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August 14, 2013

Ms. Laurie A. Kauffman
US Nuclear Regulatory Commission
Region 1
2100 Renaissance Blvd.
Suite 100
King of Prussia, PA 19406-2713

Mr. Marc Ferdas
Decommissioning Branch Chief
US Nuclear Regulatory Commission
Region 1
2100 Renaissance Blvd., Suite 100
King of Prussia, PA 19406-2713

Dear Ms. Kauffman & Mr. Ferdas:

Re: Characterization Survey Plan
Former UNC Manufacturing Facility, New Haven, CT

Attached for your review is the Characterization Survey Plan for the Former UNC Manufacturing Facility located in New Haven, CT.

Please let me know if you have any questions. We look forward to your approval and completion of decommissioning at the facility.

Sincerely,

Robert Bonito
UNC Naval Products
20 Research Parkway
Old Saybrook, CT 06475

License SNM-368 (Terminated)
Docket 070-0037 (Retired)

Attachment

NMSS/RGN1 MATERIALS-002

FINAL

CHARACTERIZATION SURVEY PLAN

Site Decommissioning Former UNC Manufacturing Facility

New Haven, Connecticut

Prepared for:

GENERAL ELECTRIC COMPANY
319 Great Oaks Blvd.
Albany, New York 12203

UNC Naval Products
20 Research Parkway, Unit E
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Prepared by:

CABRERA SERVICES
RADIOLOGICAL · ENGINEERING · REMEDIATION

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July 2013

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LIST OF ACRONYMS AND ABBREVIATIONS

1x1 NaI	one inch by one inch sodium iodide
α	alpha
ACM	asbestos containing material
AP	Cabrera Administrative Procedure
APP	Accident Prevention Plan
B	beta
Cabrera	Cabrera Services, Inc.
CDPH	Connecticut Department of Public Health
COC	chain of custody
cpm	counts per minute
CQCSM	Contractor Quality Control Systems Manager
$DCGL_W$	Derived Concentration Guideline Level used for Non-Parametric Statistical Test
DP	Decommissioning Plan
DQO	Data Quality Objectives
e.g.	for example
FIDLER	Field Instrument for the Detection of Low-Energy Radiation
FSS	Final Status Survey
FSSP	Final Status Survey Plan
ft	feet
γ	gamma
GEL	General Engineering Laboratories
IEM	Integrated Environmental Management, Inc.
IMC	intermodal container
H_a	Alternative Hypothesis
H_o	Null Hypothesis
HEU	highly-enriched uranium
i.e.	that is
LBGR	Lower Bound of the Gray Region
m^2	square meter
MARSSIM	Multi-Agency Radiological Survey and Site Investigation Manual
MDC	Minimum Detectable Concentration
MeV	million electron volts
mrem/yr	millirem per year
NaI	sodium iodide
No.	number
NRC	U.S. Nuclear Regulatory Commission
OP	Cabrera Operational Procedure
pCi/g	picocuries per gram
PVC	poly vinyl chloride
QA	Quality Assurance
QC	Quality Control
RESRAD	Residual Radioactivity
ROCs	Radionuclides of Concern
RPP	Radiation Protection Plan
s	seconds
SU	Survey Unit
TEDE	Total Effective Dose Equivalent
^{234}U	uranium-234
^{235}U	uranium-235

LIST OF ACRONYMS AND ABBREVIATIONS (CONTINUED)

^{238}U	uranium-238
UNC	United Nuclear Corporation
U.S.	United States
USEPA	U.S. Environmental Protection Agency
WRS	Wilcoxon Rank Sum

1.0 INTRODUCTION

Cabrera Services, Inc. (Cabrera) has been contracted by United Nuclear Corporation (UNC) Naval Products to perform remediation and final status survey (FSS) at their former facility at 71 Shelton Avenue in New Haven, Connecticut, hereafter referred to as "the Site." These tasks will be completed in accordance with the *Decommissioning Plan* (DP; UNC, 1998), *FSS Plan* (FSSP; IEM, 2006), Cabrera's *Accident Prevention Plan* (APP; Cabrera, 2010a) and *Nuclear Material Control and Accountability Plan* (Cabrera, 2010b), and existing standard administrative and operational procedures (Aps and OPs; Cabrera, 2000). The location of the Site is displayed in Figure 1 of the DP (UNC, 1998).

Historic operations at the Site leached uranium contamination into soils underlying portions of Building 3H/6H. Detailed information pertaining to historic operations at the Site is provided in Section 1.5 of the project APP (Cabrera, 2010a). The floors of several utility trenches present underneath the building contain many small drainage holes to allow water to drain from these trenches into the underlying soil. During the asbestos abatement and FSS of utility trench surfaces, Cabrera also collected soil samples from many of these drainage holes for investigative purposes. Analytical results revealed that soils underlying these trenches contain elevated concentrations of total uranium (i.e., uranium-234 [^{234}U], uranium-235 [^{235}U], and uranium-238 [^{238}U]), confirming that radioactive contamination had migrated through the drainage holes that are distributed throughout these trenches (refer to Attachment 1).

The purpose of this *Characterization Survey Plan* is to describe the means and methods by which Cabrera will further characterize the subsurface soils beneath the utility trenches for remediation and FSS. The purpose of this survey is two-fold:

1. Define areas of soils with concentrations of uranium that are high enough to require remediation.
2. Collect sufficient data from areas of soils beneath utility trenches that will support the unrestricted release of remaining soils.

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2.0 FACILITY BACKGROUND AND SITE INFORMATION

Facility background and site information for work completed prior to 2011 is described in Section 1.5 of the APP (Cabrera, 2010a).

Activities performed during the remedial action in 2011 and 2012 included the following:

- Mobilization and Site Preparation for Remediation;
- Remediation of the Argyle Street Sewer and Soils;
- Asbestos abatement and removal from the South Trench, Lateral Trenches, and North Trench;
- Partial characterization of soils under the South Trench, Lateral Trenches, and North Trench;
- Remediation of the Small Trench;
- Remediation of Decontamination Pit soils;
- Remediation of Decontamination Room solid surfaces;
- Remediation of X-Ray Read Room Excavation soils;
- Remediation of X-Ray Read Room solid surfaces;
- Characterization and Remediation of Laydown Area soils;
- Characterization and Remediation of Haul Road soils;
- On-site gamma spectroscopy sample analysis;
- Packaging and transporting waste material using intermodal containers (IMCs) for off-site disposal;
- FSS of decontaminated areas;
- Backfilling and Restoration of Remediated Areas (including, but not limited to, replacing Argyle Street sewer, restoring Argyle Street asphalt and Shelton Avenue sidewalk and roadway, and replacing a garage and driveway on a neighboring property); and
- Demobilization.

Final Status Survey operations of impacted land areas, exterior surfaces, and structures have been completed in accordance with the requirements specified in the *Final Status Survey Plan* (AAA/IEM, 2006). All SUs were properly classified, surveyed, and sampled. It has been concluded that the soils beneath the following utility trenches will require additional characterization and possibly remediation of residual radioactive contamination: the South Trench; "North Trench" (a utility trench running along the entire length of the northern end of the building) from Columns 1 to 30; and the "Column 17/18 Lateral Trench" (one of several lateral trenches running along the width of the building - this particular trench is located between Columns 17 and 18).

In order to generate preliminary characterization data regarding the vertical and horizontal migration of uranium in soils underlying the utility trenches, a section of the utility trench floor running along the entire length of the southern end of the building (herein referred to as the "South Trench") was broken up, the underlying soil was sampled at the center of one of the drainage holes, and soil was collected from eight locations distributed laterally around the drainage hole. This section was adjacent to Column 40 of Building 3H/6H and represented some of the highest total uranium concentrations encountered throughout drainage hole sampling efforts. After collecting these nine samples, the soil was removed six vertical inches and then another set of nine samples was collected. This process was repeated at all nine sample locations until either the total uranium concentrations decreased to below 30 picocuries per gram (pCi/g), which represented the previously accepted Site Derived Concentration Guideline Level ($DCGL_W$), or a depth of 3 feet below ground surface was achieved. Residual total uranium concentrations less than the $DCGL_W$ occurred in soils at a depth of three feet below the top of the soil at all locations except for the original drainage hole location (result was 55 pCi/g; refer to Attachment 2 for more details).

2.1 Radionuclides of Concern

The radionuclides of concern (ROCs) that were considered during the FSS are highly-enriched uranium (HEU, containing ^{234}U, ^{235}U, and ^{238}U). A list of the ROCs and their characteristics is provided in Table 2-1.

TABLE 2-1. RADIONUCLIDES OF CONCERN

ROC	Name	Half-Life	Decay Mode and Principal Emissions (Notes 1,2)
^{234}U	Uranium-234	2.45E05 yr	4.72, 4.77 MeV α; 0.053 MeV γ
^{235}U	Uranium-235	7.04E08 yr	4.39, 4.36 MeV α; 0.18, 0.14 MeV γ
^{238}U	Uranium-238	4.47E09 yr	4.19, 4.14 MeV α; 0.049 MeV γ

1. yr = year; MeV = million electron volt; γ = gamma; α = alpha
2. The principal emissions have been truncated down to those with the highest decay yields.

3.0 DATA QUALITY OBJECTIVES

This *Characterization Survey Plan* was developed in accordance with the guidance presented in the *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM; U.S. Nuclear Regulatory Commission [NRC], 2000). The MARSSIM process is meant to ensure that all impacted SUs are surveyed with the necessary rigor corresponding to their applicable contamination potential. This will ensure that enough data will be collected during the survey to ensure that statistical criteria are met to confirm an area's acceptability for unrestricted release.

The following sections describe inputs into the design of the FSS, including detailed data quality objectives (DQOs); $DCGL_W$ classification and survey unit (SU) designations; survey planning parameters; instrumentation, measurement and sampling procedures; and data quality assessments.

3.1 Project Data Quality Objectives

DQOs define the purpose of the FSS, identify the data needed to satisfy the purpose, and specify the performance requirements for the quality of information to be obtained from the data. The DQO process consisted of the following steps (U.S. Environmental Protection Agency [USEPA], 2006):

- State the problem,
- Identify the decision,
- Identify inputs to the decision,
- Define the study boundaries,
- Develop the decision rule,
- Specify tolerable limits on decision errors, and
- Optimize the design.

