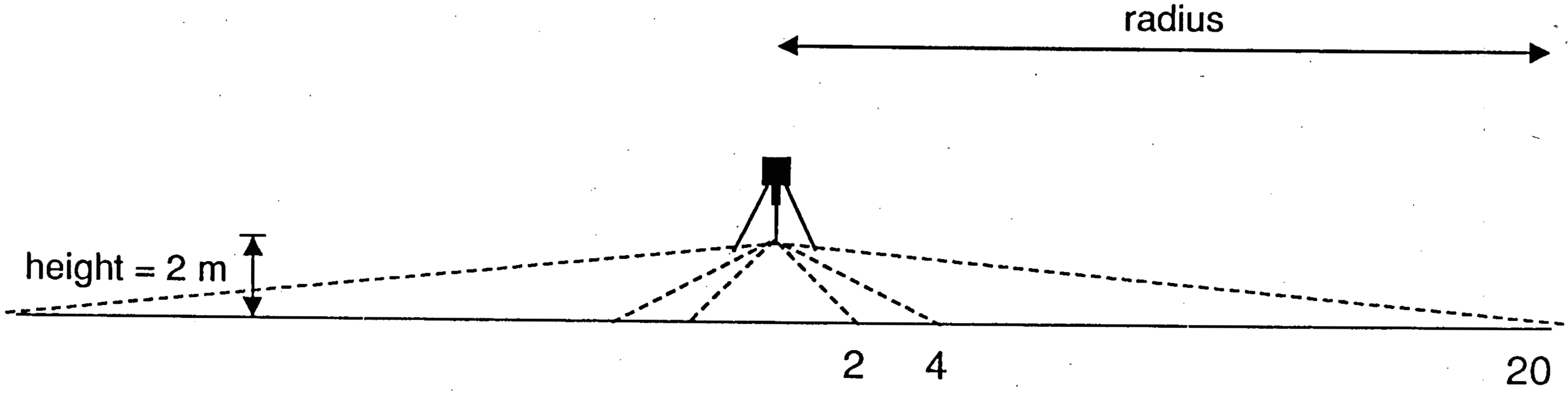


Figure 4.9-4 Relative fluence rate as a function of radius of base for a cone with a height of 2 m.



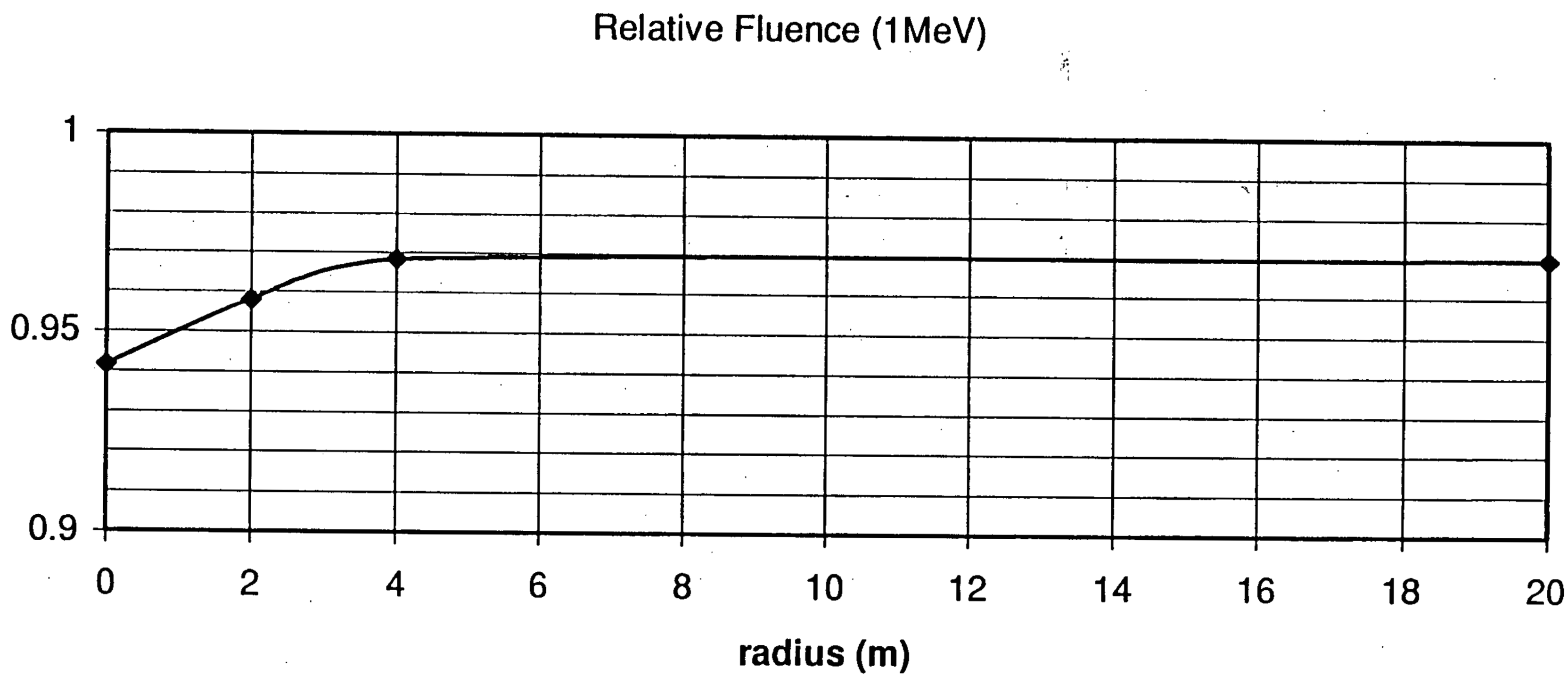
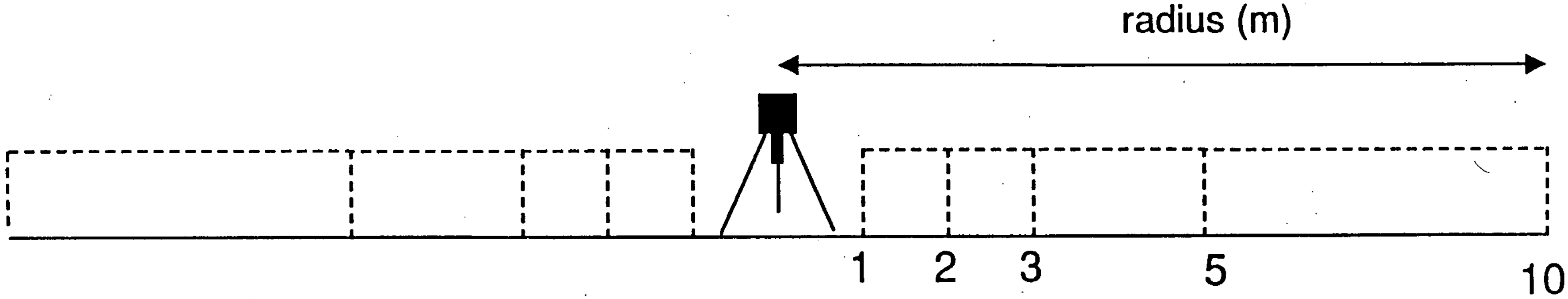


Figure 4.9-5 Relative fluence rate as a function of radius for a pit with a height of 1 m.



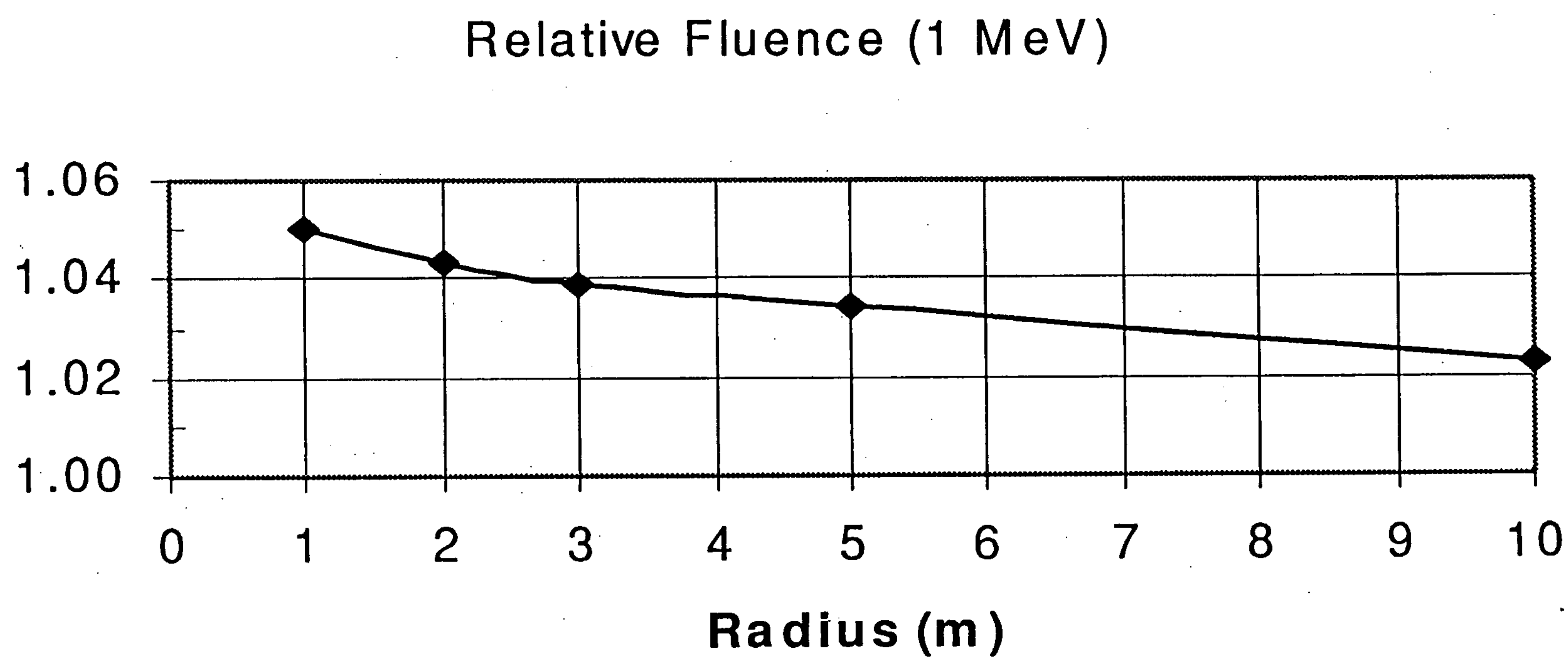
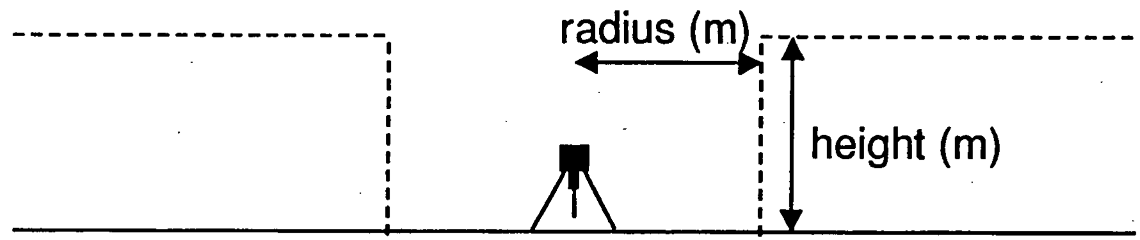


Figure 4.9-6 Relative fluence rate as a function of height for a pits of varying radii.



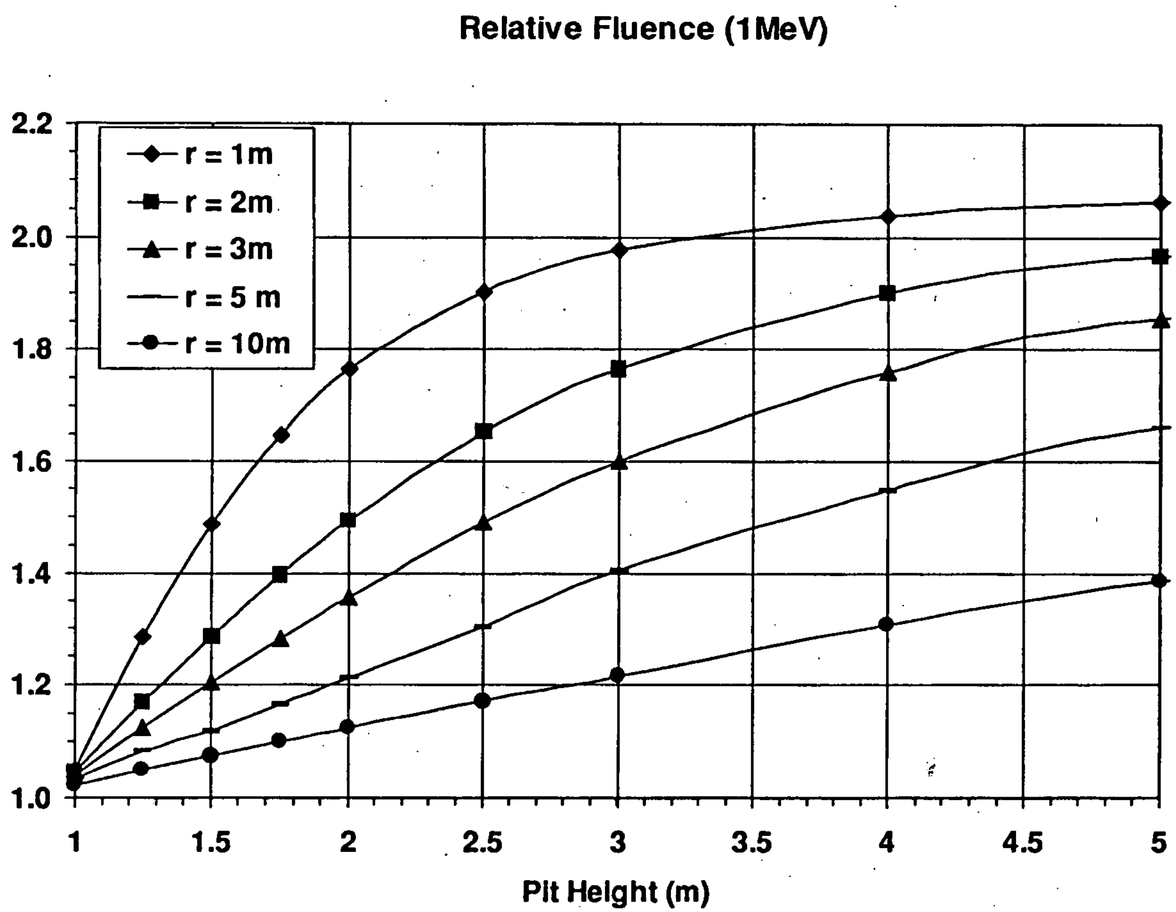


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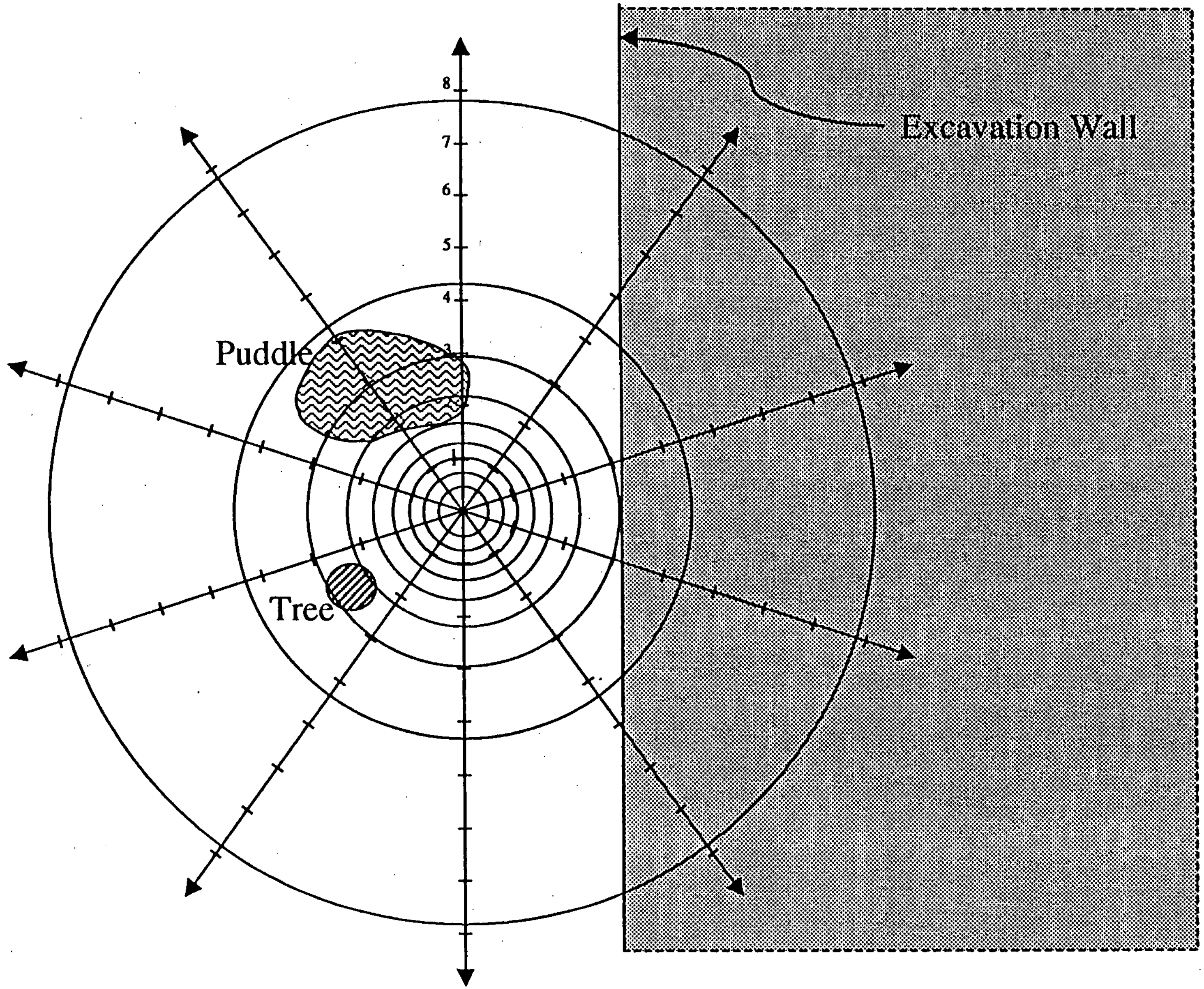
Figure 4.9-7 Example measurement location for half space corrections to fluence rate.