3.1.1 Step 1: State the Problem

The Site, in the course of operations, utilized HEU which produces alpha, beta, and gamma radiation. The objective of FSS operations is to obtain data of sufficient quality and quantity to demonstrate, to a specified degree of statistical certainty, that the concentrations of radiological constituents do not exceed the release criteria listed in Section 5.1

.

3.1.2 Step 2: Identify the Decision

The objective of this step is to develop decision statements that required site data to address the problem statement above.

Principal Study Question

Do the concentrations of the ROCs in soils at the Site exceed applicable levels for unrestricted release?

Decision Statement

Determine whether ROC soil concentrations exceed the acceptable release criteria, or if further remediation is required.

3.1.3 Step 3: Identify Inputs to the Decision

The objective of this section is to identify the informational inputs required to resolve the decision statement identified above. This section also describes the sources of those informational inputs, which inputs require environmental measurements, and discusses how the required inputs are obtained. The following site characteristics were determined to resolve the applicable decision statement:

(A) Concentration of residual radioactivity in Site soils:

This information will be used to determine whether Site soils exceed the applicable release criteria. This data facilitates decision-making regarding whether additional remediation is required in specific areas.

(B) Information Sources:

Residual radioactivity levels will be determined by means of:

- Volumetric sampling and analysis of surface and subsurface Site soils;
- Gamma scan survey measurements of soil cores and bore holes; and
- Exposure rate surveys.

3.1.4 Step 4: Define the Study Boundaries

The population of interest for the Site is the concentration of ROCs in the South Trench, North Trench, and Lateral Trench underlying soils.

The population of interest is horizontally and vertically limited to impacted areas located beneath the South Trench, North Trench, and Lateral Trench of Building 3H/6H.

3.1.5 Step 5: Develop the Decision Rules

Parameter of Interest

Parameters of interest are the mean, median, and standard deviation of data collected during the study. Based on the data distribution characteristics resulting from survey data collection, the preceding parameters will be transformed to equivalent descriptive measures (e.g., logarithms, etc.) to allow more representative statistical testing. By using a graded approach to data testing as discussed below, decisions will be made according to the decision rule stated at the end of this section.

Scale of Decision Making

Decisions will be made on two fundamental scales, individual SUs and the smaller localized areas of elevated activity, if any, within a SU. Localized areas of elevated radiation levels will be evaluated on an ongoing basis throughout the field effort. In cases where clear indications of elevated measurements are observed, decisions on remediation, SU subdivision, etc., will be recommended, as appropriate. On a larger scale, and as a final determination, data will be evaluated on a SU-specific basis.

Decision Inputs

- ROCs – A discussion of the ROCs associated with this characterization survey is provided in Section 2.1.
- Measurement and Data Assessment Inputs – Assessment of the following data sources was performed to help ensure that the criteria in the decision rules were met.
  - Average ROC activity concentrations
  - Small areas of elevated activity
  - Soil scan survey results

Decision Rules

Decisions on the potential for a SU for release are based on comparison to the DCGLw. Inputs to this decision were based on a graded approach to data analysis intended to avoid unnecessary analytical and/or remediation efforts, while also ensuring that project DQOs are met. The DCGLw employed during this sampling effort is described in Section 5.1.

3.1.6 Step 6: Define Acceptable Decision Errors

The hypotheses tested as part of the DQO process were:

> *Null Hypothesis (H_o)*: The median concentration in the SU exceeds the $DCGL_W$ (Section 5.1).
>
> and,
>
> *Alternative Hypothesis (H_a)*: The median concentration in the SU does not exceed the $DCGL_W$.

Appendix D in MARSSIM (NRC, 2000) provides a discussion regarding decision errors. This discussion includes the concept that acceptable error rates must be balanced between the need to make appropriate decisions and the financial costs of achieving high degrees of certainty.

> *Errors can be made when making site remediation decisions. The use of statistical methods allows for controlling the probability of making decision errors. When designing a statistical test, acceptable error rates for incorrectly determining that a site meets or does not meet the applicable decommissioning criteria must be specified. In determining these error rates, consideration should*

be given to the number of sample data points that are necessary to achieve them. Lower error rates require more measurements, but result in statistical tests of greater power and higher levels of confidence in the decisions. In setting error rates, it is important to balance the consequences of making a decision error against the cost of achieving greater certainty.

Acceptability decisions are often made based on acceptance criteria. If the mean and median concentrations of a contaminant are less than the associated acceptance criteria, for example, the results can usually be accepted. In cases where data results are not so clear, statistically based decisions are necessary. Statistical acceptability decisions, however, are always subject to error. Two possible error types are associated with such decisions.

The first type of decision error, called a Type I error, occurs when the H_o is rejected when it is actually true. A Type I error is sometimes called a "false positive." The probability of a Type I error is usually denoted by alpha (α). Consequences of Type I errors include higher potential doses to future site occupants than prescribed by the dose-based criterion.

The second type of decision error, called a Type II error, occurs when the H_o is not rejected when it is actually false. A Type II error is sometimes called a "false negative." The probability of a Type II error is usually denoted by beta (β). The power of a statistical test is defined as the probability of rejecting the null hypotheses when it is false. It is numerically equal to 1-β where β is the Type II error rate. Consequences of Type II errors include unnecessary remediation expense and project delays.

For the purposes of the characterization survey, the acceptable error rate for both Type I and Type II errors was five percent (that is [i.e.], $\alpha = \beta = 0.05$).

3.1.7 Step 7: Optimize the Design

As data are collected and analyzed, the assumptions in this plan will be reviewed for accuracy. Field screening techniques, soil sampling, sample analysis, gamma measurements, and the DQO process will be utilized, as appropriate, throughout sampling activities operations to focus efforts and minimize costs.

4.0 PROJECT ACTIVITIES

This section describes the activities to be performed in support of the characterization survey at the Site.

4.1 Pre-Mobilization Activities

This section describes project-related tasks that will be completed prior to full field mobilization.

4.1.1 Site-Specific Project Work Plans

Site-specific project work plans have been developed and will be used to support this sampling effort. The most current approved revision for each document will be maintained on-site, at Cabrera's project field office, in addition to applicable Cabrera standard Administrative and Operating procedures. A description of applicable Cabrera standard APs and OPs is provided in Table 4-1.

TABLE 4-1. APPLICABLE CABRERA STANDARD OPERATING PROCEDURES

REFERENCE NUMBER	TITLE, REVISION NUMBER
AP-005	ALARA, Rev. 2
AP-009	Radiation Worker Training, Rev. 2
AP-010	Personnel Protective Equipment Used Within Radiological Controlled Areas, Rev. 1
AP-013	Packaging Radioactive Material, Rev. 0
AP-014	Classifying Radioactive Waste, Rev. 0
AP-016	Radioactive Material Tracking, Rev. 0
OP-001	Radiological Surveys, Rev. 3
OP-002	Radioactive Air Sampling and Analysis, Rev. 1
OP-004	Unconditional Release of Materials from Radiological Control Area, Rev. 2
OP-005	Volumetric and Material Sampling Within Radiological Control Areas, Rev. 2
OP-008	Chain of Custody, Rev.1
OP-009	Use and Control of Radioactive Sources, Rev. 1
OP-018	Decontamination of Radioactivity from Equipment and Tools, Rev. 1
OP-019	Radiological Posting, Rev. 0
OP-021	Alpha-Beta Counting Instrumentation, Rev. 1

REFERENCE NUMBER	TITLE, REVISION NUMBER
OP-023	Operation of micro-R meters, Rev. 0
OP-028	Preparation of Samples for Gamma Spectroscopy, Rev. 0
OP-029	Gamma Spectroscopy Operations, Rev. 4
OP-061	Sample Labeling, Rev. 0.1
OP-062	Sample Handling, Packaging & Shipment, Rev.0.1
OP-066	Sample Tracking Log Rev. 0
OP-068	Sample Management - Onsite Laboratory Rev. 0
OP-075	Downhole Gamma Logging Procedure, Rev. 1
OP-076	Soil Core Scanning Procedure Rev. 1
OP-351	Surface Soil Sampling, Rev. 0

4.1.2 Procuring Equipment, Materials, and Specialty Services

An asbestos abatement contractor licensed in the state of Connecticut will be selected to abate the asbestos tiles, mastic, or materials covering the floors in planned sampling locations. A drilling subcontractor will be selected to perform the direct push sampling efforts throughout the building.

4.1.3 Notifications

Cabrera will make appropriate notification to the NRC and to the state of Connecticut Department of Public Health (CDPH) before beginning work on-site. It is expected that this portion of site work will be performed under Cabrera's current broad scope NRC license (NRC, 2011). Asbestos abatement notification will be made to the CDPH at least 10 days prior to beginning work on-site.

4.2 Pre-Remediation Field Activities

This section describes field activities that will be completed prior to initiating remediation activities.

4.2.1 Mobilization

It is anticipated that the mobilization and site preparation activities will require approximately two days and will include:

- Personnel travel to the Site;

- Review project plans with site personnel;
- Conduct required site-specific training;
- Set-up project offices and support facilities;
- Establishing paths of travel and posting construction signs and Radiological Control Areas (RCAs); and
- Performing initial quality control checks of field radiological instrumentation, including the gamma spectroscopy detector.

4.3 Remediation Field Activities

Cabrera will utilize a Geoprobe®-type direct-push system for all subsurface soil sampling at the UNC site. The direct-push system will be set up on the floor level of the warehouse, penetrate through the pre-drilled concrete slab floor, through the pre-drilled utility tunnel concrete floors, and finally into the underlying soils to collect soil core samples. Several activities will be performed before samples are collected.

Cabrera will utilize an electric core drill to pre-drill the concrete floors at each location in advance of the mobilization of the Geoprobe®-type system to conserve resources. There are also several large steel pipes in the utility trenches that obstruct the direct-push sampling system. A hydraulic hack saw will be used to cut and remove sections of piping and provide access to planned sampling locations. Prior to cutting, the type and source of each pipe to be cut will be determined, as possible, to avoid impacting pipes under pressure.

Limited remediation will be required prior to starting characterization sampling and surveys in Buildings 3H/6H. There are asbestos containing materials (ACM), including floor tile and mastic, covering the floors in several locations where sampling is planned. An asbestos abatement subcontractor licensed in the state of Connecticut will be used to abate these areas prior to pre-drilling of concrete floors. Asbestos abatement activities associated with the floors will be completed, as necessary, by using the wet method and bagging the asbestos material. Waste material will be placed in poly bags (doubled and marked ACM as necessary) and transported to the intermodal container (IMC) staged on-site for disposal. Final clearance of the asbestos containments will be performed by a third party inspector to ensure that the abatement activities were completed in accordance with local, State, and Federal requirements. Upon receipt of confirmatory final air clearance, sampling activities will begin.

It is anticipated that one IMC will be required to dispose of ACM debris, soil samples, investigation-derived waste, and spent personal protective equipment. Soil sample results from this characterization survey will also be used for waste characterization purposes. Nuclear material accountability will be performed as described in the *Nuclear Material Control and Accountability Plan* (Cabrera, 2010b).

As equipment is no longer needed at the project site, it will radiologically surveyed, in accordance with the *RPP* (Cabrera, 2010b), and returned to the vendor. As work is completed, safety barricades, caution tape, and other devices used to warn personnel of potential hazards will be removed.

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5.0 CHARACTERIZATION SURVEY DESIGN

The characterization survey was designed in accordance with project DQOs (Section 3.0) and the approach outlined in MARSSIM (NRC, 2000), such that the data could be used to support decisions regarding suitability for unrestricted release. Activities performed in support of the survey include the collection and analysis of volumetric samples, and scanning and integrated measurements for gamma radiation in soils.

5.1 Derived Concentration Guideline Levels

As described in MARSSIM (NRC, 2000), a $DCGL_W$ is used in non-parametric statistical testing to evaluate compliance with the dose-based criterion across a wide area (i.e., SU). The NRC established release criteria for enriched uranium in subsurface soils of 30 pCi/g total uranium in the Branch Technical Position document, "*Disposal or Onsite Storage of Thorium or Uranium Wastes from Past Operations*," published in the Federal Register on October 23, 1981 (NRC, 1981). These criteria were originally used by Cabrera to evaluate residual radioactivity in Site SUs during the 2011-2012 field effort. After discovering residual radioactivity in several inaccessible site areas exceeding these criteria, Cabrera, after concurrence with UNC, investigated the possibility of creating a site-specific release criteria based on dose modeling.

This release criteria for soils was established in the document *Derived Concentration Guideline Levels for the Decommissioning of the former UNC Manufacturing Facility* (IEM, 2008), which UNC submitted to the NRC for approval on July 11, 2012, and approved for use on June 5, 2013. These criteria are displayed in Table 5-1. The release criterion employed for this FSS is 435 pCi/g total uranium, which complies with the lower State of Connecticut's dose limit requirement of 19 millirem per year (mrem/yr).

TABLE 5-1. LAND AREA DERIVED CONCENTRATION GUIDELINE LEVELS

BASIC RADIATION DOSE LIMIT CRITERIA	TOTAL URANIUM[1] DCGL, PCI PER GRAM
NRC Federal Level, 25 mrem/year	573
CT State Level, 19 mrem/year	435

1) Total uranium is the sum of the concentrations of ^{234}U, ^{235}U, and ^{238}U. ^{234}U concentrations were determined by using a ratio of ^{234}U to ^{235}U of 27 to 1.

5.2 Area Classification Based on Contamination Potential

As discussed in the MARSSIM, areas of sites undergoing FSS should be classified into SUs according to their potential for residual radioactivity. Section 2.2 of MARSSIM provides the following definitions for classifying areas:

Non-impacted Areas: Areas that have no reasonable potential for residual contamination.

Impacted Areas: Any area not classified as non-impacted, and/or areas with a possibility of containing residual radioactivity in excess of natural background or fallout levels.

Class 1 Areas: Impacted areas that have, or had prior to remediation, a potential for contamination (based on site operating history) or known contamination (based on previous radiological surveys) above the $DCGL_W$.

Class 2 Areas: Impacted areas that have, or had prior to remediation, a potential for contamination or known contamination but are not expected to exceed the $DCGL_W$.

Class 3 Areas: Impacted areas that are not expected to contain any residual radioactivity, or are expected to contain levels of containing residual radioactivity at a small fraction of the $DCGL_W$.

5.3 Identification of Survey Units

All Site trench soils were classified as impacted areas and were designed as Class 1 because they have a similar potential for residual contamination. The MARSSIM recommended FSS SU sizes by classification are provided in Table 5-2. The total size of the trench soils SU is approximately 494 m^2.

TABLE 5-2. MARSSIM RECOMMENDED FSS SURVEY UNIT SIZES

CLASS	RECOMMENDED SURVEY AREA	
	STRUCTURES	SOIL AREAS
1	Up to 100 m^2	Up to 2,000 m^2
2	100 to 1,000 m^2	2,000 to 10,000 m^2
3	No limit	No limit

5.3.1 Background Reference Areas and Material-Specific Measurements

The uranium isotopes ^{234}U, ^{235}U, and ^{238}U are naturally-occurring and are present in the environment, although the concentrations of uranium isotopes naturally present in soil represent a very small fraction of the soil $DCGL_W$. Nevertheless, background soil ROC concentrations were previously determined using an on-site reference area per the FSSP (IEM, 2006). After reviewing reference area sample results, the background concentrations were determined to be low enough that background subtraction did not significantly impact results. Therefore, gross soil sample data will be directly compared to the soil $DCGL_W$ for conservatism.

5.3.2 Reference System

A reference coordinate system was utilized for interior sampling locations. These coordinates for the locations were referenced from the southwest corner of the building.

5.4 Number of Sample Locations per Survey Unit

MARSSIM Section 5.5.2.2 discusses a method to determine the number of data points required in a given area where the contaminant of concern is present in background. A minimum number of measurement locations are required to obtain sufficient statistical confidence that the conclusions drawn from the measurements are correct. The following subsections describe the basis for, and derivation of, the minimum required number of measurement locations.

5.4.1 Estimation of Relative Shift

The minimum number of measurements required is dependent on the distribution of total uranium concentrations relative to the $DCGL_W$ and acceptable decision error limits (Type I [α] and Type II [β]; refer to Section 3.1.6). The Relative Shift (Δ/σ) describes the relationship of site residual radionuclide concentrations to the $DCGL_W$ and is calculated using the following equation from MARSSIM.

$$\Delta/\sigma = \frac{DCGL_W - LBGR}{\sigma}$$

Where: Δ/σ = the Relative Shift

$DCGL_W$ = the derived concentration guideline level

LBGR = concentration at the lower bound of the gray region (LBGR) (the LBGR is the concentration to which soils must be remediated in order to have an acceptable probability of passing the statistical tests; the LBGR effectively becomes the survey's action level)

σ = estimate of the standard deviation of the concentration of residual radioactivity (which includes real spatial variability in the concentration as well as the precision of the measurement system)

In order to provide a basis for the concentration of residual radioactivity, Cabrera is using existing preliminary characterization data obtained from a total of 70 samples from drainage holes from both the North and South Trenches that provide access to underlying soils and the Column 40 survey (refer to Attachments 1 and 2). Note that an additional 14 samples collected from soils underneath the South Trench were included in the following data set; the total dataset of 70 samples is included in Attachment 3. Summary statistics for this data set are provided in Table 5-3.

TABLE 5-3. DRAINAGE HOLE CHARACTERIZATION DATA SUMMARY STATISTICS

	TOTAL URANIUM (PCI/G)
MAXIMUM	874(is this correct)
MINIMUM	0.81
MEAN	181
MEDIAN	54.6
STANDARD DEVIATION	230

MARSSIM prescribes setting the LBGR to one half the $DCGL_W$ (or 218 pCi/g) as an arbitrary starting point for developing an acceptable survey design if no data is available for the area to be surveyed. Due to the large variability of uranium concentrations in soils below the utility trenches and the fact that the standard deviation is over half the $DCGL_W$, we defer here to use of the standard deviation for both the LBGR and σ variables. Using a higher value yields lower Relative Shift, which in turn yields a higher required minimum number of samples calculated or referenced from Table 5.3 of MARSSIM.

$$\Delta/\sigma = \frac{435 - 230}{230} = 0.896$$

Where: Δ/σ = the Relative Shift

$DCGL_W$ = 435 pCi/g

LBGR = 230 pCi/g

σ = 230 pCi/g

The calculated value of the Relative Shift is between 0.8 and 0.9, which is rounded down to 0.8 in accordance with MARSSIM for conservatism.

5.4.2 Number of Required Measurement Locations (N)

The Wilcoxon Rank Sum (WRS) statistical test will be used to determine when these soils are suitable for release. The minimum number of systematic measurement locations required for the WRS statistical test is 48 using MARSSIM Table 5.3 with the following inputs:

1. The relative shift of 0.8 based on the existing characterization data (refer to Section 5.4.1)
2. Selected decision error rates of 5% for both Type I and Type II decision errors. A Type I error refers to the release of a survey unit containing residual radioactivity above the release criterion; a Type II error refers to determinations that a SU contains residual radioactivity above the release criterion when it does not. This can lead to unnecessary costs for additional remediation of SUs that are truly below the release criterion or additional survey activities to demonstrate compliance.

This number includes the additional 20% recommended by MARSSIM to account for a reasonable amount of uncertainty in the parameters used to calculate N and still allow flexibility to account for some lost or unusable data. The number of samples is effectively tripled to 144 because of sampling at three depth intervals per location (refer to Section 6.3.1).

Additional biased samples will be collected parallel to the South Trench, north of the trench footprint to collect supplemental data to bound contamination in areas that are already known to have uranium concentrations exceeding 435 pCi/g. Cabrera has identified 14 (42 total samples) biased locations to sample approximately one foot north of the South Trench footprint between Columns 21 and 48. A map of these sample locations with sample coordinates is provided as Attachment 4.