4.10 HPGe MEASUREMENT GRID CONFIGURATIONS

For area coverage applications or measurement grid applications with HPGe, the FEMP uses a triangular grid pattern with varying degrees of overlap of adjacent fields of view to achieve the desired coverage levels. Figure 4.10-1 shows triangular grid patterns, the extent of fields of view overlap, and the number of measurements per acre to achieve the desired percent coverage. The number of measurements is given as a function of detector height. Table 4.10-1 shows the amount of overlap necessary to give a specified percent coverage for a given detector height. Figure 4.10-2 demonstrates how a grid pattern with no overlap can be used to determine the number of measurements per acre.

As indicated in the guidance section below, the 100% coverage configuration is not utilized for HPGe measurements. It is included in Figure 4.10-1 only for completeness' sake and only to indicate the increase in the number of measurements relative to the 99.1 and 90.6% coverage configurations.

Note that although Figure 4.10-1 displays the degree of overlap in terms of spheres having definite boundaries (the spheres represent fields of view), the user should remember that the boundaries represent 85% to 90% of the total photon fluence (Section 4.1). Thus, even in the no overlap configuration, there will be 10% to 15% overlap of the area measured by the detector.

4.10.1 <u>Guidance</u>

Using information in Figure 4.10-1, the FEMP will employ the following measurement strategies:

- To establish general contamination patterns (when RTRAK cannot be used)~~ or to establish above-WAC boundaries~~, the no overlap configuration will be used.

- To detect potential WAC exceedances (when RTRAK cannot be used), use the 99.1% coverage configuration.

- To verify hot spot removal, use the 99.1% coverage configuration with the detector height set at 31 cm.

- Use either or both the no overlap or the 99.1% coverage configuration, depending on the objective of precertification HPGe measurements (see guidance bullets below).

- For those cases (refer to Section 2.4, "Precertification Investigations") in which HPGe is used for precertification measurements in areas where hot spots or WAC exceedances have been excavated, use the 99.1% coverage configuration as specified above with the HPGe detector height set at 31 cm.

- For those cases (refer to Section 2.4, "Precertification Investigations") in which HPGe is used for precertification measurements in areas where no elevated contamination levels have been identified, use the no overlap configuration with 1.0 meter detector height.

- In situations where a 6-inch (15 cm) detector height is specified to delineate hot spot or WAC exceedance boundaries, or for grid space measurements, use the no overlap configuration.

4.10.2 See Also:

3.3 Hot Spot Evaluation

3.4 Excavation of Above-WAC Surface Soil

3.5 Excavation Control for Lifts

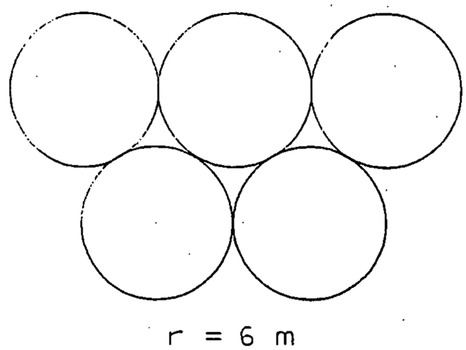
3.6 Horizontal Excavation Boundary Delineation

4.1 HPGe Detector Field of View

TABLE 4.10-1
PERCENT COVERAGE AND OVERLAP AMOUNT

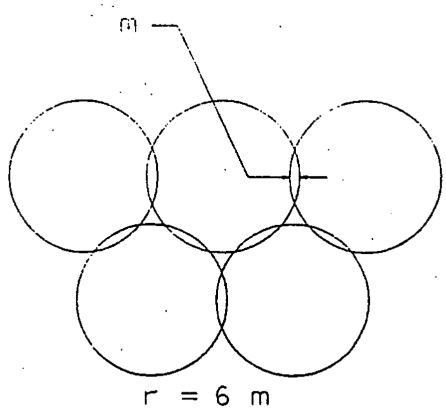
Detector Height	90.6% Coverage	99.1% Coverage	100% Coverage
1.0 m	0	1.0 *	1.6
31 cm	0	0.42	0.67
15 cm	0	0.17	0.27

* Amount of overlap in meters.



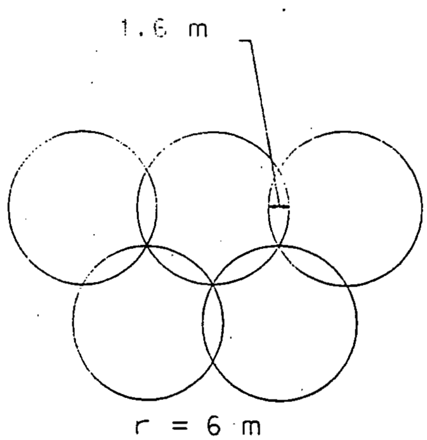
NO OVERLAP 90.6% COVERAGE

HEIGHT	MEASUREMENTS/ACRE
1 m	36
31 cm	203
15 cm	1289



MINIMAL (1 m) OVERLAP 99.1% COVERAGE

HEIGHT	MEASUREMENTS/ACRE
1 m	43
31 cm	245
15 cm	1530



100 % COVERAGE/MIMINUM (21%) OVERLAP (1.6M)

HEIGHT	MEASUREMENTS/ACRE
1 m	48
31 cm	275
15 cm	1716

NOTE: FIELD OF VIEW AT 1 m DETECTOR HEIGHT YIELDS A 6 m RADIUS, 2.5 m RADIUS AT A 31 cm HEIGHT, AND 1 m RADIUS AT A 15 cm HEIGHT

FIGURE 4.10-1. GRID CONFIGURATIONS FOR HPGe MEASUREMENTS

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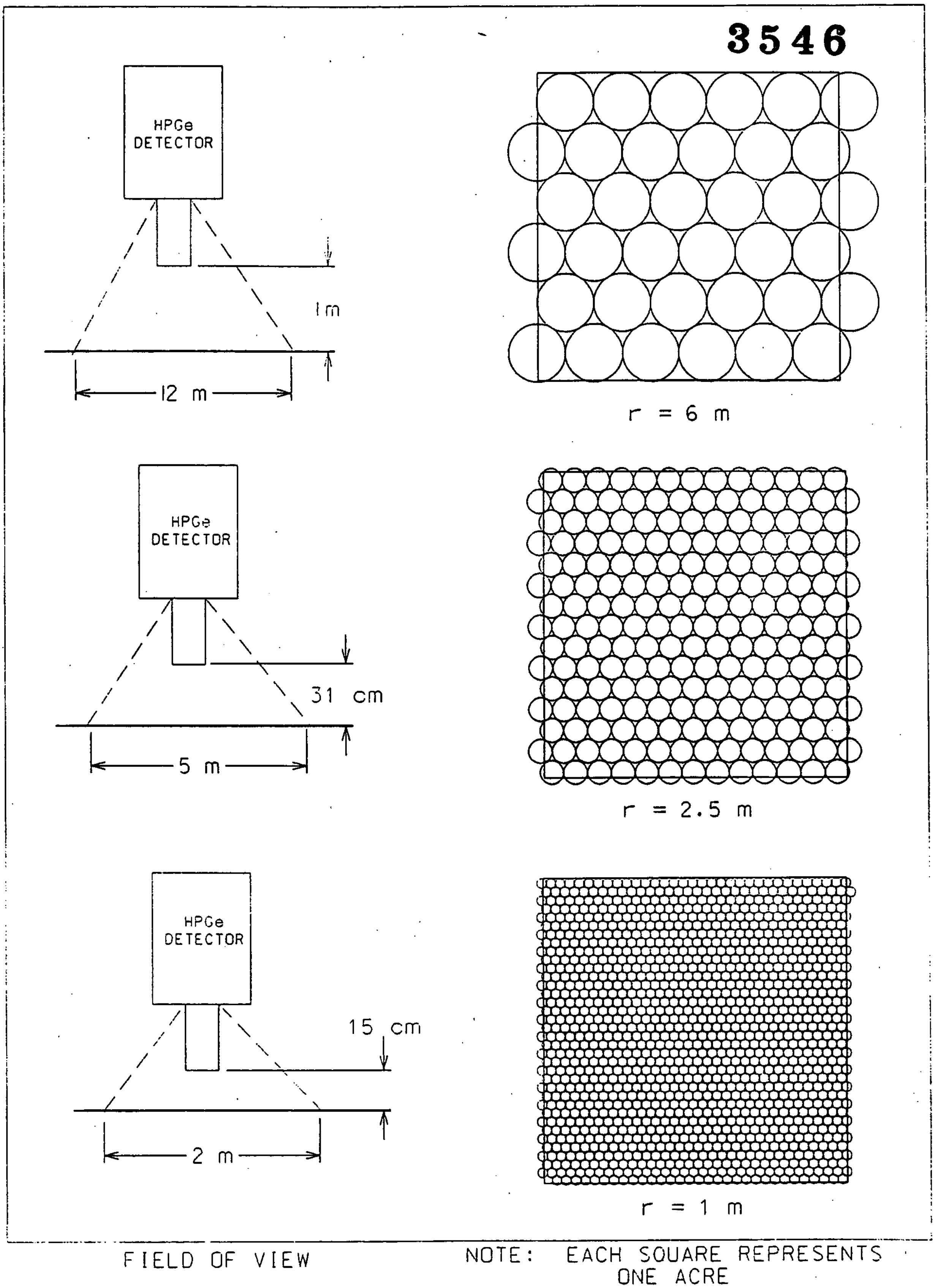

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FIGURE 4.10-2. DETECTOR FIELD OF VIEW AND AREAL COVERAGE PER ACRE WITH NO OVERLAP

4.11 ENVIRONMENTAL INFLUENCES ON *IN-SITU* GAMMA SPECTROMETRY DATA

The effect of environmental variables upon *in-situ* gamma spectrometry measurements was delineated in a report entitled "Effect of Environmental Variables Upon *In-Situ* Gamma Spectrometry Data" issued in December 1997. Environmental influences are the same on both HPGe and RTRAK measurements.

To understand the effect of environmental conditions upon HPGe measurements, daily measurements were made at a single field location. Such measurements are the field analogue of a laboratory control standard. The basic concept is that measurement variations over an extended period of time at a single field location can be related to environmental variables. Trends, peaks, and valleys in data may be related to both long-term and short-term environmental conditions. In the above report, environmental variables refer to weather-related phenomena such as soil moisture, rainfall, atmospheric temperature, and humidity. Field Quality Control Station (FCS) measurements thus offer the possibility of normalizing all *in-situ* gamma spectrometry measurements to a standard set of conditions, thereby enabling real-time project personnel to tell when the HPGe spectrometer is "in control."

The following conclusions were the most important ones noted in the environmental effects report:

1. Soil moisture has a significant effect upon the magnitude of HPGe measurements when concentrations of radionuclides are calculated on a wet weight basis. Wet weight concentrations can be as much as 50% higher in dryer soils than in wetter soils. (The attenuation effect of water or gamma photons is minor over the range of soil moistures to be encountered at the FEMP. The rule of thumb is that for every 10% absolute increase in soil moisture, gamma photons are attenuated 1%).

2. Temperature has a minor effect upon HPGe measurements over the range of 20° to 90° F. This effect, minor though it is, may be related to gradients of moisture from the surface of soils to soils at depth (10 to 15 centimeters).

3. Humidity has no observable effect upon HPGe measurements.

4. Time of day and weather conditions have significant effects upon HPGe measurements to determine radium-226 concentrations. Because HPGe actually measures gamma photons emitted by radon-222 daughters to calculate radium-226, weather conditions leading to the buildup and dissipation of radon in surface soils greatly affect the concentration of radium-226 calculated from HPGe measurements.

5. Typically, morning radium-226 concentrations are higher than afternoon radium-226 concentrations as calculated from HPGe measurements. From April 8 through October 14,

morning radium-226 concentrations averaged over 30% higher than afternoon concentrations with a high degree of variability associated with that average.

6. Control charts were established for total uranium and thorium-232 based upon the standard deviation of all measurements made at the FCS from April 8 to October 14. Excellent long-term precision was observed for these two analytes; the standard deviations of the measurement populations averaged only 5% of the population means.

7. Control charts were established for radium-226 based upon the standard deviation associated with all afternoon measurements. Long-term precision is good as the standard deviation of the measurement population averaged 7.84% of the population mean.

4.11.1 Guidance

The following items represent practical "dos" and "don'ts" relative to environmental effects on *in-situ* gamma spectrometry data:

- Always convert wet weight HPGe and RTRAK data to dry weight data in order to minimize soil moisture effects. Comparison of in-situ results to FRLs, hot spot criteria, or WAC should always be made on a dry weight basis.

- Do not take measurements immediately after a heavy rainfall in which the soil may be completely saturated with water. Even dry weight concentrations may be anomalously low, necessitating rework. The same situation applies for days in which snow has accumulated on the ground surface. Measurement should not be taken on the same day following a heavy rain; measurements should not be taken on a muddy surface, and measurement should not be taken if standing water is present within the field of view. (If standing water is less than 10% of the field of view, a correction factor may be applied per bullet #3 in Section 4.9.7. However, concentrations may still be anomalously low due to soil saturated with water.)

- Measurements may be taken throughout the day without concern for the magnitude of temperature variations. Any temperature effects upon data will probably be less than 5% of the value of any given datum.

- Both HPGe and RTRAK measurements can be taken without concern over humidity effects.

- If only a few HPGe measurements are made, or if only a small area is surveyed by RTRAK, those measurements should be made in the afternoon if at all possible. Morning measurements may lead to falsely elevated radium-226 measurements.

- If morning HPGe and RTRAK measurements are necessary, a "radon monitor" should be set up in the area of interest in order to provide "full day" information on radon emanation from soils. The results of such a monitor can be used to correct radium-226 data.

- Heavy dew, fog, no wind, and large differences between daily high and low temperatures are likely to result in conditions conducive to the buildup of radon in soil. In turn, these conditions may cause falsely elevated radium-226 concentrations to be determined from morning measurements.

- For HPGe, control charts, based upon field quality control measurements, must be utilized in order to assess the cumulative effects of environmental variables upon HPGe data. Warning and control limits specified in Addendum #3, "Effects of Environmental Variables Upon In-Situ Gamma Spectrometry," (December 1997), shall be utilized until revised. Situations in which data are "out of control," either due to environmental reasons or for instrumental reasons, can be readily recognized. Procedure ADM-16 (Appendix B) provides guidelines on how to interpret control charts and how to proceed when measurements are out of control.

4.11.2 See Also:

3.8 Field Moisture Measurements

4.14 Seasonal Precautions

5.2 Moisture Corrected Data

5.3 Radium-226 Corrections

5.7 Field Quality Control Considerations

4.12 SHINE

Shine refers to the detection of radiation (using an HPGe or RTRAK instrument) from a radiation source that is outside the normal or expected field of view. For example, gamma photon peaks in an *in-situ* spectrum collected over soil may exhibit an artificially higher count rate because of gamma photons coming from radioactive material stored in a nearby building. This form of shine will bias results high. Another form of shine can occur where the continuum, or background, under the peak is elevated because scattered radiation impinges on the detector; however, the gamma photon peaks are relatively unaffected because there is no direct line of sight to the shine source. This will cause the statistical counting error to be higher than normal, and may obscure small peaks.

The first form of shine may contribute to U-238 (total uranium) gamma photon peaks, to thorium-232 gamma photon peaks, to radium-226 gamma photon peaks, or to all three simultaneously, depending upon the radionuclide composition of the shine source. Figure 4.12-1 shows the locations of possible shine sources at the FEMP, and Table 4.12-1 names the sources. In general, shine is likely to be a problem only for measurements made in proximity to the shine sources in Figure 4.12-1.

Three concerns are associated with shine: 1) how to recognize shine, 2) how to distinguish shine from activity emanating from buried radioactive sources, and 3) how to handle the contribution from shine in RTRAK and HPGe measurements. Resolution of these concerns rests upon three premises: 1) that shine decreases in magnitude with increasing distance from the source of shine, and 2) that shine predominantly involves high energy gamma photons; low energy gamma photons are almost completely attenuated by air or by the shine source container, and 3) that buried contamination mimics shine in that lower energy gamma photons are more highly attenuated by soil than are higher energy gamma photons.

Figures 4.12-2 and 4.12-3 present HPGe data taken to assess the effect of shine on in-situ gamma spectrometry measurements at one particular location at the FEMP. This case study involves measurements taken at soil pile 5 (SP-5), and forms the basis for the guidance provided in Section 4.12-1, below. Total uranium measurements at SP-5 are used in the examples discussed in this section; however, the principles involved and the guidance also apply to thorium and radium. Figure 4.12-2 shows total uranium concentrations (calculated using the weighted average of gamma photons in Table 3-1-1) taken on and in proximity to SP-5. The solid circles represent measurements (1.0 meter HPGe detector height, 5 minute count time) taken to ascertain the magnitude of shine coming from nearby T-hoppers. Open circles represent HPGe measurements taken on the north side of SP-5. Measured total uranium concentrations decrease significantly from a high of 940 ppm adjacent to the T-hoppers to concentrations consistently less than the uranium FRL at locations well removed from the T-hoppers. (The grey area located east of the center in Figures 4.12-2 and 4.12-3 represent rubble zones.)

Figure 4.12-3 shows the ratio of total uranium calculated from low energy gamma photons (weighted average of 63.2 and 92.6 keV) to total uranium calculated from a high energy gamma photon (1001 keV). The significance of these ratios is embodied in premises 2 and 3 on page 4.12-1. That is, measurements comprised mostly of shine (and radiation coming from deeply buried sources) will have very low ratios. Conversely, measurements in which gamma photons originate within the top 10 to 15 cm of soil will have ratios near unity. (Experience at the FEMP has indicated that agreement between total uranium calculated from low and high energy gamma photons should be better than 80% in the absence of unusual or mitigating circumstances.) These ratios change from lows of approximately 0.02 adjacent to the T-hoppers to high values approaching 0.9 at the northwest corner of SP-5.

Finally, the total uranium concentrations and low to high energy gamma photon total uranium ratios for the three points (solid circles) at the west edge of the rubble zone and the two points at the easternmost edge of the soil pile represent the maximum contributions of shine that could possibly impact SP-5. The maximum contributions of shine in conjunction with applicable trigger levels/regulatory limits define three data categories. The first data category is where all contaminant concentrations fall below the regulatory limit or trigger level. The second data category is where contaminant concentrations fall between the trigger level/regulatory limit and the trigger level/regulatory limit **plus** the maximum contribution of shine for the given radionuclide. Data category 3 is where contaminant concentrations exceed the trigger level/regulatory limit **plus** the maximum contribution of shine. The three premises (page 4.12-1) applied to total uranium concentrations and their associated low to high energy gamma photon total uranium ratios for SP-5 form the basis for interpreting data falling within these three categories as indicated in the guidance below.

4.12.1 Guidance

- Using the map of potential shine sources (Figure 4.12-1) as a guide, determine if the area to be measured in likely to be affected by shine.

- Prior to measuring an area believed to be susceptible to shine, a series of HPGe measurements similar to those in Figure 4.12-2 shall be made adjacent to the potential shine source and at regular intervals to the edge of the area to be measured. Such measurements will verify the existence of shine (decreasing detector response with increasing distance from source; premise #1) and serve as the basis for interpreting *in-situ* gamma spectrometry measurement results with respect to its presence.

- RTRAK or HPGe measurements in the area of interest not exceeding a trigger level or regulatory limit will be accepted as valid regardless of the contribution of shine. If the ratio of concentrations determined from low energy gamma photons compared to high energy gamma photons is less than 80%, the data will be flagged as "S" (see Section 5.4). For example, in Figure 4.12-2, all SP-5 HPGe measurements for total uranium are less than 928 ppm (trigger level for WAC exceedances). Thus, even though they have varying contributions of shine, the data are still valid with respect to providing information relative to WAC considerations.

- The maximum amount of shine is given by the concentrations (calculated using the usual weighted average of low and high energy gamma photons) of radionuclides at the perimeter of the area to be measured, where that perimater area is between the shine source and the area to be measured.

- If RTRAK or HPGe measured concentrations in the area of interest exceed the relevant trigger level **plus** the maximum contribution of shine (data category 3), an exceedance is noted. With reference to Figure 4.12-2, the maximum contribution of shine to the soil pile is approximately 300 ppm. Any RTRAK measurement greater than 1021 ppm (721 + 300 ppm), for example, would require confirmation by HPGe. Any confirmatory or delineation HPGe measurement greater than 1228 ppm (928 + 300 ppm), for example, would indicate a definite WAC exceedance.

- The major data interpretational problem is for contaminant concentrations falling into a grey area (data category 2). Measurements in this area, defined as the range between the trigger level/regulatory limit and the sum of the trigger level/regulatory limit **plus** the maximum shine contribution, exceed the action level by definition, but possibly only do so because of the shine contribution.

- RTRAK measurements falling in data category 2 will be confirmed by HPGe per section 3.3 or 3.4.

- Explanatory or detection HPGe measurements (measurements where RTRAK cannot be used) falling in data category 2 will be confirmed by HPGe per Sections 3.3 or 3.4.

- For confirmation or delineation HPGe measurements with concentrations falling in data category 2 **and** which have low energy to high energy gamma photon concentration ratios **greater** than the corresponding ratio at the perimeter (point of maximum shine contribution) of the area of interest, the concentration shall be recalculated based upon the low energy gamma photons. This is based upon the premise that shine predominantly involves high energy gamma photons while the low energy gamma photons are predominantly originating from soil contamination.

- For HPGe measurements (detection or confirmation/delineation) in data category 2 where measured concentrations exceed the trigger level/regulatory limit **and** the concentration ratio of low energy to high energy gamma photons **decreases** relative to the corresponding ratio associated with maximum shine; the presence of buried contamination is indicated (premise 3, page 4.12-1). In this case the data shall not be recalculated and resultant action (confirmation/delineation by HPGe or excavation, for example) shall be taken per other sections of this manual (in particular, Sections 3.3 and 3.4).

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4.12.2 See Also:
5.4 Data Review

TABLE 4.12-1
POTENTIAL SOURCES OF SHINE AT THE FEMP

Source Index Number	Potential Source	Type of Shine
1	T-hopper at SP-5	uranium
2	Quonset hut #3	thorium-232
3	KC-2 Warehouse	uranium
4	T-hoppers by Plant 5 Warehouse	uranium
5A	Old Plant 5 Warehouse	thorium-232
5B	Thorium Warehouse	thorium-232
6	Tension Support Structure #6, Plant 1 Pad Area	uranium
7	Tension Support Structure #5, Plant 1 Pad Area	uranium
8	Tension Support Structure #4, Plant 1 Pad Area	uranium
9	General In-Process Warehouse, Plant 1 Pad Area	uranium
10	Chemical Warehouse	uranium
11	Incinerator Building	uranium
12	Hot Raffinate Building	uranium
13	Plant 4 Warehouse	uranium
14	Metals Production Plant	uranium
15	Finished Products Warehouse	uranium
16	Pilot Plant Warehouse	uranium
17	Sewage Treatment Plant Incinerator	uranium
18	K-65 Storage Tank (South)	radium-226
19	K-65 Storage Tank (North)	radium-226
20	Uranium Metal Storage Area	uranium

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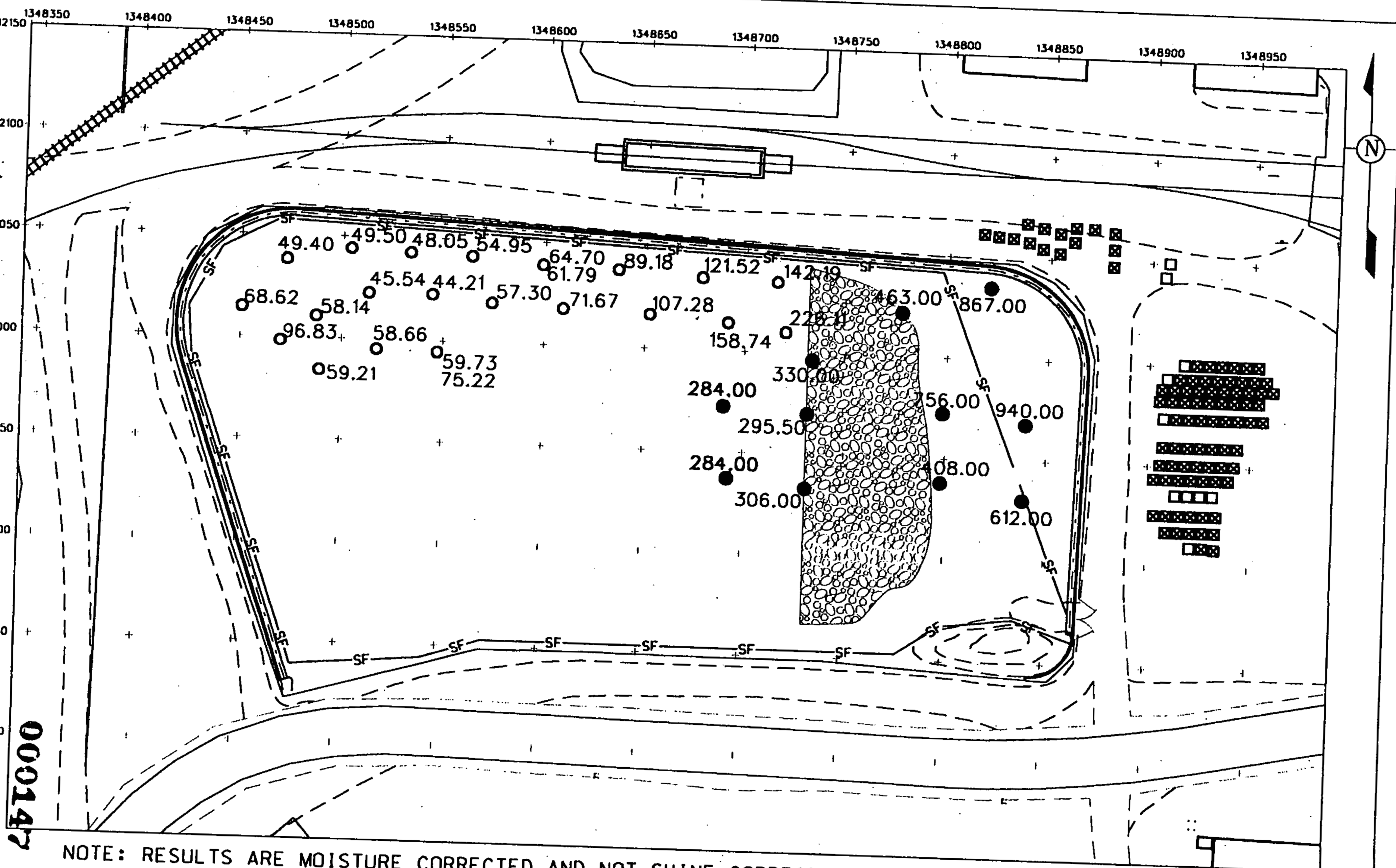


NOTE: RESULTS ARE MOISTURE CORRECTED AND NOT SHINE CORRECTED

LEGEND:

⊠ URANIUM CONTAMINATED T-HOPPERS

●,o HPGE MEASUREMENT LOCATIONS

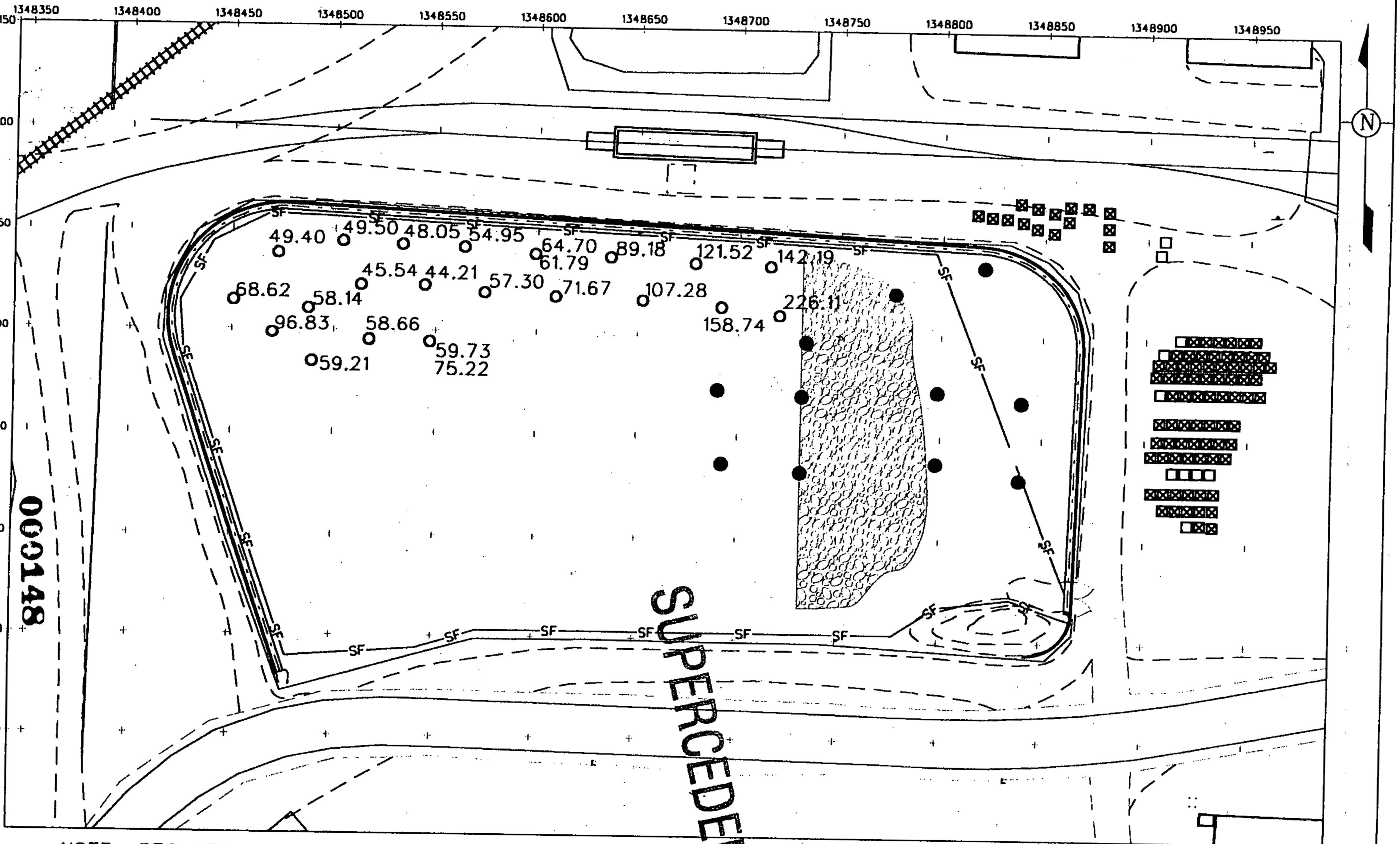
SCALE

70 35 0 70 FEET

v:#2fm12#dgn#bmp#sp5wac03.dgn
STATE PLANAR COORDINATE SYSTEM 1983

FIGURE 4.12-2. URANIUM CONCENTRATIONS (ppm) AT SOIL PILE 5

17-AUG-1998



NOTE: RESULTS ARE MOISTURE CORRECTED AND NOT SHINE CORRECTED

LEGEND:

⊠ URANIUM CONTAMINATED T-HOPPERS

●,○ HPGE MEASUREMENT LOCATIONS

SCALE

70 35 0 70 FEET

v:=2fm12=dgn=bmp=sp5=...03.dgn
STATE PLANAR COORD... SYSTEM 1983

FIGURE 4.12-2. URANIUM CONCENTRATIONS (ppm) AT SOIL PILE 5

09-J...998

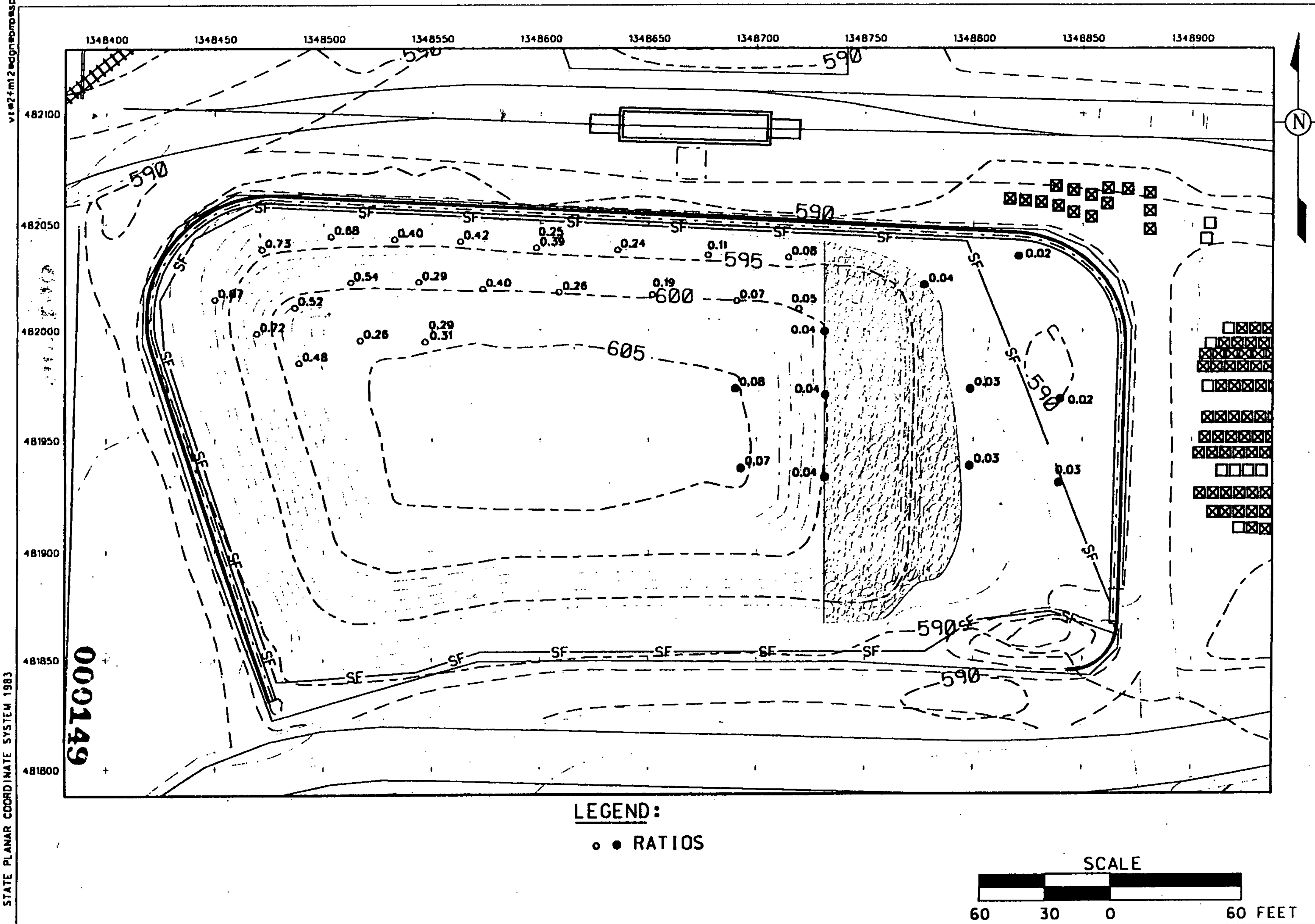


FIGURE 4.12-3. URANIUM CONCENTRATION RATIO FOR LOW TO HIGH ENERGY PHOTONS AT SOIL PILE 5

4.13 TIME REQUIRED FOR *IN-SITU* GAMMA SPECTROMETRY MEASUREMENTS

From a practical perspective, two questions must be answered in order to properly plan an *in-situ* gamma spectrometry program:

1. How many measurements (HPGe) can be made in one day?

2. How long does it take to measure one acre of ground with either the RTRAK or HPGe?

At first glance, these may seem like trivial questions. For example, if the data acquisition time for HPGe is 15 minutes, then theoretically, 32 measurements can be made in an 8-hour day. At a one meter detector height, this would correspond to 60-90% coverage of an acre depending on the degree of overlap (Table 4.10-1). Similarly, as shown in Table 4.3-5, it theoretically takes from 972 to 1656 four-second measurements (65 to 110 minutes) to cover an acre of ground with RTRAK at 1 mph, depending upon degree of overlap.