5.4.3 Distribution of Measurement Locations

Systematic measurements within a Class 1 area are typically assigned using a random-start, systematic grid. In this case, the conceptual site model for contamination of soils below the utility trenches is deposition of uranium through the drainage holes in the trench floors (drainage holes represent preferential pathways for contamination beneath the concrete floor). The drainage holes were placed with some uniformity, approximately 10 feet apart, with placement within two feet of a single wall of each trench. Therefore, systematic sample locations will be distributed length-wise at a uniform distance of approximately one sample for every 28 lateral feet of trench. The distribution of sample locations across the width of each trench will be randomly-calculated.

5.4.4 Survey Design Limitation

The floor of the South Trench is four to eight inches thick between Columns 26 to 48, but it is twelve inches thick or more between Columns 1 and 26. Drainage hole sampling performed to date in this portion of the South Trench has not accessed the soils underneath the trench floor. These samples represent soil and soil-like materials that were deposited on the concrete floor and accumulated in these drainage holes, rather than providing information regarding the underlying soils. Cabrera is assuming that the total uranium concentrations in the underlying soils are well below 435 pCi/g and similar to the concentrations observed from drainage hole sampling efforts within this portion of the South Trench. If samples with total uranium concentrations exceeding 435 pCi/g are collected from this portion of the South Trench (based on soil core scanning and downhole gamma logging field screening efforts), Cabrera will collect an additional ten biased samples at locations approximately one foot north of the South Trench footprint between Columns 1 and 19.

6.0 SURVEY METHODS AND TECHNIQUES

Cabrera will utilize a Geoprobe®-type direct-push system for all subsurface soil sampling at the UNC site. Due to varying site/drilling conditions, various Geoprobe®-type systems (both hand-held and track mounted) may be utilized throughout the sampling effort. A Geoprobe®-type system is a hydraulically-powered (vehicle or auxiliary engine), percussion/probing machine that relies on a relatively small amount of integrated (vehicle) weight combined with percussion for the advancement of probing tools. Direct-push refers to tools that are "pushed" into the ground without the use of turning to remove soil or to make a path for the tool. Direct push rigs can drive macrocore samplers to obtain continuous soil cores, discrete soil samples, or groundwater samples. Soil sampling will be performed in a continuous five-foot interval per location using steel casings (varying diameters) with dedicated acetate liners. Depth capabilities of direct-push rigs are typically limited by the type of soils encountered.

Samples will be marked to show the sample identification number. Sample identification number and other pertinent data will be recorded on appropriate field data recording sheets. Samples will be collected in accordance with Cabrera's soil collection and COC procedures (Cabrera, 2000).

The following equipment (or equivalent) will be required for this task.

- Geoprobe® rig and ancillary macrocore sampling rods and equipment (as necessary);
- Large stainless steel mixing bowls;
- Stainless steel utensil for removal of soil core from soil core rod or hand auger after sample is retrieved and for mixing and packaging samples in containers;
- Soil sieve set with 3/8-in screen and collection tray;
- Sample containers and COC forms/seals.

Radiological release surveys will be performed on equipment and materials used for this effort in accordance with the project *Radiation Protection Plan* (RPP; Cabrera, 2010b).

6.1.1 Soil Core Scanning

Soil core scanning will be performed in accordance with Cabrera OP-76, *Soil Core Scanning Procedure Rev 1* (Cabrera, 2000). The sample core acetate sleeve will be cut open to expose the subsurface soils. Once exposed, the soil sample cores will be scanned for beta-gamma activity to identify thin layers of elevated radioactivity. A Field Instrument for the Detection of Low-Energy Radiation (FIDLER) detector will be moved slowly over the surface of the soils, with the maximum count rate for each 1-foot interval recorded on a log sheet to identify grossly-contaminated sample intervals and assist in creating a depth profile of residual HEU contamination.

6.1.2 Downhole Gamma Logging

Downhole gamma logging will be performed in accordance with OP-75, *Downhole Gamma Logging Procedure, Rev 1* (Cabrera, 2000). Downhole gamma logging will be performed at each borehole to provide data regarding the variation in gamma fluence with depth. A one-minute integrated measurement will be performed using a Bicron G1 environmentally encapsulated one inch by one inch sodium iodide (1x1 NaI) detector. Measurements will be collected and recorded at one foot intervals, starting at the bottom of the borehole and working toward ground surface. Each borehole will be sleeved with schedule-40, threaded Polyvinyl Chloride (PVC) pipe casing prior to insertion of the probe to prevent cave-in of sidewall soils and capture of the detector at depth.

6.1.3 On-Site Laboratory Analyses

Sample results will be used to quantify surface soil contaminant concentrations at the discrete locations shown in Attachment 4 and at the 0-1', 1-2', and 2-3' depth intervals as described in Section 6.3.1. The subsurface soil samples will be counted in the on-site laboratory via gamma spectroscopy analysis for ^{235}U and ^{238}U. The results will be used to determine the extent of the remediation required, if any. Field duplicate samples will be collected for QA/QC considerations at approximately 5% of all sample locations and sent to General Engineering Laboratories (GEL) in Charleston, South Carolina, for gamma spectroscopy analysis.

The on-site lab will utilize a Canberra *In Situ Object Counting System* high-purity germanium detector to count soil samples. Samples will be collected in accordance with the FSSP (IEM, 2006) and Cabrera standard OPs. Samples will be analyzed via gamma spectroscopy in accordance with OP-029, *Gamma Spectroscopy Operations, Rev. 4* (Cabrera, 2000). The analytical test methods used to analyze radionuclides in volumetric samples at the on-site laboratory will verified as being able to achieve a minimum detectable concentration (MDC) of at least 10% of the soil $DCGL_W$.

6.2 Gamma Scanning

Using NUREG-1507, *Minimum Detectable Concentrations With Typical Radiation Survey Instruments For Various Contaminants and Field Conditions*, (NRC, 1998) as guidance, scan MDCs and scanning sensitivity utilizing both a Bicron G-5 FIDLER and a Bicron G-1 1x1 NaI detector used in downhole gamma measurements were calculated for HEU (assumed to be 93% ^{235}U) using Microshield® Version 8.02. The results of these calculations are presented in Table 6-1. A more detailed evaluation of the MDC for the gamma scanning instrumentation is presented in Attachment 5.

TABLE 6-1. SODIUM IODIDE SCANNING SENSITIVITIES FOR SOIL

DETECTOR	ROC	SCAN MDC (pCi/g)	SCANNING SENSITIVITY (cpm/pCi/g)
Bicron G-5	HEU	24.2	70.9
Bicron G-1	HEU	57.6	7.37

6.3 Volumetric Sample Collection

Soils underlying the site utility trenches are logistically-challenging to access. Using MARSSIM guidance, a survey was designed to characterize the soils in place, without having to remove the floor or other structural features of the building to render these soils accessible. Sample locations were distributed throughout the footprint of the South Trench, the North Trench, and the Column 17/18 Lateral Trench. Soil samples will be collected directly through the floor of the building and through the underlying utility trenches at a sufficient number of locations to horizontally and vertically bound the contamination. Sampling will be performed in accordance with OP-005, *Volumetric and Material Sampling Within Radiological Control Areas, Rev. 2* (Cabrera, 2000).

This survey will be performed through the use of a direct push sampling rig (Geoprobe®-type) to collect samples from defined areas beneath the North, South, and Column 17/18 Lateral Trenches. MARSSIM guidance was used to categorize these areas as requiring a Class 1 level of survey effort, and quantify the number of sample locations necessary to draw disposition conclusions regarding the residual uranium concentrations with statistical confidence. This process is described starting in Section 5.0.

6.3.1 Sampling at Multiple Depth Intervals

Samples will be collected from three depth intervals at each sample location to provide sufficient data for vertical bounding of contamination: 0-1', 1-2', and 2-3'. These depth intervals were selected pursuant to results from the portion of the South Trench floor broken up and sampled adjacent to Column 40 (refer to Section 2.0 and Attachment 2 for more information). Data from this limited survey also suggests that contamination above 435 pCi/g will not extend below a maximum of two feet below grade. Samples with total uranium concentrations exceeding 435pCi/g will be flagged for remediation; and samples with total uranium concentrations below 435 pCi/g will be entered into the final set of final status survey data to support release of these soils. Once samples above 435 pCi/g are remediated, the next lower depth interval sample at each location will then serve as the FSS sample for that location. For example, if at a given location the 1-2' sample has 600 pCi/g and the 2-3' sample has 400 pCi/g, the location will be remediated to a depth of two feet below grade and the 2-3' sample will serve as the FSS sample for that location.

6.3.2 Lateral Bounding

Lateral bounding will be achieved through systematic samples with total uranium concentrations below 435 pCi/g and through the placement of the additional biased sample locations. Lateral spreading of contamination into soils adjacent to the utility trenches is not anticipated; biased sample locations have been distributed one additional foot laterally north of the footprint of the South Trench. No additional biased samples for bounding purposes are currently planned outside the footprint of the North Trench or the Column 17/18 Lateral Trench; additional biased sampling will be based on systematic sampling results.

This survey will be performed in accordance with all project work plans, including the APP (Cabrera, 2010a) which includes the RPP, and the *Nuclear Material Control and Accountability Plan* (Cabrera, 2010b), and the procedures listed in Table 4-1.

7.0 SAMPLE PROCEDURES AND CHAIN OF CUSTODY

Sampling and chain of custody will be performed in accordance with *OP-005, Volumetric and Material Sampling Within Radiological Control Areas, Rev. 2*, and *OP-008, Chain of Custody, Rev.1* (Cabrera, 2000).

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8.0 QUALITY ASSURANCE/QUALITY CONTROL

Activities associated with this *Characterization Survey Plan* shall be performed in accordance with written procedures and/or protocols in order to ensure consistent, repeatable results. Topics covered in project procedures and protocols include proper use of instrumentation, sampling methods and procedures, and reporting requirements. Implementations of quality assurance (QA) and quality control (QC) measures for this work plan are described in the *FSS Plan* (IEM, 2006), OP-021, *Alpha-Beta Counting Instrumentation, Rev. 1*, and OP-029, *Gamma Spectroscopy Operations, Rev. 4* (Cabrera, 2000).

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9.0 WASTE MANAGEMENT

During the course of this project, it is anticipated that one IMC will be required to dispose of bagged ACM debris, soil samples, investigation-derived waste, and spent personal protective equipment. Soil sample results from this characterization survey will also be used for waste characterization purposes. Nuclear material accountability and tracking of ^{235}U content in wastes will be performed as described in the *Nuclear Material Control and Accountability Plan* (Cabrera, 2010b).