However, these "theoretical times" do not take into account daily briefings and plans, pre-operational and post-operational QA/QC checks, instrument calibrations, transportation/movement of equipment to and from the area of measurement, transportation and setup of equipment between measurements (HPGe), and various tasks (such as donning and doffing PPE, frisking tools) associated with working in radiologically controlled areas.

Taking all of these factors into account, the following guidance is offered.

4.13.1 <u>Guidance</u>

- Allow two hours per acre for RTRAK with a 4-second data acquisition time, moving at 1.0 mph, and a 0.4 meter overlap.

- Allow for 30 HPGe measurements per day in a non-radiological area, assuming that three instruments are used (Figure 4.10-1 can be consulted to translate measurements per day to acres measured per day).

- Non-contiguous areas and partial coverage will take longer to measure by RTRAK than contiguous areas of the same size with full coverage.

- Radiologically controlled areas will reduce the number of possible measurements per day by RTRAK. It will take RTRAK the same length of time to measure an acre, only the number of measurement hours per day will be reduced.

- Working in radiologically controlled areas will reduce the number of possible 15-minute HPGe measurements to 18 per day (3 detectors). Figure 4.10-1 can be consulted to translate measurements per day to acres measured per day.

- If the 5-minute data acquisition times are used for WAC evaluations, 40 HPGe measurements per day (3 detectors) can be made in non-radiological areas and 24 measurements per day can be made in radiologically controlled areas.

4.13.2 See Also:

4.3 RTRAK Multiple Measurement Field of View

4.10 HPGe Measurement Grid Configuration

4.14 Seasonal Precautions

5.9 Cost of RTRAK and HPGe Measurements

4.14 SEASONAL PRECAUTIONS

Certain weather and seasonal factors have the potential to affect equipment, personnel, and productivity. All of the factors described below represent guidance pertaining to weather and seasonal factors.

4.14.1 Guidance

- Summer

Physical:

a. Heat stress and dehydration can become a factor during prolonged field work during excessive heat. Frequent breaks to rest and rehydrate are needed. If work is being performed in a contamination area and Personal Protective Equipment (PPE) is worn, heat stress can become a problem at cooler temperatures, sometimes as low as 70-80° F.

b. Biological hazards increase in the summer due to chiggers, ticks and poison ivy prevalent in the field. Ensure the field is mowed prior to data collection to reduce the hazard.

c. The longer daylight hours enable increased field acquisition time resulting in increased field productivity. Overtime to make up a slipped schedule can be arranged on evenings or weekends.

Equipment:

a. Wind-blown soil over the very dry ground can present a problem by getting grit into the computers and detectors.

b. Amplifiers tend to drift more in high heat conditions. Amplifier operating temperature is approximately 72° ± 15° (estimated), extreme heat or cold can affect stability. (Amplifier gain circuit stabilization limits can be exceeded in extreme heat or during large temperature gradient transition periods, especially for large volume scintillation detectors).

c. Liquid nitrogen usage increases at ambient air temperature above 80° F. The liquid nitrogen tends to get used up, quickly warming the detectors; need to watch them more closely to ensure they do not warm up.

d. Detectors are designed to operate optimally between approximately 40-90° F. Summer temperatures may exceed 90° F.

e. Morning fog creates "bad radon days" which must be compensated for by using a detector to monitor the radon during field activities.

f. Rain must be kept off the computers and detectors to reduce the risk of equipment damage. At the slightest drizzle work must stop.

- Fall

Physical:

a. Fall is the best season for real time data collection unless it is a wet fall. Temperatures are comfortable even if PPE is needed.

b. Freezing and thawing of saturated ground (if it is a wet fall) create slick and hazardous ground conditions.

Equipment:

a. High winds may topple over the detectors and computers.

b. Rain must be kept off the computers and detectors to reduce the risk of equipment damage. At the slightest drizzle work must stop.

- Winter

Physical:

a. Extreme cold can be a deterrent to work being performed in the field especially on the exposed face and hands. Frequently gloves need to be removed to work computer keys and fingers get cold easily.

b. The short daylight hours result in shortened data collection periods. Overtime to make up slipped schedule can only occur on weekends.

c. Winter snow prohibits the collection of data until the snow melts. This usually is accompanied by standing water and mud for several days until enough drying has occurred to make the fields accessible again.

d. Working on muddy ground presents a slip and fall hazard while working in the field.

Equipment:

a. At the first hint of snow flurries, HPGe work must stop to prevent snow from melting on the computer and detector.

b. Detectors are designed to operate optimally between approximately 40-90° F. Winter temperatures frequently drop below 40° F.

c. Temperatures below 32° F will affect computer battery life; below 15° F, it will start affecting the electronic display device which will become sluggish and eventually "freeze."

d. Rain must be kept off the computers and detectors to reduce the risk of equipment damage. At the slightest drizzle work must stop.

- Spring

Physical:

a. Rain and sudden violent storms are the limiting factors governing work during the spring.

b. Data collection cannot be performed while there is standing water on the ground.

c. Slick, muddy soil makes for hazardous working conditions. Carrying the HPGe over slick mud requires additional care. Driving the RTRAK over slick slopes can be hazardous. Some work areas, especially plowed or excavated areas are not accessible when muddy. A period of drying must occur before such areas are accessible to equipment.

Equipment:

a. Excessive winds may overturn detectors and computers.

b. Rain must be kept off the computers and detectors to reduce the risk of equipment damage. At the slightest drizzle, work must stop.

c. Morning fog creates conditions conducive to the buildup of radon in surface soils which must be compensated for by using a separate radon monitor.

4.14.2 See Also:

4.11 Environmental Influences on *In-Situ* Gamma Spectrometry Data

4.13 Time Required for In-Situ Gamma Spectrometry Measurements

5.3 Radium-226 Corrections

4.15 MAPPING CONVENTIONS

The use of maps for displaying and interpreting real-time *in-situ* gamma spectroscopy data is crucial for proper analysis and decision-making. This section discusses mapping protocols, including minimum mapping requirements to support various *in-situ* gamma spectroscopy uses, color maps and measurement aggregation strategies for RTRAK data.

4.15.1 RTRAK Aggregation Strategies

The RTRAK produces concentration data points with associated coordinate data attached. These data points typically include gross activity values as well as isotopic concentrations calculated from those activity levels. Because of the relatively high MDCs and measurement errors associated with the isotopic concentration estimates of individual readings, for many applications RTRAK data points must be aggregated. The number of points that need to be aggregated depends on the application and may range from as little as two for hot spot analyses to as many as 100 or more for FRL evaluations.

A more complete discussion of RTRAK measurement error and the relationship between aggregation strategies and measurement error can be found in the RTRAK Applicability Study (DOE 1997b). The brief discussion that follows summarizes the RTRAK Applicability Study. The measurement errors associated with individual RTRAK isotopic results are random and normally distributed. At a speed of 1 mph and an acquisition time of 4 seconds, the standard deviations of individual RTRAK isotopic results at FRLs are 62 ppm for total uranium, 0.65 pCi/g for radium-226, and 0.33 pCi/g for thorium-232.

Measurement error can be reduced by increasing effective count times. The effective count time is defined as the amount of data acquisition time associated with a measurement value. The magnitude of measurement error is roughly inversely proportional to the square root of the effective counting time. For example, increasing effective count times by a factor of four (from 1 second to 4 seconds) reduces the standard deviations associated with individual stationary RTRAK isotopic measurements by a factor of two. Effective counting times can be increased in one of two ways, by either increasing the acquisition time associated with an individual measurement value, or by basing a measurement value on a pooled or aggregated set of individual RTRAK measurements. For example, increasing the count time by a factor of four (from 1 to 4 seconds) has exactly the same impact on measurement error as averaging the results of 4 one-second RTRAK readings. Note that as long as the RTRAK's speed remains constant, the overall field of view for 1 four-second scan will be exactly the same as the total field of view for the four consecutive one-second scans.

Aggregating RTRAK data points by averaging data from adjacent RTRAK readings can be an effective means for reducing the measurement error associated with an isotopic estimate. In theory, measurement error can be reduced to negligable levels by simply averaging enough individual RTRAK data points. The trade-off is that as the number of data points contributing to the average grows, the associated total field of view grows as well, although at a slightly slower rate because of the inherent overlap in adjacent individual RTRAK measurements. For example, for RTRAK data collected at 1 mph with a 4-second acquisition time, aggregating two consecutive RTRAK measurements together reduces the measurement error associated with a total uranium estimate (when the actual concentration is around the FRL) from 62 ppm to 44 ppm, but increases the total field of view from 8.8 m^2 to 13.1 m^2. Averaging 100 adjacent RTRAK readings together reduces the overall measurement error associated with the average to only 6 ppm, but increases the total field of view to approximately 500 m^2.

Because of the increasing total field of view, only enough data aggregation is done to satisfy the MDCs and levels of measurement error required by the data collection program. For example, if the purpose of the investigation is to find WAC, no aggregation of individual RTRAK measurements is required. If the purpose is to find hot spots, two consecutive RTRAK measurements is required. If the purpose is to find hot spots, two consecutive RTRAK measurements averaged together provide acceptable measurement error rates. If the purpose is to define excavation boundaries, as many as 100 individual adjacent measurements would be aggregated.

The process of aggregating RTRAK data points begins by laying a relatively tight grid over the area of interest, where tight is defined as a grid spacing that is less than or equal to the average spacing between RTRAK data points along a single run. For example, when the RTRAK is operated at a speed of 1 mph and a data acquisition time of 4 seconds, the spacing between consecutive measurements is slightly less than 6 feet, so a 5 foot grid spacing would be appropriate. Every RTRAK data point is then assigned to its closest grid node. In the case where more than one data point is assigned a grid node, the node carries the average parameter values of all of the node points assigned to the node as well as the number of points contributing to the average. Each grid node and the data it contains represents the base unit for all aggregating analyses done--in the case of a 5 foot grid, the base unit has an area of 25 square feet, or 2.3 square meters.

Aggregation then takes place as moving averages built from this grid. For example, using a 5 foot grid, a hot spot analysis requiring the evaluation of RTRAK data over 10 square meters (approximately 100 square feet) would require constructing moving averages from the data contained in blocks of four grid cells (2x2). A hot spot analysis requiring the evaluation of RTRAK data over 25 square meters (approximately 270 square feet) would require constructing moving averages from the data contained in blocks for approximately 9 grid cells (3x3). FRL evaluation may involve the aggregation of data from as many as 225 individual grid cells (15x15). The degree of spatial resolution required depends on the application. For example, in the case of hot spots, one would calculate a moving average at every 5 foot grid node since one is looking for isolated elevated areas of contamination. For FRL attainment, however, a moving average might be calculated every 40 feet since the probable use is either the development of general excavation footprints, or for verifying that an area will likely pass certification before moving into certification. Whenever moving averages are used, the minimum items to be reported are the average values obtained from a moving average calculation, and the number of individual data points that contributed to that average.

4.15.2 Color Maps

When practical, color coding will be used for measurement points on maps to provide a visual indication of the level of contamination observed and its relationship to FRL, hot spot and WAC. To ensure consistency between color maps, the general guidelines for the selection of mapping colors are that shades of green are reserved for concentration levels that range from background to something below the FRL, yellows are reserved for concentrations in the vicinity of the FRL, oranges and reds are reserved for values in the range of 2xFRL to 3xFRL, and violet is reserved for levels that would pose WAC concerns. Table 4.15-1 provides an example color set for total U where the FRL is 82 ppm.

Maps based on gross activity values such as counts per second (cps) may also be used to evaluate the general spatial patterns of contamination. For maps displaying cps in color, the general guidelines are for color ramps that begin with green, move through yellow and finish in reds, with greens corresponding to low levels of activity and reds to high levels. Table 4.15-2 provides an example color set for cps.

4.15.3 Mapping for Spatial Distribution and FRL Evaluation

One of the uses of RTRAK data is to determine the general spatial distribution of contamination across an area. This can be done both with cps data and also with appropriately aggregated isotopic information. Minimum mapping requirements include one map that indicates the locations of individual measurements and color codes those measurements by cps value, and one set of maps (one for radium-226, one for thorium-232 and one for total uranium) that show aggregated moving average results for the RTRAK data sets. A method of quickly estimating the size of the area represented by the aggregates is in Section 4.3.

4.15.4 Mapping for Hot Spot Analysis

An analysis for the presence of hot spots is required in areas that have undergone remediation and are slated for certification, and areas where no remediation based on FRL exceedances is deemed necessary. RTRAK data may be used to determine the presence or absence of hot spots in these areas. Because of the measurement error associated with individual RTRAK measurements, individual total uranium measurements cannot be used for determining the presence or absence of hot spots with concentrations that are 3xFRL and below. This fact, coupled with hot spot definitions that are based on areas larger than the field of view of an individual RTRAK reading, requires the use of aggregated measurements.

The minimum mapping that is required for hot spots are maps that indicate the extent of the area that is being evaluated for the presence or absence of hot spots, and the locations of measurement aggregates that fail the hot spot trigger levels, along with an indication of which isotope presents the hot spot concern. At a minimum, hot spot aggregation/evaluation will be based on a two-point running average, with the results from this average compared to a 3xFRL standard. A two-point running average is defined as the average of two consecutive RTRAK readings.

In addition to this initial hot spot evaluation, additional aggregation/evaluation may be performed and the results mapped if deemed necessary. Section 4.5 specifies the size of the measurement aggregate and trigger levels to be used when evaluating RTRAK data for the presence of hot spots. A secondary set of maps may also be developed for hot spot detection that show the probability of aggregate measurements exceeding the hot spot criteria for radium-226, thorium-232 and total uranium.

In the event that the RTRAK identifies a potential hot spot, additional data collection will occur to confirm the presence of the hot spot and, if confirmed, to delineate the extent of the hot spot material using *in-situ* HPGe measurements (Section 3.3). For each location where a hot spot has been potentially identified, a final set of maps will be prepared that indicate the results of the confirmation and delineation data collection effort (including a best estimate of hot spot extent, if hot spot material is found to exist) for use in excavating hot spots and the final results of post-hot spot removal data collection to verify that all the hot spot has been removed.

4.15.5 Mapping for WAC Exceedance

RTRAK will be used to assist in determining the presence or absence of WAC material in a given area. For WAC exceedance detection purposes, individual RTRAK data points will be used. The minimum mapping that is required are maps that indicate the lateral extent of the RTRAK data set that exceed the WAC trigger levels. A more complete discussion of WAC trigger levels can be found in Section 4.5-2. A secondary set of maps may also be developed for WAC exceedance detection that show the probability of individual measurements exceeding the WAC criteria.

In the event that the RTRAK identifies potential WAC exceedance problems, additional data collection will occur to confirm the presence of above-WAC material and, if necessary, to delineate its extent using *in-situ* HPGe measurements (Section 3.4). For each location where above-WAC material has been potentially identified, a final set of maps will be prepared that indicate the results of the confirmation and delineation data collection effort (including a best estimate of above-WAC extent if above-WAC material is found to exist) for use in excavation and the final results of post-excavation data collection to verify that all above-WAC material has been removed.

4.15.6 Guidance

1. In all maps displaying radium-226 data, the radium-226 values should be corrected as described in Section 5.3.

2. As described in the "RTRAK Multiple Measurement Field of View" topic and in the "Hot Spot Detection" topic, care must be taken so that the area represented by aggregated measurements does not greatly exceed the size of the potential hot spot.

3. Color codes for mapping total activity data should follow interpretation conventions discussed in Section 4.15-2.

4.15.7 See Also:

3.3 Hot Spot Evaluation

3.4 Evaluation of Above-WAC Surface Soil

3.6 Horizontal Excavation Boundary Delineation

4.3 RTRAK Multiple Measurement Field of View

4.8 RTRAK Total Activity Data Interpretation

5.3 Radium-226 Corrections

5.0 TECHNICAL TOPICS

Topics included in this section are related to more technical aspects of *in-situ* gamma spectrometry usage than are topics in previous sections. Some of the topics, like "MDCs" and "Moisture Corrections," are analytical in nature. Others, like "positioning and survey" and "field quality control issues" are more related to field operations. These topics will be of interest not only to users of *in-situ* gamma spectrometry data, but also to all personnel concerned with collecting the data, processing the data, and overseeing data quality.

5.1 MINIMUM DETECTABLE CONCENTRATIONS (MDCs)

MDCs are discussed in this document from a data user's perspective. Detailed information may be obtained from Section 5.4 of the July 1997 HPGe Comparability Study (DOE 1997a).

MDC refers to the statistically determined quantity of a radionuclide that can be measured at a preselected confidence level. The MDC is the *a priori* activity concentration that a specific instrument and technique can be expected to detect 95% of the time. When stating the detection capability of an instrument, this value should be used. The MDC is the detection limit L_D, multiplied by an appropriate conversion factor to give units of activity concentration (Marssim 1997). The magnitude of the MDC is a function of instrument parameters, radiological background levels, and the measurement procedure.

The concept of using the MDC for radionuclide measurements was first proposed by Currie (1968). The MDC is intended to be an *a priori* estimate of the minimum activity concentration that a system or technique can reliably measure under a given set of conditions. **The MDC as defined here is not intended to be used *a posteriori* to evaluate individual measurements.**

5.1.1 <u>HPGe MDCs</u>

By analogy with the statistical methodology used for certification testing, the MDC criterion for a given isotope will be that the 95% upper confidence limit of the MDC must be less than the regulatory limit under investigation (in this report the final remediation level [FRL] is used as the default regulatory limit) for Analytical Support Level (ASL) D data quality levels. By analogy with the radiochemistry performance specifications in the Sitewide CERCLA Quality Assurance Project Plan (SCQ), a less stringent criterion for ASL B data quality levels will be that the 90% upper confidence limit of the MDC must be less than the FRL of concern. Table 5.1-1 shows the 90 and 95% upper confidence limits in relation to the FRLs. Given the data in Table 5.1-1, the HPGe detector should easily be capable of reliably detecting each radionuclide when it is present at, or near, its FRL for a data acquisition time of 15 minutes. This statement holds true even for total uranium when its FRL is 10 ppm.

5.1.2 RTRAK MDCs

In addition to detector and system parameters, RTRAK MDCs are a function of the data acquisition time and the number of multiple measurements which may be aggregated to yield an average value for a given area. Table 5.1-2 shows single measurement MDCs as a function of data acquisition time. Clearly, only the MDC for thorium-232 is consistently below its FRL. When multiple measurements are aggregated (Tables 5.1-3 and 5.1-4), RTRAK MDCs for individual isotopes may be well below their FRLs depending upon the number of measurements aggregated. MDCs in Table 5.1-4 have been estimated by multiplying data in Table 5.1-3 by 1.4 to obtain approximate MDCs for a 4 second data acquisition time.

5.1.3 Guidance

1. HPGe MDCs are sufficiently low for all isotopes so that HPGe can be used to make measurements relative to all soil regulatory limits.

2. Single measurement RTRAK MDCs are sufficiently high so that such RTRAK data should only be used for hot spot and WAC exceedance measurements. However, they can be used for FRL applications for thorium-232.

3. RTRAK data collected in areas with low soil concentrations of radionuclides must be handled and interpreted carefully. In this regard, the effective MDCs can be reduced by using an aggregation of individual measurements rather than relying upon individual measurements. This is equivalent to averaging the data over a larger area than the RTRAK field of view for a single measurement. While this allows the applicability of RTRAK to be extended to low concentrations, the spatial resolution of the data is reduced.

4. The number of points that must be aggregated for use of RTRAK for WAC and FRL applications is given in Table 4.5-2 through 4.5-6 in the Trigger Level topic (Section 4.5).

5.1.4 See Also:

4.3 RTRAK Multiple Measurement Field of View

4.15 Mapping Conventions

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TABLE 5.1-1
HPGe MINIMUM DETECTABLE CONCENTRATIONS (15 MINUTE DATA ACQUISITION TIME) COMPARED TO FRLs

Analyte	MDC[a]	95% UCL[a]	90% UCL[a]	FRL
Total Uranium	5.8 ppm	6.2 ppm	6.1 ppm	82 ppm[b]
Thorium-232	0.075 pCi/g	0.076 pCi/g	0.075 pCi/g	1.5 pCi/g
Radium-226	0.076 pCi/g	0.078 pCi/g	0.077 pCi/g	1.7 pCi/g

a The method of calculating MDCs and UCLs is given in Section 5.4 of the July 1997 HPGe Comparability Study (DOE July 1997a).

b FRL for total uranium will be 20 ppm in the former production area and 10 ppm in certain portions of the South Field. Off-property FRLs are also different than those in Table 5.1-1.

TABLE 5.1-2
RTRAK SINGLE MEASUREMENT MDCs[a]

Radionuclide	2 mph/2 sec	0.5 mph/2 sec	0.5 mph/8 sec	FRL
Total Uranium (ppm)	215[b]	211	140	82
Thorium-232 (pCi/g)	1.1	1.2	0.8	1.5
Radium-226 (pCi/g)	2.2	2.2	1.4	1.7

a 8-second data acquisition time MDCs may be multiplied by 1.4 to obtain approximate MDCs using a 4-second data acquisition time (DOE 1997b).

b Numbers are MDCs.

TABLE 5.1-3
RTRAK MDCs FOR AGGREGATED MEASUREMENTS
(0.5 mph/8 sec data acquisition time)[a]

		Number of Aggregated Measurements				
Radionuclide	FRL	1	5	10	50	100
Total Uranium (ppm)	82	140 [b]	63.0	45.0	19.8	14.1
Thorium-232 (pCi/g)	1.5	0.8	0.37	0.26	0.12	0.08
Radium-226 (pCi/g)	1.7	1.4	0.63	0.45	0.20	0.14

a 8-second data acquisition time MDCs may be multiplied by 1.4 to obtain approximate MDCs using a 4-second data acquisition time (DOE 1997b). These are shown in Table 5.1-4.

b Numbers are MDCs.

TABLE 5.1-4
APPROXIMATE MDCs FOR
4 SECOND DATA ACQUISITION TIME

		Number of Aggregated Measurements				
Radionuclide	**FRL**	1	5	10	50	100
Uranium (ppm)	82	196 [a]	88.2	63.0	27.7	19.7
Thorium-232 (pCi/g)	1.5	1.12	0.52	0.36	0.17	0.11
Radium-226(pCi/g)	1.7	1.96	0.88	0.63	0.28	0.20

a Numbers are MDCs.

5.2 MOISTURE CORRECTED DATA

Measurements from HPGe and RTRAK detectors need to be adjusted to take into account the soil moisture at or near the time of measurement. The instrument which measures soil moisture in the field is a Troxler soil moisture/density gauge. It measures soil moisture differently than a laboratory determines soil moisture. In a laboratory, soil moisture is defined as:

$$\text{Lab Moisture (decimal fraction)} = \frac{\text{weight water in soil}}{\text{wet weight soil sample}} \quad [1]$$

However, Troxler moisture is defined on a dry weight basis:

$$\text{Troxler Moisture (decimal fraction)} = \frac{\text{weight water in soil}}{\text{dry weight in soil sample}} \quad [2]$$

Equations 3 and 4 below show how to convert Troxler moisture to laboratory moisture based upon the definitions in Equations 1 and 2:

$$\text{Troxler moisture (decimal fraction)} = \frac{\text{lab moisture (decimal fraction)}}{\text{1.0 - lab moisture (decimal factor)}} \quad [3]$$

$$\text{Lab moisture (decimal fraction)} = \frac{\text{Troxler moisture (decimal fraction)}}{\text{1.0 + Troxler moisture (decimal fraction)}} \quad [4]$$

Moisture corrected *in-situ* gamma spectrometry data are calculated as:

$$\text{Data (dry weight basis)} = \frac{\text{Data (wet weight basis)}}{\text{1.0 - lab moisture (decimal fraction)}} \quad [5]$$

where the data may be in either units of ppm or pCi/g. By substituting Equation 4 into Equation 5, the wet weight *in-situ* gamma spectrometry data may be converted to dry weight data using Troxler moistures.

$$\text{Data (dry weight basis)} = \frac{\text{Data (wet weight basis)}}{\text{1.0 - [Troxler moisture (decimal fraction)/(1.0 + Troxler moisture (decimal fraction)]}} \quad [6]$$

Equation [6] simplifies to:

$$\text{Data (dry weight basis)} = \text{Data (wet weight basis)[1.0+Troxler moisture (decimal fraction)]} \quad [7]$$

5.2.1 Guidance

1. All *in-situ* gamma spectrometry data should be displayed in maps or tables on a dry weight basis. Comparison to limits such as FRLs on WAC shall be made on a dry weight basis.

2. If Troxler moisture data are presented in tables, the data shall be converted to a lab moisture basis using Equation 4.

3. If Troxler moisture data are entered into the SEP, the data shall be converted to a lab moisture basis using Equation 4.

5.2.2 See Also:

3.8 Field Moisture Measurements

4.11 Environmental Influences on *In-Situ* Gamma Spectrometry Data

5.3 RADIUM-226 CORRECTIONS

Radium-226 concentrations in soil are determined by *in-situ* gamma spectrometry at the FEMP by measuring gamma photons emitted by radioactive daughters of radon-222. An abbreviated decay series is shown below for radium-226:

$${}_{88}Ra^{226} \text{ ----- -}\alpha\text{ -----> } {}_{86}Rn^{222} \text{ --- -}\alpha\text{ ---> } {}_{84}Po^{218} \text{ -- -}\alpha\text{ ---> } {}_{82}Pb^{214}$$

$$|$$

$$|$$

$${}_{82}Pb^{206} \text{ <------- <------- <------- } {}_{83}Bi^{214} \text{ <----- -}\beta\text{ -------}$$

Table 5.3-1 shows the gamma photons used to quantify radium-226 for HPGe and RTRAK detectors. Sodium iodide detectors generally cannot resolve the lead and bismuth gamma peaks below 1500 keV from other interfering peaks, and so the RTRAK system uses the 1764.5 keV bismuth peak to quantify radium-226.

The problem with measuring radium-226 concentrations in soil is that its daughter, radon-222, is a gas. Radon-222 may build up in soils, diffuse from soils, accumulate near the surface of soils, etc., in response to a number of weather and soil conditions. Therefore, *in-situ* gamma spectrometry measurements of radium-226 also reflect processes which lead to the accumulation or depletion of radon-222 in soils, as well as the true concentration of radium-226 in soils. Sections 5.3.1 and 5.3.2 show how to correct HPGe data for radon disequilibrium effects while Section 5.3.3 discusses the correction of RTRAK data.

5.3.1 Correction of Afternoon HPGe Radium-226 Measurements

Table 3 and Figure 6C in the "Effect of Environmental Variables Upon *In-Situ* Gamma Spectrometry Data" (December 1997) report indicate that morning radium-226 measurements at a given location average 30% higher than afternoon measurements at the same location with a larger (relative) standard deviation. Afternoon radium-226 measurements represent steady-state dissipation of radon-222 from soils, and lead to consistent values for the concentration of radium-226. The report entitled "Comparability of *In-situ* Gamma Spectrometry and Laboratory Measurements of Radium-226" (October 1997) demonstrates that afternoon *in-situ* gamma spectrometry data are consistently lower than laboratory data, and that the difference between *in-situ* gamma spectrometry measurements and laboratory measurements increases as the concentration of radium-226 in soils increases. That same report derives a correction algorithm that empirically compensates for radon emanation from soils, thereby allowing radium-226 concentrations to be calculated from *in-situ* gamma spectrometry measurements that would be comparable to concentrations derived from laboratory analysis of physical samples.

As shown in Table 5-B of the report "Effect of Environmental Variables Upon *In-Situ* Gamma Spectrometry Data," when correction factors were applied to six months' worth of afternoon data from the field quality control station, the corrected average radium-226 concentration (1.55 pCi/g) was almost in perfect agreement with the laboratory measured value of 1.60 pCi/g, based upon the weighted mean of 10 soil samples. Just as important is the fact that such good agreement occurred at concentration levels close to the value of the FRL (1.7 pCi/g) of radium-226. Such good agreement demonstrates the validity of the correction factors for radium-226 concentrations in the vicinity of the FRL and also indicates that the HPGe accuracy for radium-226 meets ASL B data quality criteria.

5.3.1.1 <u>Guidance</u>

- Wet weight HPGe radium-226 concentrations based upon measurements taken between 12:00 pm and 6:00 pm may be corrected to concentrations that would be obtained if the measurement were performed in a laboratory on a physical sample.

- A correction factor for each measurement is calculated from the following equation:

  Correction factor (pCi/g) = 0.4369 (HPGe concentration, pCi/g)^2 + 0.167 (HPGe concentration, pCi/g) + 0.0001

- Add the correction factor to the HPGe radium-226 concentration:

  Corrected radium-226 concentration (pCi/g) = correction factor (pCi/g) + uncorrected radium-226 concentration (pCi/g)

- Convert corrected wet weight measurements to dry weight measurements as described in the section on moisture corrections.

- Do not use the above correction algorithm with RTRAK data. See Section 5.3.3 for correction of RTRAK data.

5.3.2 <u>Correction of Morning HPGe Radium-226 Measurements</u>

As noted above, morning radium-226 measurements are often higher than afternoon radium-226 measurements. Further, morning radium-226 measurements may exhibit considerable variability due to variability in weather and soil conditions. In order for morning radium-226 measurements to be useful and quantitatively correct, they must be corrected or adjusted to compensate for variability in radon-222 buildup and dissipation in soils. The guidance and example provided below illustrate how this will be accomplished. Several different ways to computationally adjust for morning radon-222 variability have been evaluated. The method presented below has been chosen for ease of implementation, amenability to automation, and simplicity.

5.3.2.1 Guidance

- A "radon monitor" will be set up in the vicinity of the area in which HPGe measurements will be made. This monitor will consist of a HPGe detector or a NaI gamma photon detector. The monitor will make periodic measurements of radon-222 daughters (i.e., it will determine radium-226 concentrations) throughout the period of HPGe measurements.

- For large, relatively flat areas such as the East Field, the radon monitor should be within 400 meters of the measurements. For small, flat areas, the radon monitor should be within the periphery of the area. For areas with significant differences in topographic elevations, such as deep pits, valleys and hills, consult the *In-Situ* Gamma Spectrometry Group for guidance.

- The detector height of the radon monitor should be the same height as the *in-situ* gamma spectrometry detector performing the field measurements.

- Measurements to determine radium-226 will be taken using a 15-minute data acquisition time. Thus, for an eight-hour work day, there could be as many as 32 measurements. Figure 5.3-1 shows an example of measurements taken by a HPGe radon monitor throughout the day at a given location . Clearly at this location, morning measurements for radium-226 are substantially higher than afternoon measurements.

- Calculate the ratio (hereafter called calibration ratio) of each radon monitor measurement to the lowest afternoon radon monitor measurement and plot these ratios vs. time of day. Figure 5.3-2 is an example of a plot of calibration ratios vs. time of day for the data in Figure 5.3-1.

- Actual HPGe data (as opposed to radon monitoring data) will be calibrated by using the closest (in time) calibration ratio to the beginning data acquisition time of the actual measurement. The beginning data acquisition time of the measurement is recorded electronically by the HPGe instrument and is subsequently loaded into the in-situ gamma spectrometry database. The determination of the closest (in time) calibration ratio is made in the database. The closest (in time) calibration ratio could be either before or after the beginning of data acquisition for a given HPGe measurement.

- Calibrate environmental HPGe data collected at a given time by **dividing** those data by the corresponding calibration ratio (taken from the nearest calibration ratio as described above) for that time. The resulting concentration will be equivalent to the concentration that would have been determined if the measurement had taken place in the afternoon at the time of maximum radon-222 depletion in soils. Table 5.3-2 shows a set of HPGe measurements taken on January 31, 1998 from the east field (Area 1 Phase II). The calibration ratios from Figure 5.3-2 are used to calculate calibrated radium-226 values (column 4 in Table 5.3-2) as described above.

- Using correction factors, calculate final corrected radium-226 concentrations, following the guidance in Section 5.3.1.1. These appear in Table 5.3-2 in the fifth column called "Wet Weight Radium-226 (pCi/g)."

- The last column in Table 5.3-2 shows the wet weight radium-226 data converted to dry weight radium-226 data. These HPGe data are comparable to what a laboratory would have measured by the analysis of physical sample.

- The above guidance will yield radium-226 data that satisfies ASL B quality control requirements for accuracy.

5.3.3 Correction of RTRAK Data

The principles for the correction of RTRAK data are similar to those described above for HPGe. Morning RTRAK data must be adjusted to compensate for variability in radon-222 build-up and dissipation in soils. Afternoon RTRAK data must be corrected to compensate for radon-222 disequilibrium in soils. The correction algorithm used in the guidance below is somewhat different from that used for HPGe, reflecting the facts that the RTRAK NaI detector is always 31 cm above the ground and that RTRAK is calibrated against HPGe data (errors are propagated).

5.3.3.1 Guidance

- Correct individual RTRAK measurements using "radon monitor" data per the first seven guidance bullets in Section 5.3.2.1.

- Aggregate the "radon monitor" corrected data based upon the data's intended useage. For example, for hot spots, take the running average of two consecutive measurements.

- A correction factor for each aggregated measurement is calculated from the following equation:

  $$\text{Correction factor (pCi/g)} = 0.47715\,(\text{HPGe concentration, pCi/g})^2 - 0.229\,(\text{HPGe concentration, pCi/g})$$

- Add the correction factor to the aggregated HPGe radium-226 concentration.

  Corrected aggregated radium-226 concentration (pCi/g) = correction factor (pCi/g) + uncorrected aggregated radium-226 concentration (pCi/g)

- Convert corrected aggregated wet weight measurements to dry weight measurements as described in the sections on moisture corrections.

- Corrected RTRAK radium-226 data must only be used at ASL A data quality levels.