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10.0 REMEDIAL ACTION COMPLETION AND FINAL STATUS SURVEY REPORTS

Cabrera will prepare a *Remedial Action Completion Report* and *FSS Report* following FSS and demobilization. Records, files, reports, results, and any other applicable documentation for the work described in this *Characterization Survey Plan* will be added, as applicable, to information collected during previous mobilizations at the Site.

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11.0 REFERENCES

(Cabrera, 2000) Cabrera Services, Inc.; Cabrera *Radiation Safety Program*; Rev 1. May 2010; including all current revisions of standard Administrative and Operational radiological procedures.

(Cabrera, 2010a) Cabrera Services, Inc. *Accident Prevention Plan.* Site Decommissioning Former UNC Manufacturing Facility, New Haven, Connecticut. March 2010.

(Cabrera, 2010b) Cabrera Services, Inc. *Nuclear Material Control and Accountability Plan.* Site Decommissioning Former UNC Manufacturing Facility, New Haven, Connecticut. March 2010.

(IEM, 2006) Integrated Environmental Management, Inc. *Final Status Survey Plan for Decommissioning the former UNC Manufacturing Facility.* September 6, 2006.

(IEM, 2008) Integrated Environmental Management, Inc. *Derived Concentration Guideline Levels for Decommissioning the former UNC Manufacturing Facility.* June 16, 2008.

(NRC, 1974) U.S. Nuclear Regulatory Commission. Regulatory Guide 1.86, *Termination of Operating Licenses for Nuclear Reactors*, 1974.

(NRC, 1981) U.S. Nuclear Regulatory Commission. Branch Technical Position, *Disposal or Onsite Storage of Thorium or Uranium Wastes from Past Operations*, dated October, 1981.

(NRC, 1998) U.S. Nuclear Regulatory Commission. NUREG-1507, *Minimum Detectable Concentrations With Typical Radiation Survey Instruments For Various Contaminants and Field Conditions,* June, 1998.

(NRC, 2000) U.S. Nuclear Regulatory Commission. *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM). NUREG-1575. U.S. Environmental Protection Agency, EPA 402-R-97-016. Revision 1, August, 2000.

(NRC, 2011) U.S. Nuclear Regulatory Commission. Radioactive Materials License Amendment Number 4. License Number 06-30556-01. Docket Number 030-35316. Cabrera Services Inc. Dated May 27, 2011. Expiration Date September 30, 2020.

(UNC, 1998) UNC Naval Products. *Decommissioning Plan for the Previously Licensed Facility in New Haven, CT.* August, 1998.

(USEPA, 2006) U.S. Environmental Protection Agency, *Guidance on Systematic Planning Using the Data Quality Objectives Process*, EPA/240/B-06/001, February 2006.

ATTACHMENT 1
DRAINAGE HOLE SAMPLING MAP

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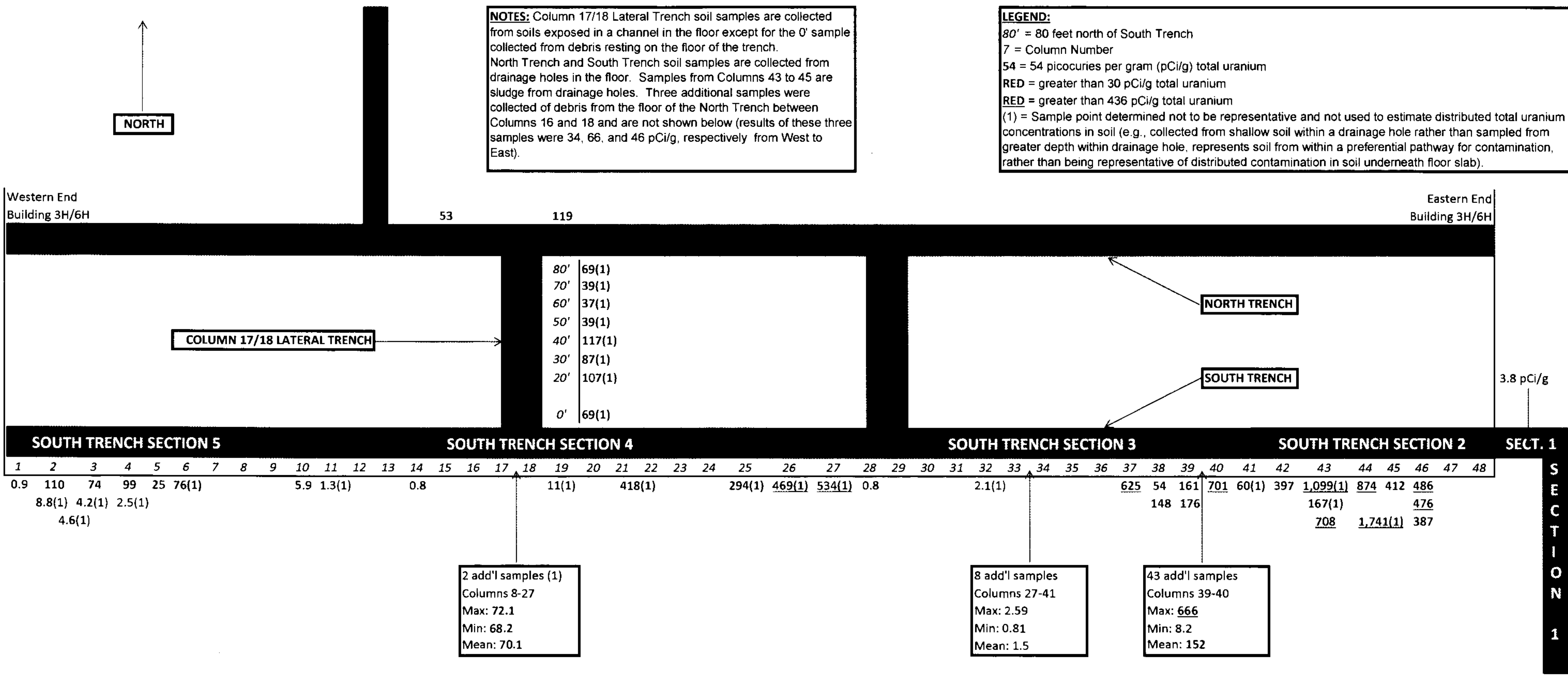
NORTH
NOTES: Column 17/18 Lateral Trench soil samples are collected from soils exposed in a channel in the floor except for the 0' sample collected from debris resting on the floor of the trench.
North Trench and South Trench soil samples are collected from drainage holes in the floor. Samples from Columns 43 to 45 are sludge from drainage holes. Three additional samples were collected of debris from the floor of the North Trench between Columns 16 and 18 and are not shown below (results of these three samples were 34, 66, and 46 pCi/g, respectively from West to East).
LEGEND:
80' = 80 feet north of South Trench
7 = Column Number
54 = 54 picocuries per gram (pCi/g) total uranium
RED = greater than 30 pCi/g total uranium
RED = greater than 436 pCi/g total uranium
(1) = Sample point determined not to be representative and not used to estimate distributed total uranium concentrations in soil (e.g., collected from shallow soil within a drainage hole rather than sampled from greater depth within drainage hole, represents soil from within a preferential pathway for contamination, rather than being representative of distributed contamination in soil underneath floor slab).
Western End
Building 3H/6H
53
119
Eastern End
Building 3H/6H
80' 69(1)
70' 39(1)
60' 37(1)
50' 39(1)
40' 117(1)
30' 87(1)
20' 107(1)
0' 69(1)
NORTH TRENCH
COLUMN 17/18 LATERAL TRENCH
SOUTH TRENCH
3.8 pCi/g
SOUTH TRENCH SECTION 5
SOUTH TRENCH SECTION 4
SOUTH TRENCH SECTION 3
SOUTH TRENCH SECTION 2
SECT. 1
SECTION 1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48
0.9 110 74 99 25 76(1) 5.9 1.3(1) 0.8 11(1) 418(1) 294(1) 469(1) 534(1) 0.8 2.1(1) 625 54 161 701 60(1) 397 1,099(1) 874 412 486
8.8(1) 4.2(1) 2.5(1) 148 176 167(1) 476
4.6(1) 708 1,741(1) 387
2 add'l samples (1)
Columns 8-27
Max: 72.1
Min: 68.2
Mean: 70.1
8 add'l samples
Columns 27-41
Max: 2.59
Min: 0.81
Mean: 1.5
43 add'l samples
Columns 39-40
Max: 666
Min: 8.2
Mean: 152

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ATTACHMENT 2
DOWNHOLE 12 SAMPLING MAP