5.3.4 See Also:

4.11 Environmental Influences on *In-Situ* Gamma Spectrometry Data

4.15 Mapping Conventions

5.2 Moisture Corrected Data

5.4 Data Review

TABLE 5.3-1
GAMMA PHOTONS USED TO QUANTIFY RADIUM-226
FOR HPGe AND RTRAK MEASUREMENTS

Detector	Radionuclide of Emission	Gamma Photon Energy (keV)	Gamma Photon Abundance (%)
HPGe	Pb-214	351.9	35.0
	Bi-214	609.3	43.0
	Bi-214	1120.4	17.0
RTRAK	Bi-214	1764.5	15.8

TABLE 5.3-2
HPGe MEASUREMENTS CORRECTED FOR RADON DISEQUILIBRIUM

Time of Day (minutes corrected to fractional hours)	A1PII Radium-226 (pCi/g)	Calibration Ratio*	Calibrated Radium-226 (pCi/g)**	Wet Weight Radium-226 (pCi/g)	Dry Weight Corrected Radium-226 (pCi/g)
8.52	0.84	1.39	0.61	0.87	1.16
8.78	0.79	1.43	0.55	0.77	1.04
9.05	0.78	1.42	0.55	0.77	0.99
9.24	0.75	1.42	0.53	0.74	1.01
9.55	0.71	1.33	0.53	0.75	1.10
9.91	0.79	1.26	0.63	0.91	1.32
10.03	0.82	1.30	0.63	0.91	1.14
10.28	0.76	1.32	0.58	0.82	1.08
10.34	0.71	1.32	0.54	0.75	1.01
10.53	0.63	1.20	0.52	0.73	0.90

* Taken from Figure 5.3-2

** Equals values in Column 2 divided by values in Column 3.

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Figure 5.3-1
Radium-226(pCi/g) from Radon Monitor at a Single Location as a Function of Time of Day
(Example Data Set)

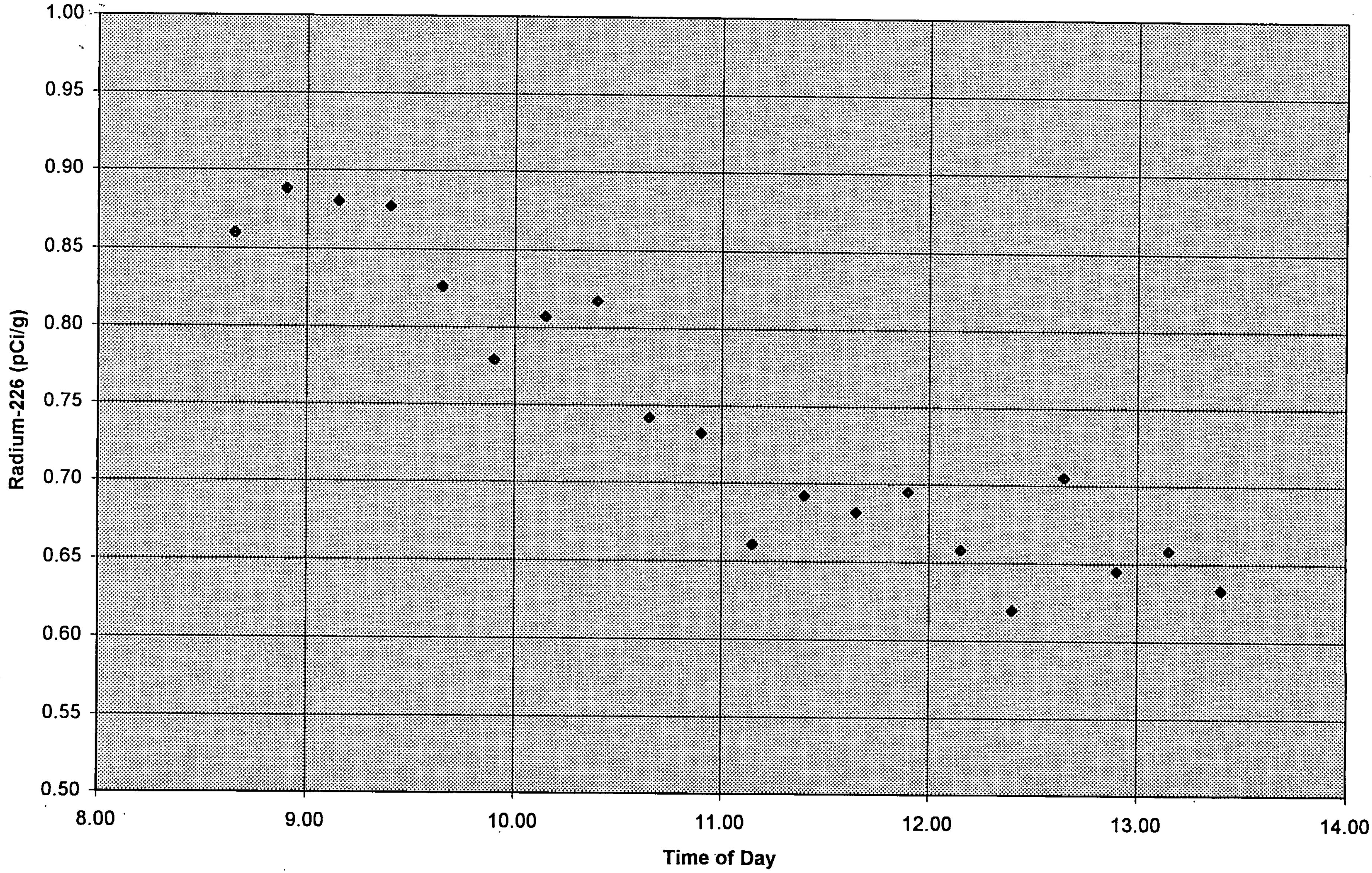
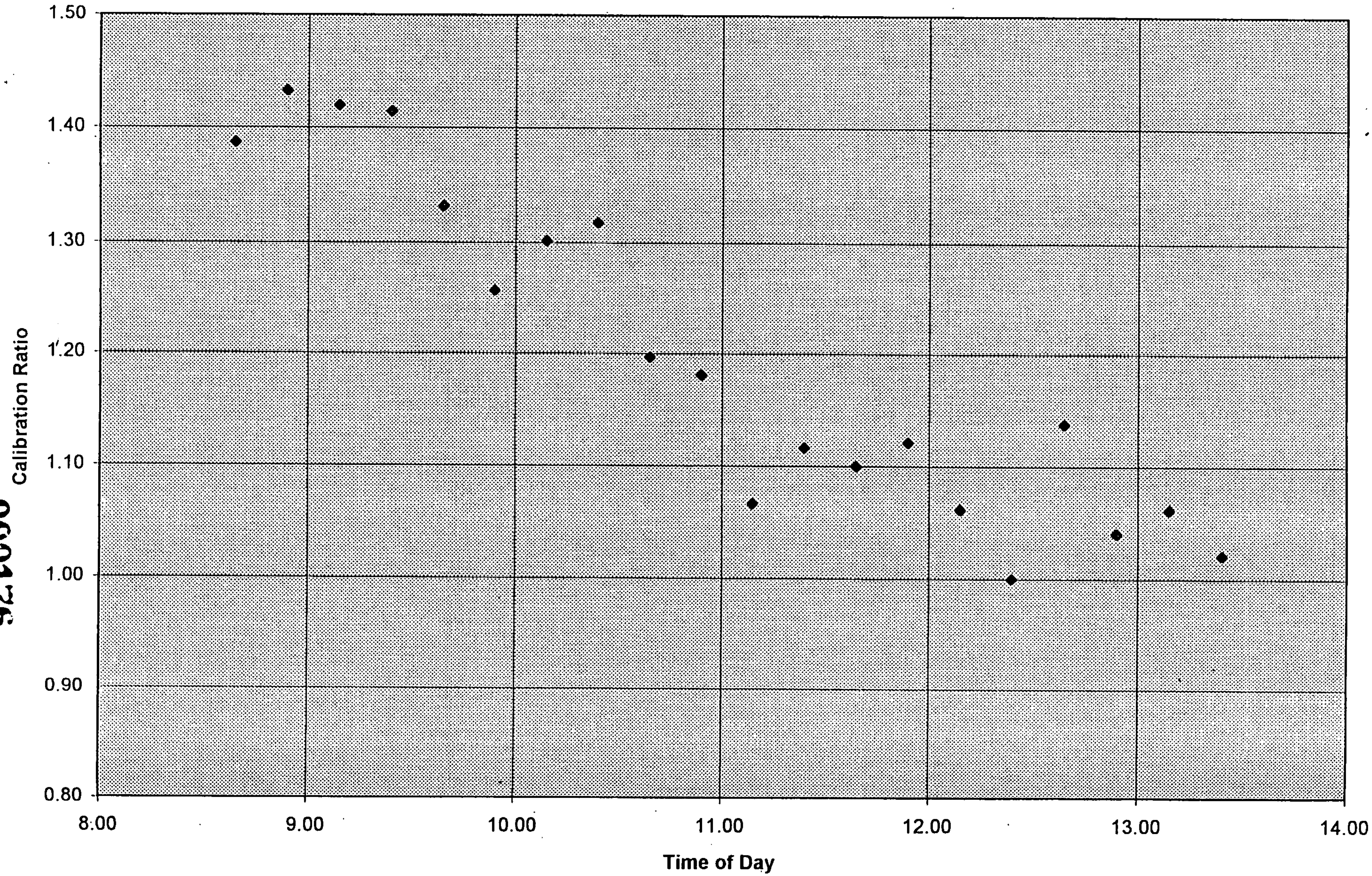


Figure 5.3-2

Calibration Ratio vs Time of Day for a Single Measurement Location (Example Data Set)



5.4 DATA REVIEW

Data review is an integral part of the QC process. Data review encompasses an evaluation of the reasonableness of the data, an evaluation of the quality of the data, an evaluation of certain computational factors, a review of certain data records, the flagging of suspect or unusable data, and the initiation of actions resulting from the review process. The sections below describe checklists used for the review of HPGe and RTRAK data. A more comprehensive discussion appears in Procedure ADM-17 (refer to Appendix A for reference).

5.4.1 HPGe Data

Table 5.4-1 contains elements pertinent to the review of HPGe data. Note that part of the data review process requires assurance that pre-operational and operational QC checks were performed and that acceptance criteria for those checks were met. Generally, 10% of all HPGe measurements performed in place of RTRAK or performed to get general patterns of contamination will be reviewed using the checklist in Table 5.4-1. One hundred percent of all HPGe confirmation or delineation measurements will be reviewed using the checklist in Table 5.4-1.

5.4.2 RTRAK Data

Table 5.4-2 contains elements pertinent to the review of RTRAK data. Note that part of the data review process requires assurance that pre-operational and operational QC checks were performed and that acceptance criteria for those checks were met. One data review element requires the examination of spectra. However, because RTRAK collects 900 spectra per hour at a 4-second data acquisition time, individual spectra are only examined for anomalies when they are flagged for some other reason. The checklist applies to the entire RTRAK data set collected in a single measurement location. Measurements taken at different locations on the same day must have separate checklists. Measurements continuing on different days in the same location must have separate checklists.

5.4.3 Guidance

- If all answers to the checklist items are "yes," the data are useable without restriction at the ASL data quality level under which measurements were made.

- If one or more data review elements are not met (one or more checklist items answered "no"), the data should be flagged with an "R" or an "S," unless the review of other data quality elements indicates otherwise and documentation is maintained.

- Data are qualified in two ways in the database: "R" means that data are rejected and must not be used. "S" means that even though one or more QC or data review elements have not been met, the data are useable for their intended purpose, but are still considered suspect. Suspect means that the values of the data are approximations of the true concentrations of the analytes in the samples. Suspect data must be reviewed before being used for any other purpose than originally intended.

- For HPGe data rejected as unuseable, a repeat measurement should be taken as appropriate.

- For RTRAK data rejected as unuseable, repeat RTRAK measurements or confirmation measurements with HPGe should be taken as appropriate.

- Individual RTRAK measurements may be rejected as unuseable without rejecting the entire RTRAK batch.

5.4.4 See Also:

3.2 RTRAK Measurements

4.9 Topographic Effects

4.12 Shine

5.2 Moisture Corrections

5.3 Radium-226 Corrections

TABLE 5.4-1
CHECKLIST FOR DATA REVIEW ELEMENTS FOR HPGe MEASUREMENTS

Yes or No?	Data Review Element
	Pre-Operational QC Elements
	Was an energy calibration performed using Am-241, Cs-137, and Co-60; and were the 59.5, 661.6 and 1332.5 keV photons in the proper channels?
	Was a photopeak resolution check performed using the 1332.5 keV photon from Co-60, and were the resolution criteria (FWHM $\pm 3\sigma$) met?
	Was a detector response check performed using the 1332.5 keV photon from Co-60, and were the net peak counts (cps) within tolerance limits ($\pm 3\sigma$)?
	At the measurement location was FWHM of the 1460.8 keV photopeak ≤3.0 keV?
	Operational QC Elements
	Was a measurement taken at the FCS, and were the measurement values in control?
	If duplicate measurements were taken, is the RPD ≤ 20% (for measured value ≥5 x MDC), or is measurement difference ≤ MDC (for measured value ≤ 5 x MDC)?
	Do Micro Rem readings indicate a lack of high background?
	Is FWHM of the 1460.8 photopeak ≤ 3.0 keV for each measurement?
	Was the "dead time" less than 20%? If not, is high dead time due to high activities or some other factor?
	If dead time was greater than 20%, are the data useable without restriction for their intended purpose?
	Are both the 63.2 and 92.6 keV lines 80% or more of the 1001.1 keV line?
	Even if both the 63.2 and 92.6 keV lines are less than 80% of the 1001.1 line, are the data useable without restriction for their intended purpose?
	Do energy calibration peaks and other key peaks have centroids and FWHM within QC criteria tolerances?
	Have radium-226 data been adjusted to reflect radon monitor measurements?
	Have radium-226 data been adjusted using ~~laboratory~~ radium-226 correction factors?
	Does the spectrum exhibit a lack of excessive noise?
	Does the spectrum appear normal and exhibit an absence of anomalies, such as double peaks or peak tailing?
	Have the data been moisture corrected to a dry weight basis before reporting, and is the moisture "laboratory moisture" and not "geotechnical moisture?"

TABLE 5.4-1 1
CHECKLIST FOR DATA REVIEW ELEMENTS FOR HPGe MEASUREMENTS 2

Yes or No?	Data Review Element 3
	Pre-Operational QC Elements 4
	Was an energy calibration performed using Am-241, Cs-137, and Co-60; and were the 59.5, 661.6 and 1332.5 keV photons in the proper channels?
	Was a photopeak resolution check performed using the 1332.5 keV photon from Co-60, and were the resolution criteria (FWHM $\pm 3\sigma$) met?
	Was a detector response check performed using the 1332.5 keV photon from Co-60, and were the net peak counts (cps) within tolerance limits ($\pm 3\sigma$)?
	At the measurement location was FWHM of the 1460.8 keV photopeak $\leq$3.0 keV?
	Operational QC Elements 5
	Was a measurement taken at the FCS, and were the measurement values in control?
	If duplicate measurements were taken, is the RPD $\leq$ 20% (for measured value $\geq$5 x MDC), or is measurement difference $\leq$ MDC (for measured value $\leq$ 5 x MDC)?
	Do Micro Rem readings indicate a lack of high background?
	Is FWHM of the 1460.8 photopeak $\leq$ 3.0 keV for each measurement?
	Was the "dead time" less than 20%? If not, is high dead time due to high activities or some other factor?
	If dead time was greater than 20%, are the data useable without restriction for their intended purpose?
	Are both the 63.2 and 92.6 keV lines 80% or more of the 1001.1 keV line?
	Even if both the 63.2 and 92.6 keV lines are less than 80% of the 1001.1 line, are the data useable without restriction for their intended purpose?
	Do energy calibration peaks and other key peaks have centroids and FWHM within QC criteria tolerances?
	Have radium-226 data been adjusted to reflect radon monitor measurements?
	Have radium-226 data been adjusted using laboratory radium-226 factors?
	Does the spectrum exhibit a lack of excessive noise?
	Does the spectrum appear normal and exhibit an absence of anomalies, such as double peaks or peak tailing?
	Have the data been moisture corrected to a dry weight basis before reporting, and is the moisture "laboratory moisture" and not "geotechnical moisture?"

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TABLE 5.4-1
(continued)

Yes or No?	Data Review Element
	Do the data seem reasonable relative to other spectra and data within the data set?
	If the soil moisture is greater than 30%, are the data useable without restriction for their intended purpose?
	Does the variability in Micro Rem readings among the measurements indicate a homogeneous environment?
	Have field notes been checked for items which could affect data such as standing water in the field of view, topographic irregularities, surface vegetation, or heterogeneities of some kind?
	If factors noted above which have the potential to affect data exist, do the data appear reasonable relative to other values in the data set? Can the data be used without restriction for their intended purpose?
	Can the data be used without correction factors such as those described by Equation 1 in Section 4.9 of the User's Manual?
	Do listed spectrum files exist in the appropriate file folder as recorded on worksheets?
	Do date, time and sample header information match worksheet/FADL entries?

TABLE 5.4-2
CHECKLIST FOR DATA REVIEW ELEMENTS FOR RTRAK MEASUREMENTS

Yes or No?	Data Review Element
Pre-Operational QC Elements	
	Was an energy calibration performed using Tl-208 and Pb-212; and were the 2614.5 and 238.6 keV photons in the proper channels?
	Was a detector response check performed using the 2614.5 keV photon, and were the net peak counts within tolerance limits ($\pm 3\sigma$)?
	Have Troxler moisture measurements been taken for the area to be measured by RTRAK?
Operational QC Elements	
	Do Micro Rem readings indicate a lack of high background?
	Has complete coverage of the area under investigation been achieved?
	Has the GPS been in contact with a minimum of 4 satellites consistently throughout the period of measurement?
	Is PDOP $\leq$ 6 for all measurements?
	Have GPS quality indicators been reviewed to indicate the quality of the signal?
	If GPS quality indicators indicate poor signal quality, have the data been flagged as suspect or rejected as appropriate?
	Was the "dead time" less than 20% for all measurements? If not, is high "dead time" due to high activities or some other factor?
	If dead time was greater than 20%, are the data useable without restriction for their intended purpose?
	Do all measurements have less than 20 negative thorium net counts per second?
	Are measurements with more than 20 negative thorium net counts per second useable without restriction for their intended purpose?
	Do all measurements have less than 500 thorium net counts per second?
	Are measurements with more than 500 thorium net counts per second useable without restriction for their intended purpose?
	Do all measurements have less than 20 negative radium net counts per second?
	Are measurements with more than 20 negative radium net counts per second useable without restriction for their intended purpose?
	Do all measurements have less than 50 negative uranium net counts per second?

TABLE 5.4-2
(continued)

Yes or No?	Data Review Element
	Are measurements with more than 50 negative uranium net counts per second useable without restriction for their intended purpose?
	Do spectra of flagged measurements appear normal and exhibit an absence of anomalies?
	Have the data been moisture corrected to a dry weight basis before reporting, and is the moisture "laboratory moisture" and not "geotechnical moisture?"
	Have radium-226 data been adjusted to reflect radon monitoring measurements?
	Have radium-226 data been adjusted using laboratory radium-226 factors?
	Do flagged measurements seem reasonable relative to other spectra and measurements within the data set?
	If the soil moisture is greater than 30%, are the data useable without restriction for their intended purpose?
	Have field notes been checked for items which could affect data such as standing water in the field of view, topographic irregularities, surface vegetation, or heterogeneities of some kind?
	If factors noted above which have the potential to affect data exist, do the data appear reasonable relative to other values in the data set? Can the data be used without restriction for their intended purpose?

5.5 HETEROGENEITY

Heterogeneity can exist with respect to both the lateral and depth distribution of a radionuclide. Heterogeneity at the FEMP can take the form of variations in the radionuclide concentration across various distances: a centimeter or less, as would result from hot particles; meters, as might occur from dumping and localized spills; and tens or hundreds of meters, as from airborne sources. No single measurement technique can be expected to average all potential variations. In general, characterization in a heterogeneous environment is a sampling and measurement approach issue. Thus, measurement approaches must incorporate appropriate detector fields of view and appropriate measurement grid densities/configurations to address heterogeneities.

Heterogeneity is a function of both scale and concentration for individual radionuclides (a given size area can be homogeneous for one radionuclide but heterogeneous for another). With regard to concentration, working definitions of the degree of heterogeneity are given below. These definitions are not universal in that they are related to FEMP remediation criteria.

Low Heterogeneous Areas	Radionuclide concentrations range over a factor of 2 or less. Low heterogeneous areas are most likely to be uniformly below FRLs.
Medium Heterogeneous Areas	Radionuclide concentrations range over a factor of 2 to 5. Medium heterogeneity areas are most likely to contain hot spots.
High Heterogeneous Areas	Radionuclide concentrations range over a factor of 5 or more. High heterogeneous areas are most likely to contain WAC exceedances.

The degree of heterogeneity will be assessed both *a priori* and *a posteriori* relative to remediation operations. Before (*a priori*) remediation operations in a given area, the degree of heterogeneity will be estimated based upon RI/FS data and by process knowledge. After (*a posteriori*) remediation operations in a given area, the degree of heterogeneity can be assessed based upon *in-situ* gamma spectrometry data as well as upon any physical sample data.

The scale of heterogeneities can be related to their detectability with the HPGe, RTRAK, and hand-held survey meters.

- Medium and high heterogeneities with < 0.5 m radius may be detected with hand-held survey meters and by HPGe at a 15 cm detector height.
- Medium and high heterogeneities having a 0.5 to 2.0 m radius can be detected by HPGe at either 15 cm or 31 cm detector height, depending upon the value of radionuclide concentrations, and by RTRAK.

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- Low, medium and high heterogeneities having a 2.0 m to 4.0 m radius can be detected by HPGe at either 31 cm or 1.0 m detector height, depending upon the range of radionuclide concentrations, and by RTRAK.

- Low, medium or high heterogeneities with a > 4.0 m radius can be detected by HPGe at 1.0 m detector height and by RTRAK.

The concentration and scale of heterogeneities and their detectability can all be combined as shown in Tables 5.5-1 through 5.5-3. For example, in **medium heterogeneous** areas in which 0.5 to 2.0 meter radius hot spots occur (Table 5.5-2), HPGe at a 31 cm detector height is the primary instrument for detection. Similarly, in **high heterogeneous** areas, if WAC exceedances with greater than 4.0 meter radii occur, such exceedances can be detected with either HPGe or RTRAK (Table 5.5-3). Finally, as noted in Table 5.5-1, small areas of low heterogeneity are not of particular concern in remediation. **Large, low heterogeneous** areas are of interest, particularly for FRL boundary excavation evaluation reasons. Both RTRAK and HPGe at 1.0 meter detector height are well suited to provide reliable data on large, low heterogeneous areas.

Because RTRAK is the primary tool for measuring 100% of accessible areas, and because RTRAK is the primary tool for providing general patterns of contamination in pre-design investigations and in precertification surveys, RTRAK is the primary tool for recognizing heterogeneous areas. Given the results of RTRAK surveys, HPGe is then focused on specific measurement objectives; for example, WAC exceedance confirmation. Heterogeneity issues, then, become important only within the context of the measurement objective. The guidance bullets below refer the user to sections where measurement approaches for various measurement objectives are addressed.

5.5.1 Guidance

- For protocols on how to detect, confirm, and delineate hot spots in heterogeneous areas, as well as to interpret data from such measurements, refer to Sections 3.3 ("Hot Spot Evaluation").

- For protocols on how to detect, confirm, and delineate WAC exceedances in very heterogeneous areas, as well as how to interpret data from such measurements, refer to Sections 3.4 ("Evaluation of Above-WAC Surface Soil") , 4.6 ("WAC Exceedance Detection") and 4.5 ("Trigger Levels").

- For guidance on how to present RTRAK data to display general patterns of contamination, as well as how to interpret RTRAK data, refer to Sections 4.15 ("Mapping Conventions") and 4.8 ("RTRAK Total Activity Data Interpretation").

- Refer to Tables 5.5-1 through 5.5-3 for guidance and information as to instrument type and detector height for various measurement objectives in heterogeneous areas.

5.5.2 <u>See Also</u>

3.3 Hot Spot Evaluation

3.4 Evaluation of Above-WAC Surface Soi

4.1 HPGe Detector Field of View

4.3 RTRAK Multiple Measurement Field of View

4.5 Trigger Levels

4.6 WAC Exceedance Detection

4.7 Use of Hand-Held Survey Meters

4.8 RTRAK Total Activity Data Interpretation

4.15 Mapping Conventions

TABLE 5.5-1
Instrument Selection and Detector Height for Evaluation of FRL Excavation Boundaries and CU Delineation in Heterogeneous Areas

Scale of Heterogeneity (Radius in m)	Degree of Heterogeneity		
	Low Heterogeneity (<2x)	Medium Heterogeneity (2x-5x)	High Heterogeneity (>5x)
<0.5	Very small, low heterogeneous areas not of remediation concern for FRL boundary excavation or CU delineation	Very small, medium heterogeneous areas not of remediation concern for FRL boundary excavation or CU delineation.	Very small, high heterogeneous areas not of remediation concern for FRL boundary excavation or CU delineation
0.5-2.0	Small, low heterogeneous areas not of remediation concern for FRL boundary evaluation or CU delineation	Small, medium heterogeneous areas not of remediation concern for FRL boundary evaluation or CU delineation	Small, high heterogeneous areas not of remediation concern for FRL boundary evaluation or CU delineation
2.0-4.0	Small, low heterogeneous areas not of remediation concern for FRL boundary evaluation or CU delineation	Detectable by RTRAK and by HPGe at 31 cm detector height. May be of interest for CU delineation	Detectable by RTRAK and by HPGe at 1.0 m detector height. May be of interest for CU delineation
>4.0	Large, low heterogeneous areas detectable by RTRAK and HPGe at 1.0 meter detector height. Of interest for FRL boudary evaluation	Detectable by RTRAK and by HPGe at 1.0 m detector height. May be of interest for CU delineation	Detectable by RTRAK and by HPGe at 1.0 m detector height. May be of interest for CU delineation

TABLE 5.5-2
Instrument Selection and Detector Height for Evaluation of Hot Spots in Hetergeneous Areas

Scale of Heterogeneity (Radius in m)	Degree of Heterogeneity		
	Low Heterogeneity (<2x)	Medium Heterogeneity (2x-5x)	High Heterogeneity (>5x)
<0.5	Very small, low heterogeneous areas not of remediation concern; probably do not contain hot spots	Very small hot spots may be detectable by hand-held survey meters. Not of remediation concern	Very Small Hot Spots detectable by hand-held survey meters and HPGe at 15 cm detector height
0.5-2.0	Small, low heterogeneous areas not of remediation concern; probably do not contain hot spots	Small hot spots detectable by HPGe at 15 cm detector height.	Small hot spots detectable by RTRAK and by HPGe at 31 cm detector height
2.0-4.0	Small, low heterogeneous areas not of remediation concern ; probably do not contain hot spots	Hot spots detectable by RTRAK and by HPGe at 31 cm detector height	Hot spots detectable by RTRAK and by HPGe at 1.0 m detector height
>4.0	Large, low heterogeneous areas detectable by RTRAK and HPGe at 1.0 meter detector height; but probably do not contain hot spots	Large hot spots detectable by RTRAK and by HPGe at 1.0 m detector height	Large hot spots detectable by RTRAK and by HPGe at 1.0 m detector height

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TABLE 5.5-3
Instrument Selection and Detector Height for Evaluation of WAC Exceedances in Heterogeneous Areas

Scale of Heterogeneity (Radius in m)	Degree of Heterogeneity		
	Low Heterogeneity (<2x)	Medium Heterogeneity (2x-5x)	High Heterogeneity (>5x)
<0.5	Very small, low heterogeneous areas not of remediation concern for WAC exceedances	Very small, medium heterogeneity areas not of remediation concern for WAC exceedances	WAC exceedances detectable by hand-held survey meters and HPGe at 15 cm detector height
0.5-2.0	Small, low heterogeneous areas not of remediation concern for WAC exceedances	Detectable by HPGe at 15 cm detector height, but not of remediation concern for WAC exccedances	WAC exceedances detectable by RTRAK and by HPGe at 31 cm detector height
2.0-4.0	Small, low heterogeneous areas not of remediation concern for WAC exceedances	Detectable by RTRAK and by HPGe at 31 cm detector height, but probably not of remediation concern for WAC exceedances	Detectable by RTRAK and by HPGe at 1.0m detector height
>4.0	Large, low heterogeneous areas not of remediation concern for WAC exceedances	Large medium heterogeneity areas detectable by RTRAK and by HPGe at 1.0 m detector height and may contain WAC exceedances.	WAC exceedances detectable by RTRAK and by HPGe at 1.0m detector height

5.6 STRENGTHS AND LIMITATIONS OF *IN-SITU* GAMMA SPECTROMETRY

As noted in sections throughout this document, RTRAK and HPGe each have certain strengths and certain limitations. Sometimes the strengths and limitations have been stated explicitly; sometimes they have been implied. This section succinctly summarizes information contained in all other sections by compiling strengths and limitations for HPGe and RTRAK for easy reference.

5.6.1 RTRAK Strengths and Limitations

5.6.1.1 Strengths

- The RTRAK is able to provide rapid, 100% coverage of an area. An acre may be measured with 100% coverage in as little as two hours. The complete coverage provides the ability to identify WAC, hot spot, and FRL problems better than would be possible with discrete samples.

- The cost of RTRAK data is relatively low. Depending upon amount of site preparation, degree of overlap between passes, terrain considerations, and the radiological environment, RTRAK data costs between $500 and $1000 per acre. Assuming that one physical sample every hundred square feet is adequate to characterize an area, then 440 physical samples would need to be collected per acre. Sample collection, sample management office, and analytical costs total approximately $300 per sample. Thus, RTRAK is 130 to 260 times less expensive than physical samples on a per acre basis.

- RTRAK produces gross activity data which provide excellent survey information relative to general patterns of surface soil radioactivity.

- RTRAK provides quantitative data (in the form of concentrations given in ppm or pCi/g) for total uranium, thorium-232, radium-226, potassium-40, cesium-137 and other radionuclides. This enables general patterns of contamination to be delineated. It allows average concentrations to be determined for a CU.

- Because of its small field of view and its capability to provide 100% coverage, RTRAK is well suited to make measurements enabling the degree of heterogeneity and homogeneity on the scale of 3 to 5 meters within an area to be determined.

- The minimum detectable concentration is low enough and the precision is good enough for single RTRAK measurements for total uranium to detect WAC exceedances. Gross activity data may also be used to detect potential WAC exceedances.

- By aggregating two measurements, RTRAK data for thorium-232 and radium-226 may be used to reliably detect hot spots at either 2 x FRL or 3 x FRL.

- By aggregating two measurements, RTRAK data may be used to detect total uranium hot spots at 3 x FRL. By aggregating five measurements, total uranium hot spots at 2 x FRL can be detected. This holds only when the FRL for total uranium is 82 ppm.

- Turn-around times are low. Forty-eight hour turn-around times are currently achievable and the goal of work presently in progress is to reduce this to 24 hours for data output involving mapping algorithms. The goal of work in progress is also to provide real time data output involving the simple posting of individual measurement values on a map.

- When a scaled-down version of RTRAK is in routine operation, RTRAK will be able to make measurements in almost every terrain except vertical sidewalls, trenches, and sloping walls with a greater than 1:1 slope.

- RTRAK data are readily amenable to mapping and a variety of mapping algorithms are employable. In addition to patterns of contamination, hot spots, and WAC exceedances, RTRAK maps can show natural and anthropogenic features such as abandoned roads.

- Data quality can be improved, if necessary, by decreasing RTRAK speeds and increasing the data acquisition time.

- May be used when the ground is frozen and samplers cannot take core samples easily.

- Measurements are non-destructive and non-intrusive.

5.6.1.2 Limitations

- In its current configuration, RTRAK cannot perform measurements in heavily wooded areas, in deep pits, or on sloping walls in which the slope is greater than 0.5:1.

- The precision is low and the minimum detectable concentration is high for individual measurements. As a result, individual measurements cannot be used to accurately quantify total uranium and radium-226 at concentrations near their FRLs (82 ppm and 1.7 pCi/g, respectively). Thorium-232 may be reliably quantified at concentrations near its FRL.

- Low FRLs of 10 ppm and 20 ppm for total uranium in various locations at the FEMP effectively limits the use of RTRAK for FRL screening given that the MDC is greater than the FRL and the very high number of data points that must be aggregated to achieve acceptable precision and MDC.

- Care must be taken when aggregating measurements such that the size of the area represented by the aggregation is not significantly larger than the scale of the object of interest. Aggregation reduces spatial resolution.

- Correction algorithms are needed to adjust radium-226 measurements to compensate for radon-222 disequilibrium in surface soils.

- Unrecognized shine may give falsely elevated readings. Shine may not be recognized.

- RTRAK measurements cannot be made immediately after heavy rain, when snow is on the ground, or when soil is saturated with water.

- RTRAK only measures surface soil contamination

- RTRAK is limited to measuring only certain gamma photon emitting radionuclides.

5.6.2 HPGe Strengths and Limitations

5.6.2.1 Strengths

- HPGe provides quantitative data for a wide variety of gamma emitting isotopes. These data exhibit very high degrees of precision, low minimum detectable concentrations, and high degrees of accuracy. (Note: the major issue with HPGe data is not its accuracy or precision, but rather how to interpret the data. See other points in Strengths and Limitations.)

- HPGe can provide accurate and meaningful information on primary radiological COCs with regard to FRL attainment; hot spot detection, confirmation, and delineation; and WAC (for total uranium) exceedances.

- For all areas, individual HPGe measurements provide results that are more representative of a significant volume of soil than are measurements obtained by the analysis of conventional samples.

- Varying the detector height on the HPGe allows measurements to be made over a variety of viewing areas. This allows different sized areas to be examined quickly and also allows for boundary delineation. Additionally, multiple measurements at different detector heights at a given location may provide valuable information on the heterogeneous vs homogeneous distribution of analytes.

- Variable fields of view (i.e., different viewing areas at different detector heights) more closely match clean-up criteria than do discrete samples (i.e., areas associated with hot spot criteria).

- As necessary, HPGe can provide 100% coverage of an area. This allows the identification of WAC, hot spot, and FRL problems better than physical samples.

- HPGe allows measurements to be performed rapidly. A single measurement may take from 5 to 15 minutes. However, other factors limit the number of measurements that can be made in a day. Refer to Section 4.13, "Time Required for In-Situ Gamma Spectrometry Measurements" for details.

- HPGe is well suited to having multiple systems working in tandem to quickly cover an area.

- Twenty-four hour turn-around times for data are easily achievable with HPGe.

- HPGe data are amenable to storing, manipulating, and archiving electronically just as conventional analytical data are.

- The cost of HPGe data is significantly less than laboratory gamma spectrometry data, particularly when turn-around times are considered. It costs from $150 to $200 for an *in-situ* gamma spectrometry measurement with a 24-hour turn-around time (or less), taking into account site preparation, QA/QC, transportation of units, and radiological constraints. The cost of a conventional gamma spectrometry analysis with a 30-day turnaround time is approximately $300, taking into account sampling, sample management office, and analytical costs.

- Results are not very sensitive to topographic effects for conditions likely to be found at the FEMP.

- A wide variety of terrains may be measured. These include vertical sidewalls, trenches, pits, and sloping walls. The algorithms used by HPGe can be customized as necessary to achieve measurement objectives in terrains.

- The superior resolution of HPGe detector relative to sodium iodide detectors may allow shine to be recognized as well as interfering gamma photons from radionuclides other than the ones of interest.

- HPGe can be used when the ground is frozen and samplers cannot take core samples easily.

- Measurements are nondestructive and non-intrusive.

5.6.2.2 Limitations

- QA/QC requirements are still evolving. No promulgated requirements exist such as those associated with CLP or SW846 protocols.