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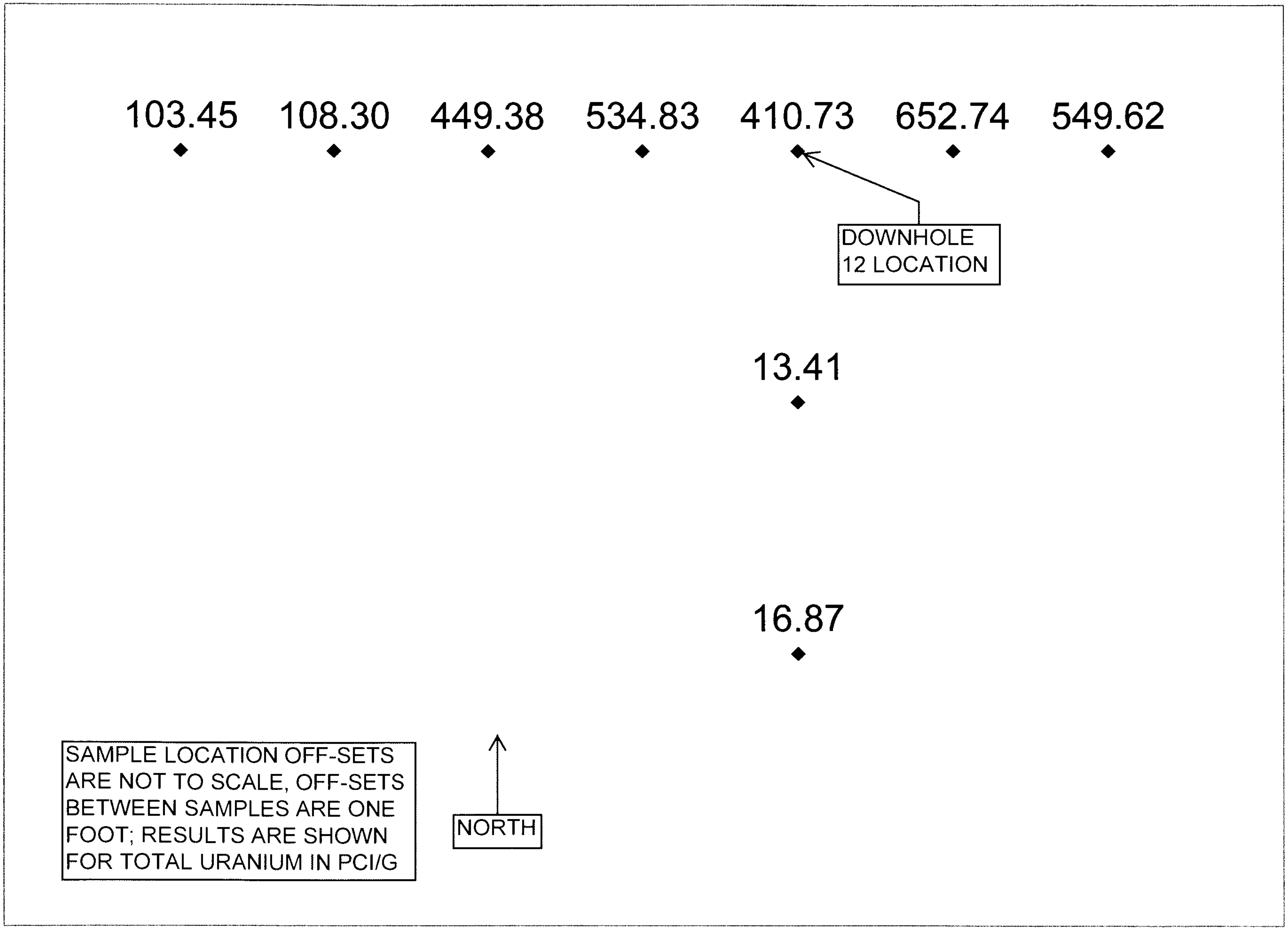
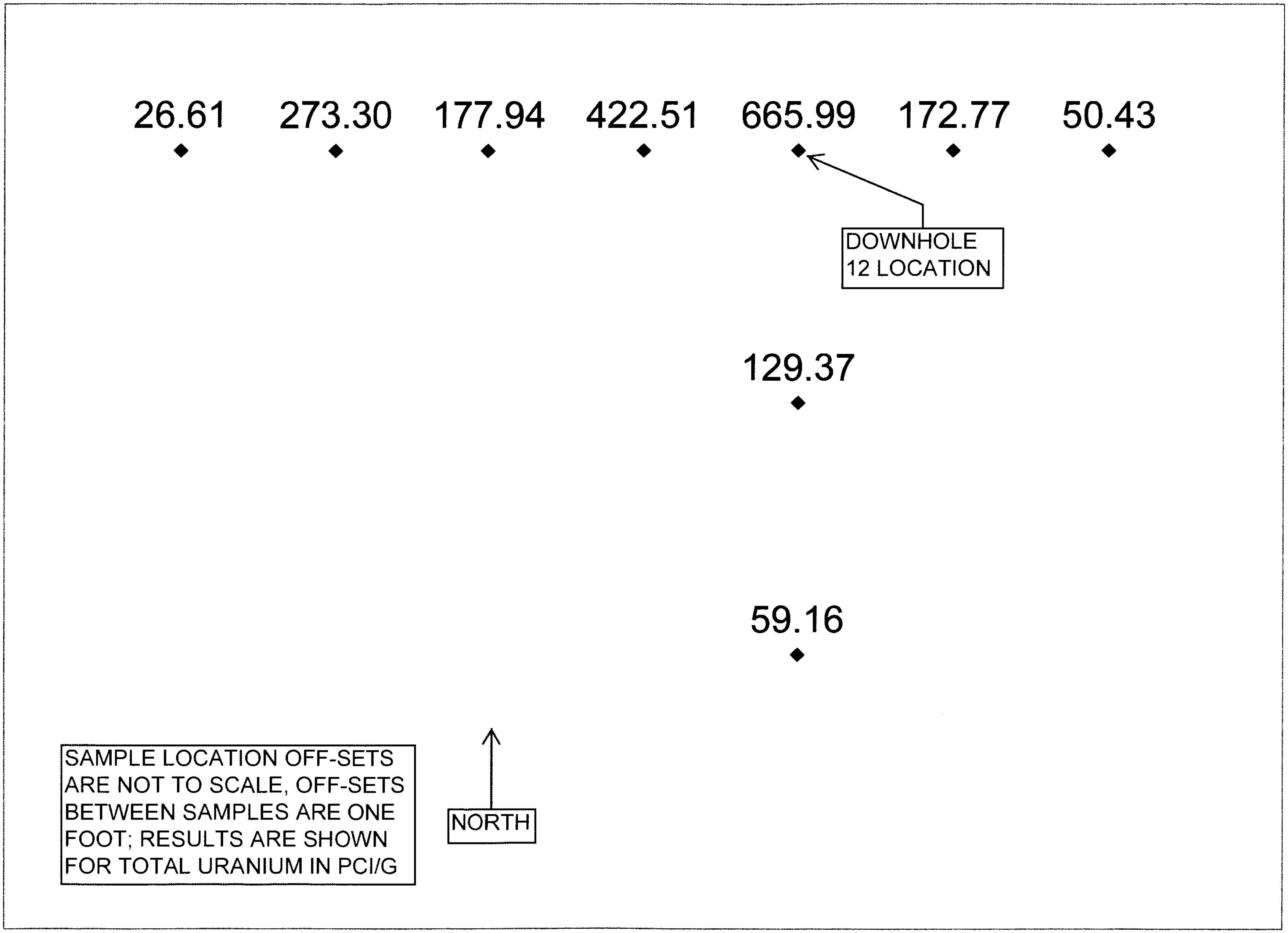
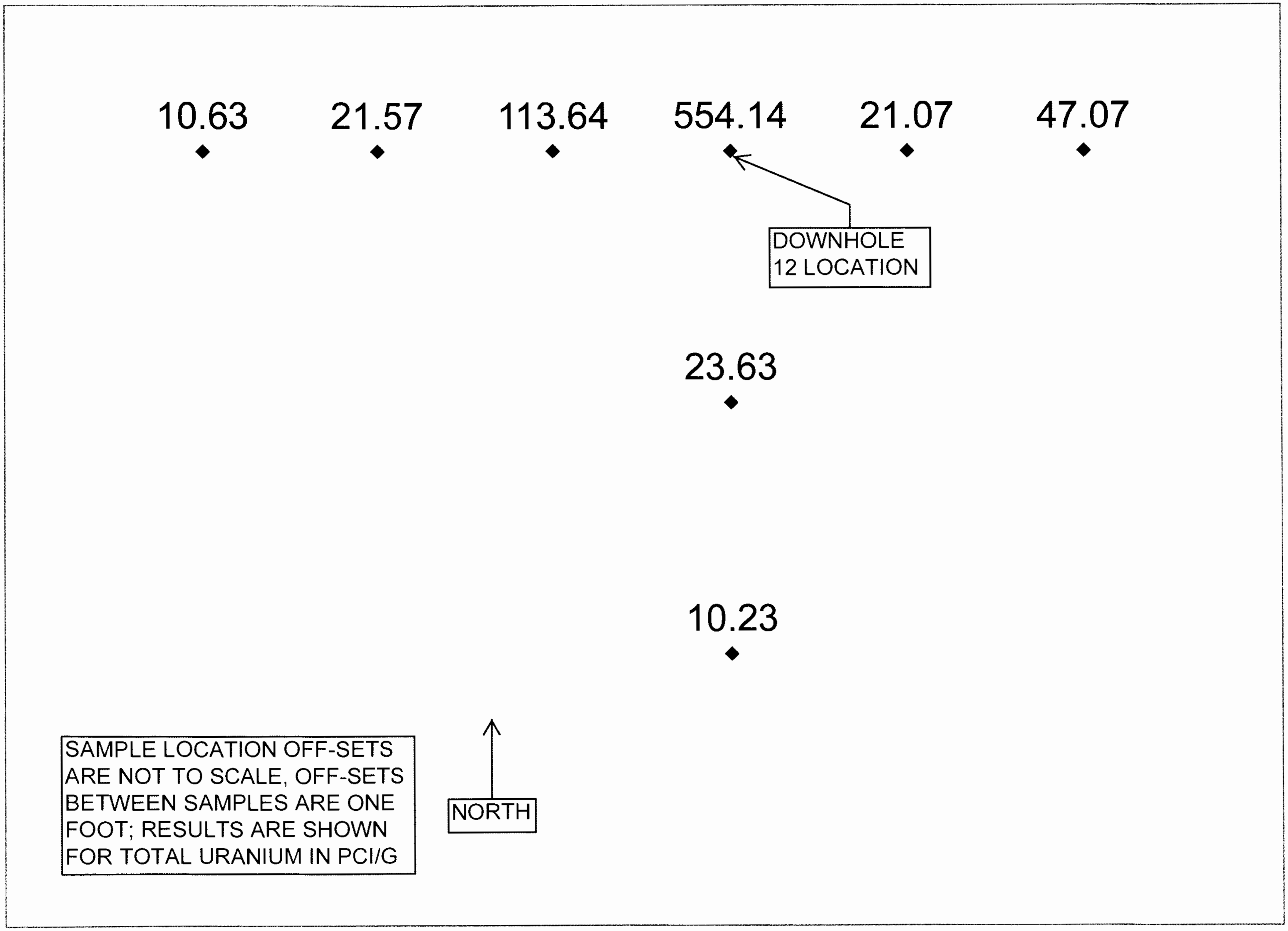
Downhole 12: 0.0 - 0.5 ft