- Radium-226 measurements cannot be used without correction or adjustments in order to compensate for radon-222 disequilibrium in surface soils. When conditions (particularly in the morning) are not conducive to the dissipation of radon-222 from surface soils, a separate radon monitor must be employed to provide information for radium-226 correction algorithms. When very few measurements are to be made, the measurements should be made in the afternoon to avoid possible morning radon-222 buildup.

- Individual measurements are hard to interpret in heterogeneous environments. This is particularly true when the scale of the heterogeneities is on the order of or less than 50% of the field of view at a given detector height. (This is also true for any other analytical technique.)

- If used in small, confined areas, such as pits or trenches, correction factors may be needed to account for the unique geometries of the areas. (But measurements are conservative in that concentrations will be higher than actual concentrations when correction factors are not employed.)

- HPGe measurements cannot be made in rain or snow. Measurements must not be made after a heavy rainfall, when snow is on the ground, or when the ground is saturated with water.

- One soil moisture measurement within the field of view may not represent the average moisture within the field of view.

- When making measurements in the vicinity of building or drums where radioactive material is stored, gamma radiation from the radioactive material may interfere with gamma radiation from radionuclides of interest in the soil. This "shine" may lead to falsely elevated measurements.

5.6.3 <u>Guidance</u>

- The strengths and limitations listed above for HPGe and RTRAK must be consulted when writing PSPs, IRDPs, and certification design letters.

- HPGe and RTRAK complement each other. Limitations in one system may be compensated for by strengths in the other. When used in tandem, the strengths of the tandem system may exceed the sum of the strengths of the individual systems.

- When in doubt as to the correct usage of HPGe or RTRAK, consult the *In-Situ* Gamma Spectrometry Group for advice.

5.6.4 <u>See Also</u>:

2.1 Overview of RTRAK and HPGe Usage

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5.7 FIELD QUALITY CONTROL CONSIDERATIONS

QA and QC procedures (20300-PL-0002 and ADM-16, respectively) have been written in order to implement an *in-situ* gamma spectrometry quality program. Although the QC procedure primarily addresses traditional QC elements such as accuracy, precision, use of control charts, etc., it also specifies a number of daily checks to equipment that must be performed. However, other factors may occur in the field while taking measurements that can detract from the quality of the data. These factors have been delineated based upon the experience of the field crews and are presented below.

5.7.1 Guidance

Field Use of HPGe

- If High Voltage LED is not illuminated, check the following:
  1. Ensure power switch is on
  2. Ensure low battery LED is not illuminated. Note: If low battery light is illuminated, there will probably not be enough power to operate the MCB.
  3. Ensure battery is properly installed in the MCB.

- If program indicates "can't read MCB" or won't switch over from the buffer to the detector, check the following:
  1. Ensure 9-pin preamp cable and BNC connectors are secured to MCB
  2. Ensure 25-pin parallel printer port cable is securely connected
  3. Ensure cable connectors are in their proper terminals

- If detector voltage cannot be enabled, check the following:
  1. Ensure bias shutdown cable is securely connected in its proper terminal (i.e., SD)
  2. Ensure voltage on detector matches voltage applied
  3. Ensure detector is properly cooled (i.e., filled with LN_2)

- During energy calibration if RESOLUTION or NET PEAK AREA are not within QC limits, check the following;
  1. Ensure detector is in proper fixed geometry.
  2. Ensure no foreign (shielding) objects are between source and detector.
  3. Ensure no other radiological sources are in the area.

- If (when taking field readings) the RESOLUTION of potassium-40 (channel 3895) is too high (i.e. greater than 3 keV or 8 channels), check the following:
  1. Electromagnetic/radio frequency interference.
  2. Interference from another radiological source.
  3. Possibility of actual high resolution from equipment failure.
  4. Interference from isotopes with energy close to that of potassium-40 (thorium-230, -232)

Note: When working in high dirt/dust areas and on a periodic basis, the cable connectors and terminals should be cleaned with denatured alcohol and air to ensure good connection and thus, proper operation. Also, wrapping the connectors with aluminum foil helps to fix potassium-40 resolution problems.

Field Use of the RTRAK

- The RTRAK should not be driven in/on the following areas:
  1. Steep inclines
  2. Over ditches or into deep pits (could rip detector off)
  3. Over standing water

- Take proper precautions when traveling and crossing roadways.

- Do not drive under tree canopy or near low lying tree branches - GPS signal could get blocked or GPS antenna could get snagged on limbs.

- Ensure energy calibration sources (i.e., thorium mantles) are removed from the detector after use and placed in a shielded storage area.

- Use caution when working around calcium chloride-filled tires. Tire punctures can result in personnel being sprayed with calcium chloride.

- Jarring and bumping of instrumentation may cause calibration of spectrum to shift and render data useless.

- When using NIMBin-type analyzer, ensure constant and proper temperature inside cab. Temperature changes can cause spectrum shifts.

- When starting on-board generator, manually choke if it does not start up right away.

- If low end peak is out (>2 channels), use zero adjust to bring it in.

General Considerations:

- No radioactive sources such as that in the Troxler gauge must be present (at least within 75 meters) during operation of RTRAK or HPGe.

- Personnel must not wander into or place objects within the detector field of view.

- To the extent possible, field of view obstructions should be minimized.

- Live time agrees with preset value; dead time not excessive for level of contamination in area; dead time must not exceed 40%.

- Spectrum continuum has characteristic shape - no abrupt shifts in general smoothness, broad humps, excessive counts at low channels, spurious counts or dropped channels.

- Peak shape good - no low or high energy side tailing, peak broadening, double peaks.

5.7.2 See Also:

4.9 Topographic Effects

4.14 Seasonal Precautions

5.4 Data Review

5.8 POSITIONING AND SURVEYING

Static and dynamic positioning techniques are required to identify the geographic locations of the HPGe and RTRAK measurements. Field coordinates for HPGe readings are easily determined using conventional survey methods and equipment (total stations, electronic theodolites, or GPS) to stake out locations or grid points. The physical location of spectra acquired by the RTRAK system is determined by differential GPS (DGPS).

5.8.1 RTRAK System

The RTRAK acquired from the Uranium Mill Tailings Remedial Action (UMTRA) program originally utilized a microwave ranging technology based upon Motorola's Ranger system. That positioning system required setting up an expensive network of antennae and a base transmitter to track the vehicle's movement. Positioning was not provided in real time and an extensive baseline was required to be established over each work area.

Upon acquiring the RTRAK in 1996, the FEMP decided that GPS technology was affordable and dependable enough to replace the complex microwave positioning system. The FEMP selected a sub-meter GPS receiver as the primary positioning system for the RTRAK due to the receiver's ability to achieve sub-meter positioning accuracies and the versatility of the receiver to interface or "speak" with external electronic devices. The receiver incorporates the GPS and DGPS signals into a single housed unit, thus eliminating the need to interface two separate receivers, each supplying its respective signal. The GPS "engine" consists of a 12-channel, parallel tracking receiver with a latency update of one hertz. A single antenna integrates the GPS and the differential correction or beacon signal, thereby providing the user with an instantaneous corrected position. The system is compatible with a variety of external electronic sensors, including lasers, rangefinders and dataloggers, making it ideal for various mapping applications. Recent hardware upgrades to the submeter mapping grade receiver provide typical accuracies of greater than 50% improvement in positioning over the previous system. These new receivers can deliver a horizontal RMS error as low as 15 cm and vertical RMS errors as low as 30 cm. Ideal GPS conditions have produced accuracies better than 10 cm.

A GPS receiver capable of receiving a differentially corrected signal can increase position precision from 100 meters to centimeters. The user can select from various methods of accessing the DGPS signal. These include post-processing data, real time corrections through use of a base station, through use of a differential correction service, or at no cost from a government agency such as the US Coast

Guard if available in the user's general area. Although the FEMP can currently receive two to four of these "free" frequencies continuously, the base stations are far enough from the FEMP to propagate an error in position (approximately one meter error for every 100 km the signal travels). Each method has its advantages and disadvantages regarding cost, accuracy and availability. The RTRAK utilizes a differential correction signal service provider since the service provider incorporates the user's geographic location into a correction algorithm and since the service provider provides service worldwide. The ability to receive a DGPS signal worldwide is a consideration should a radiological mapping package become commercially developed for use across the US and abroad.

5.8.2 Factors Affecting GPS Positioning

The NAVSTAR global positioning system is highly reliable and provides consistent operation when used properly. Although the occurrence of errors during GPS positioning is uncommon, users must be familiar with factors and limitations that can adversely impact positioning data. GPS satellites are operated and controlled by the Department of Defense. Their atomic clocks and signals can be adjusted to provide erroneous signal information. Although the GPS is available 24 hours a day, certain time periods exhibit optimal satellite telemetry and availability (see Figure 5.8-1). Mission planning software is used to monitor optimal time frames for conducting GPS operations and to identify periods which may not yield satisfactory results. Also, resources are available that indicate periods of poor satellite health. Resources include various web pages, typically provided by government institutions, including the Coast Guard, US Navy, several gas manufacturers, and some universities with advanced mapping programs. Knowing this, the user can "turn off" any signals that may be received from the unhealthy satellite.

Dense tree canopies or tall structures may be responsible for blocking GPS signals, geostationary differential correction signals, or for producing a multipath error or bounced signal effect. Similar to "ghost" effects as seen on television, multipath error occurs when satellite signals are reflected from nearby objects such as trees, fences, vehicles, buildings, and water surfaces. This type of error cannot be blamed on the satellite or the receivers. Modern receivers use advanced signal processing techniques to minimize the problem, but in some severe cases it can add some uncertainty to the location of a GPS measurement. Field experience with the use of GPS equipment will educate the user as to degrees of latitude for antenna placement when working around obstructions that may interfere (block or bounce) with the GPS radio signal.

The use and application of GPS technology provides a cost effective and dependable method of positioning anywhere on or above the earth's surface. Proper use of the positioning equipment and an awareness of its operational limitations will yield valuable information. GPS will not function when satellite positioning signals are not received. Familiarity with the prospective work site and prior satellite mission planning will significantly reduce, if not eliminate, possible GPS positioning errors, allowing proper focus towards radionuclide detection efforts. The use of GPS positioning has demonstrated an ideal application for this unique and successful radionuclide detection system.

5.8.3 Guidance

- Planning software and almanacs should be used to plan optimal periods in a given day for conducting GPS operations. The objective is to avoid running RTRAK at potentially poor times to receive satellite signals, such as those occurring at 9:30 am, 2:30 pm, and 8:30 pm, as illustrated in Figure 5.8-1 (note that these times are not constant on a day-to-day basis).

- The FEMP considers GPS signals associated with PDOP values less than or equal to 6 to be acceptable for use.

- Do not perform work where GPS signals will be blocked or in locations which could lead to multipath error effects. Multipath errors cannot be corrected for in the field. Multipath errors may be identified with a real-time mapping display. Multipath errors that occur along a straight line can be corrected by interpolation. Through use and experience, the user should become familiar with the types of features that cause multipath to occur and learn to avoid those obstacles to the extent possible. Familiarity with the prospective work site and prior satellite mission planning will significantly reduce, if not eliminate, possible GPS positioning errors and allow proper focus toward radionuclide detection errors.

- GPS quality indicators (0, 1, 2) sent from the GPS receiver indicate the quality of the GPS signal being recorded. Zero indicates an invalid GPS fix (loss of GPS signal); a "1" indicates a GPS fix (GPS signal received with loss of the differential correction); and a "2" represents a differential GPS fix. By reviewing these data records, the analyst can determine positioning errors resulting from satellite signal loss or lock. Additionally, when plotted on site reference maps, it is possible for the analyst to determine the source or factor that may have contributed to signal loss.

5.8.4 See Also:

4.9 Topographic Effects

4.15 Mapping Conventions

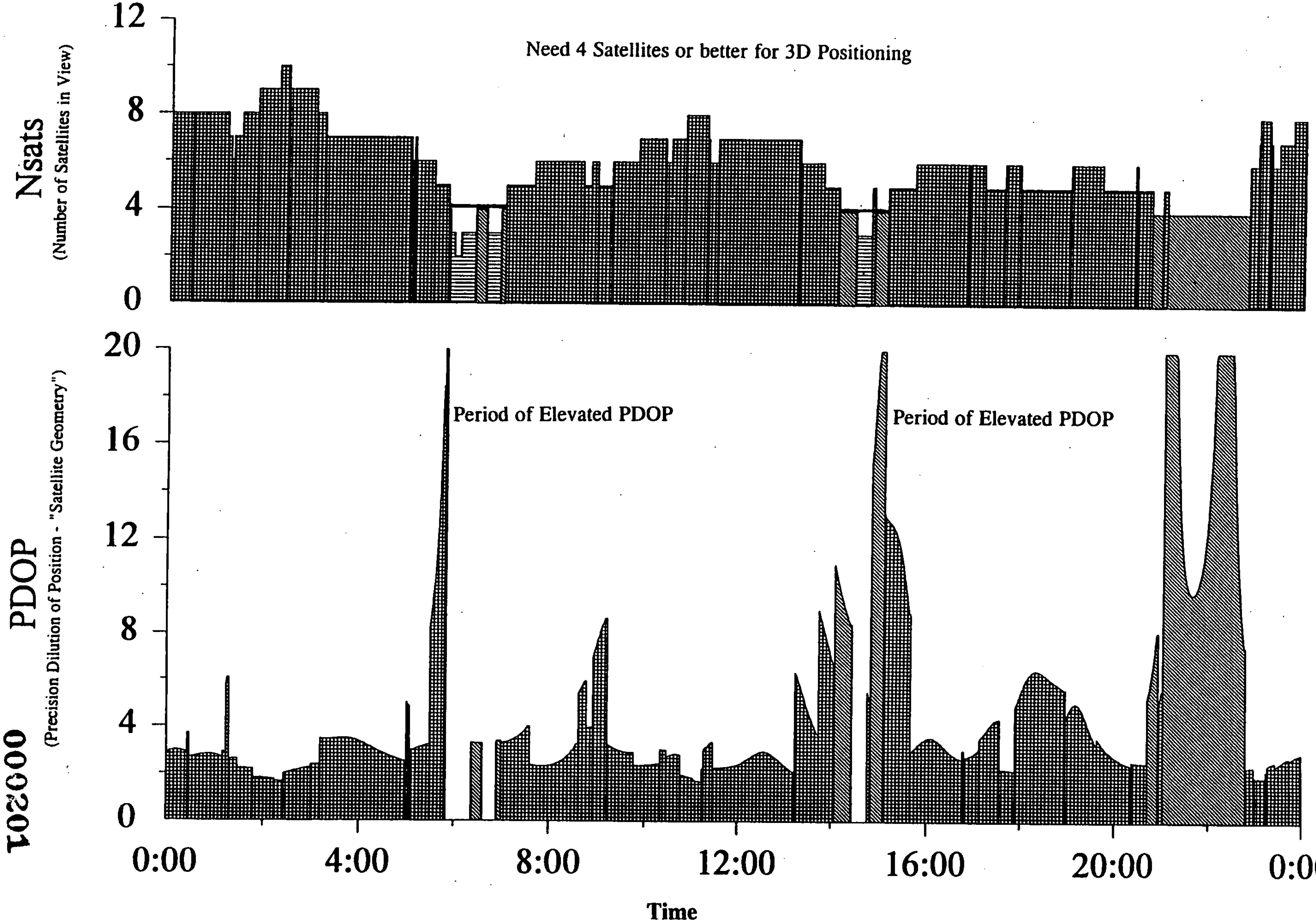
5.7 Field Quality Control Considerations

Optimal Time Periods for GPS Satellite Telemetry

Point: Cincinnati
Date: Wednesday, April 01, 1998
24 Satellites considered : 1 2 4 5 6 7 9 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 31

Lat 39:06:0 N Lon 84:26:0 W
Threshold Elevation 15 (deg)

Almanac: R020619A.SSF 2/6/98
Time Zone 'Eastern Std USA' -5:00



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APPENDIX A
PROCEDURES

A.1 REAL TIME WORK GROUP PROCEDURES

1.	ADM-16	*In-Situ* Gamma Spectrometry Quality Control Measurements
2.	ADM-17	Data Review and Reporting of *In-Situ* Gamma Spectrometry Data
3.	EQT-22	Characterization of Gamma Sensitive Detectors
4.	EQT-23	Operation of ADCAM Series Analyzers with Gamma Sensitive Detectors
5.	EQT-30	Operation Radiation Tracking Vehicle Sodium Iodide Detection System
6.	EQT-32	Troxler 3440 Series Surface Moisture/Density Gauge--Calibration, Operation and Maintenance
7.	EQT-34	Operation of the Radiation Scanning System
8.	EQT-36	Operation of a FIDLER
9.	EQT-37	*In-Situ* Gamma Spectrometry Maintenance/Preventive Maintenance
10.	20300-PL-0002	Real Time Instrumentation, Measurement Program Quality Assurance Plan
11.	In Process	Transfer, Processing, and Storage of *In-Situ* Gamma Spectrometry Data

A.2 HEALTH, SAFETY, AND RADIATION CONTROL PROCEDURES

1.	RP-0014	Radiation Source Accountability and Control
2.	RC-DPT-035	Inspection and Performance Testing of Portable Radiological Survey Instruments
3.	RC-DOS-21	Operation of the Liquid Nitrogen Transfer Dewar
4.	RC-TWD-003	Radiological Requirements for Transporting, Starting, and Using the Troxler Moisture/Density Gauge

A.3 ENVIRONMENTAL MONITORING PROCEDURES

1.	ADM-01	Procedure Development and Training
2.	ADM-02	Field Project Prerequisites
3.	ADM-12	Required Reading
4.	EQT-10	AC Portable Generator - Operation and Maintenance

5. EQT-33 Real-Time Differential Global Positioning System (GPS) - Operation
4. SMPL-01 Solids Sampling

A.4 SITE-WIDE DOCUMENTS

1. RM-0012 FEMP Quality Assurance Program Description
2. FD-1000 FEMP Sitewide CERCLA Quality Assurance Project Plan (SCQ)
3. RM-0029 FDF Conduct of Operations (CONOPS) Program

APPENDIX B
REFERENCES

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