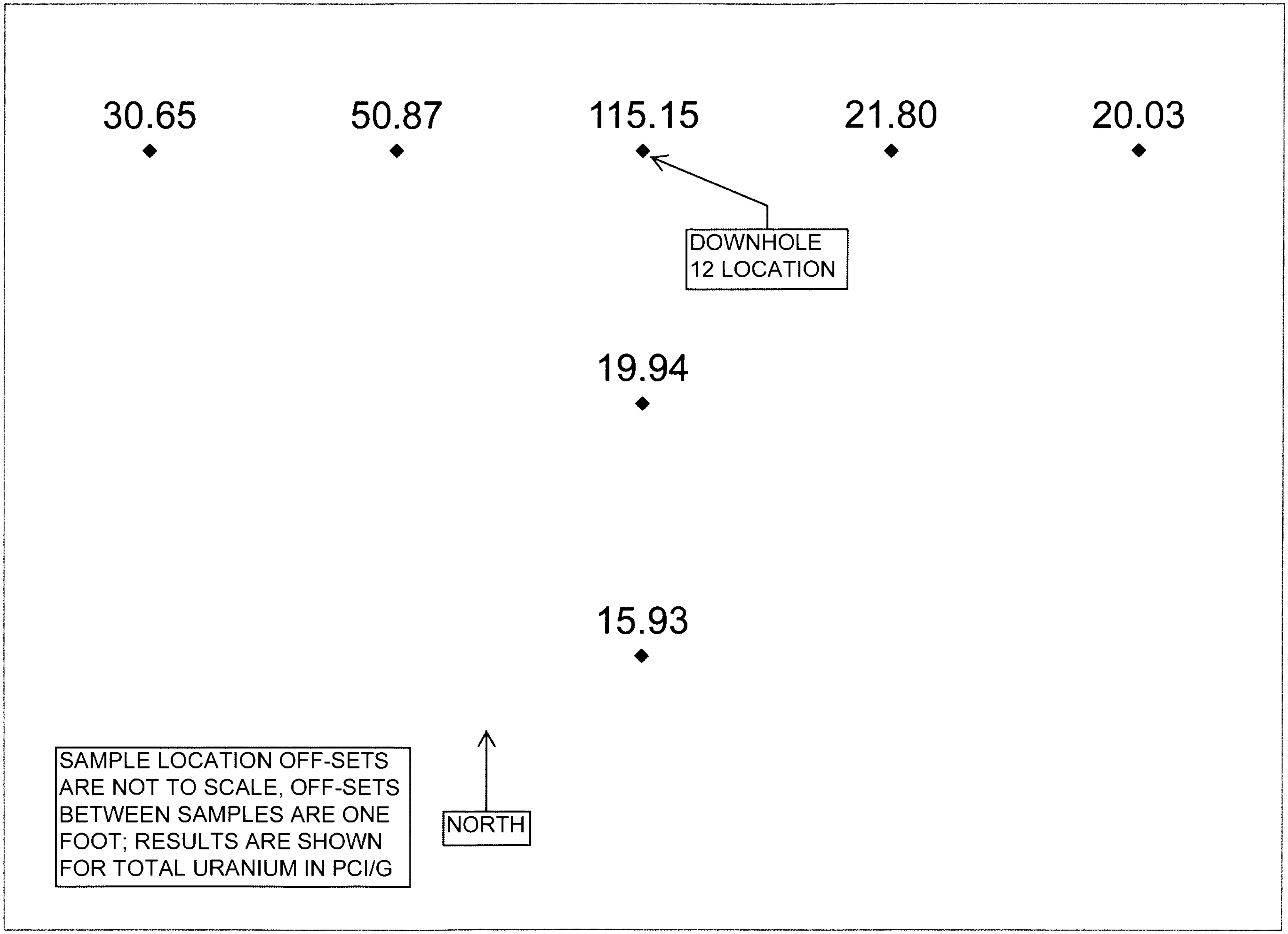
Downhole 12: 0.5 - 1.0 ft



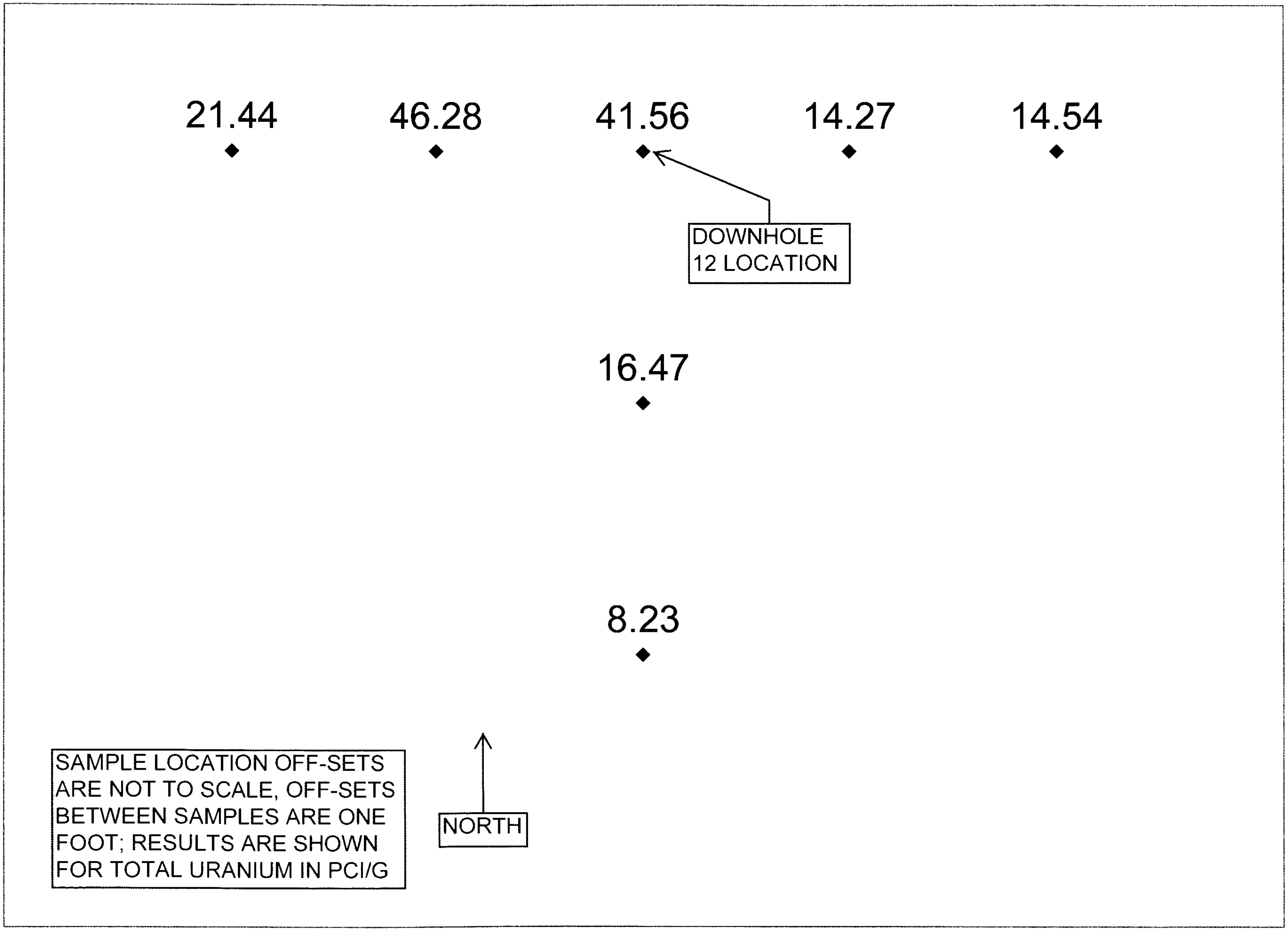
Downhole 12: 1.0 - 1.5 ft



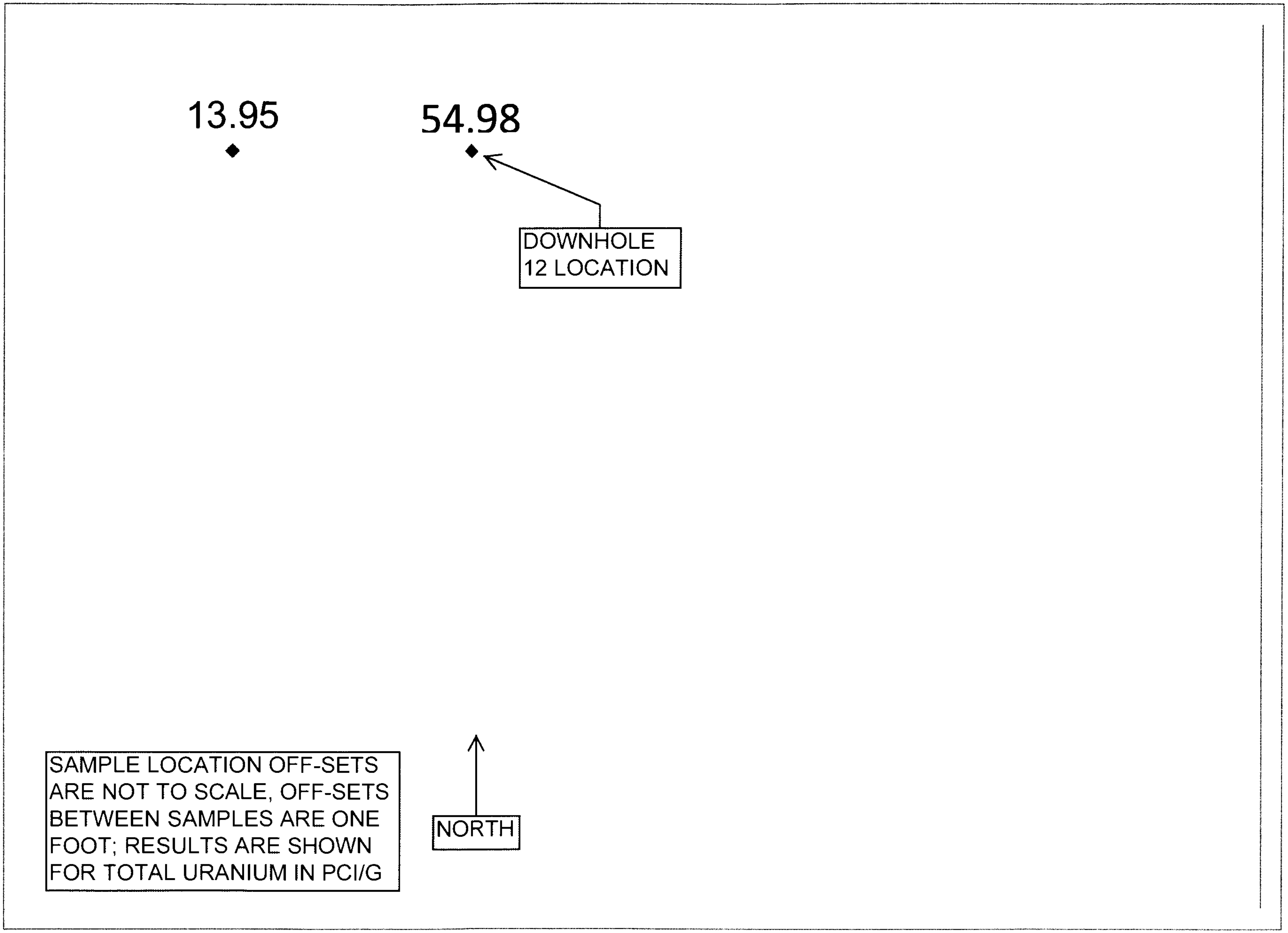
Downhole 12: 1.5 - 2.0 ft



Downhole 12: 2.0 - 2.5 ft



Downhole 12: 2.5 - 3.0 ft



ATTACHMENT 3
TRENCH SOILS DATA

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Trench ID	Sample ID	Trench Sample Data (pCi/g) U-234	U-235	U-238	Total U	Analysis (GS/AS)	U-234: U-235 Ratio	U-235 Mass Enrichment
South Trench	UNC-INV-DH2-001	0	0	1.1	1.10	GS		0.0%
South Trench	UNC-INV-DH2-003	0	0	1.07	1.07	GS		0.0%
South Trench	UNC-INV-DH2-004	0	0	1.05	1.05	GS		0.0%
South Trench	UNC-INV-DH2-007	0	0	2.59	2.59	GS		0.0%
South Trench	UNC-INV-DH2-009	0	0	0.81	0.81	GS		0.0%
South Trench	UNC-INV-DH2-010	0	0	1.1	1.10	GS		0.0%
South Trench	UNC-INV-DH2-012	0	0	2.35	2.35	GS		0.0%
South Trench	UNC-INV-DH2-013	0	0	1.92	1.92	GS		0.0%
South Trench	UNC-INV-DH12-2FS2430	7.04	0.26	0.93	8.23	GS	27.1	4.2%
South Trench	UNC-INV-DH12-3FW1218	8.75	0.32	1.56	10.63	GS	27.3	3.1%
South Trench	UNC-INV-DH12-2FS1218	9.06	0.34	0.83	10.23	GS	26.6	6.0%
South Trench	UNC-INV-DH12-1FS06	11.61	0.43	1.37	13.41	GS	27.0	4.6%
South Trench	UNC-INV-DH12-1FW3036	12.18	0.45	1.32	13.95	GS	27.1	5.0%
South Trench	UNC-INV-DH12-2FE2430	12.49	0.46	1.59	14.54	GS	27.2	4.3%
South Trench	UNC-INV-DH12-1FE2430	12.65	0.47	1.15	14.27	GS	26.9	6.0%
South Trench	UNC-INV-DH12-2FS1824	14.23	0.33	1.36	15.92	GS	43.1	3.6%
South Trench	UNC-INV-DH12-1FS2430	14.34	0.53	1.6	16.47	GS	27.1	4.9%
South Trench	UNC-INV-DH12-2FS06	14.42	0.53	1.92	16.87	GS	27.2	4.1%
South Trench	UNC-INV-DH12-1FS1824	17.47	0.65	1.82	19.94	GS	26.9	5.2%
South Trench	UNC-INV-DH12-2FE1824	17.54	0.65	1.84	20.03	GS	27.0	5.2%
South Trench	UNC-INV-DH12-1FE1218	18.9	0.7	1.47	21.07	GS	27.0	6.9%
South Trench	UNC-INV-DH12-2FW2430	19.45	0.72	1.27	21.44	GS	27.0	8.1%
South Trench	UNC-INV-DH12-2FW1218	19.78	0.73	1.06	21.57	GS	27.1	9.6%
South Trench	UNC-INV-DH12-1FE1824	20.03	0.74	1.02	21.79	GS	27.1	10.1%
South Trench	UNC-INV-DH12-1FS1218	20.84	0.77	2.01	23.62	GS	27.1	5.6%
South Trench	UNC-INV-TR-034	23.21	0.86	1	25.07	GS	27.0	11.7%
South Trench	UNC-INV-DH12-4FW612	23.49	0.87	2.25	26.61	GS	27.0	5.7%
South Trench	UNC-INV-DH12-2FW1824	27.73	1.03	1.89	30.65	GS	26.9	7.8%
South Trench	UNC-INV-DH12-2430	38.13	1.41	2.02	41.56	GS	27.0	9.8%
South Trench	UNC-INV-DH12-1FW2430	43.35	1.13	1.81	46.29	GS	38.4	8.8%
South Trench	UNC-INV-DH12-2FE1218	44.67	1.65	0.74	47.06	GS	27.1	25.6%
South Trench	UNC-INV-DH12-2FE612	45.94	1.7	2.79	50.43	GS	27.0	8.6%
South Trench	UNC-INV-DH12-1FW1824	47.79	1.77	1.31	50.87	GS	27.0	17.3%
South Trench	UNC-INV-DH12-2436	49.95	1.85	3.18	54.98	GS	27.0	8.3%
North Trench	UNC-INV-NDH-001	50.86	1.88	0.68	53.43	GS	27.0	29.9%
South Trench	UNC-INV-DH-015	51.04	1.89	1.3	54.23	GS	27.0	18.4%
South Trench	UNC-INV-DH12-2FS612	54.27	2.01	2.88	59.16	GS	27.0	9.8%
South Trench	UNC-INV-TR-032	69.99	2.59	1.21	73.79	GS	27.0	24.9%
South Trench	UNC-INV-TR-033	92.18	3.41	3.07	98.66	GS	27.0	14.7%
South Trench	UNC-INV-DH12-4FW06	96.66	3.58	3.21	103.45	GS	27.0	14.7%
South Trench	UNC-INV-DH12-3FW06	100.71	3.73	3.86	108.30	GS	27.0	13.0%
South Trench	UNC-INV-TR-031	102.54	3.8	3.98	110.32	GS	27.0	12.9%
South Trench	UNC-INV-DH12-1FW1218	104.76	3.88	5	113.64	GS	27.0	10.7%
South Trench	UNC-INV-DH12-1824	106.65	3.95	4.55	115.15	GS	27.0	11.8%

Trench ID	Sample ID	Trench Sample Data (pCi/g) U-234	U-235	U-238	Total U	Analysis (GS/AS)	U-234: U-235 Ratio	U-235 Mass Enrichment
North Trench	UNC-INV-NDH-002	112.12	4.15	2.94	119.21	GS	27.0	17.9%
South Trench	UNC-INV-DH12-1FS612	119.61	4.43	5.33	129.37	GS	27.0	11.4%
South Trench	UNC-INV-DH-016	137.87	5.11	5.12	148.10	GS	27.0	13.4%
South Trench	UNC-INV-DH-013	143.69	5.32	12.4	161.41	GS	27.0	6.2%
South Trench	UNC-INV-DH12-1FE612	161.19	5.97	5.61	172.77	GS	27.0	14.1%
South Trench	UNC-INV-DH-014	164.03	6.08	6.16	176.27	GS	27.0	13.3%
South Trench	UNC-INV-DH12-2FW612	166.92	6.18	4.84	177.94	GS	27.0	16.5%
South Trench	UNC-INV-DH12-3FW612	261.9	9.7	1.7	273.30	GS	27.0	46.7%
South Trench	UNC-INV-DH-003	371.35	13.75	1.65	386.75	GS	27.0	56.1%
South Trench	UNC-INV-DH-010	380.67	14.1	2.18	396.95	GS	27.0	49.8%
South Trench	UNC-INV-DH12-06	393.66	14.58	2.49	410.73	GS	27.0	47.4%
South Trench	UNC-INV-DH-004	395.55	14.65	1.6	411.80	GS	27.0	58.3%
South Trench	UNC-INV-DH12-VOID	399.69	14.8	1.98	416.47	GS	27.0	53.4%
South Trench	UNC-INV-DH12-1FW612	405.27	15.01	2.23	422.51	GS	27.0	50.8%
South Trench	UNC-INV-DH12-2FW06	431.21	15.97	2.2	449.38	GS	27.0	52.7%
South Trench	UNC-INV-DH-002	454.1	16.82	2.28	473.20	GS	27.0	53.1%
South Trench	UNC-INV-DH-001	467.22	17.3	1.95	486.47	GS	27.0	57.6%
South Trench	UNC-INV-DH12-1FW06	513.54	19.02	2.27	534.83	GS	27.0	56.2%
South Trench	UNC-INV-DH12-2FE06	527.79	19.55	2.29	549.63	GS	27.0	56.7%
South Trench	UNC-INV-DH12-1218	532.17	19.71	2.26	554.14	GS	27.0	57.2%
South Trench	UNC-INV-DH-017	600.44	22.24	2.49	625.17	GS	27.0	57.7%
South Trench	UNC-INV-DH12-1FE06	626.4	23.2	3.14	652.74	GS	27.0	53.1%
South Trench	UNC-INV-DH12-612	639.9	23.7	2.39	665.99	GS	27.0	60.2%
South Trench	UNC-INV-DH-012	674.41	24.98	1.98	701.37	GS	27.0	65.8%
South Trench	UNC-INV-DH-007	680.17	25.19	2.21	707.57	GS	27.0	63.5%
South Trench	UNC-INV-DH-005	840.65	31.14	2.49	874.28	GS	27.0	65.6%

ATTACHMENT 4
SAMPLE LOCATION MAP AND COORDINATES

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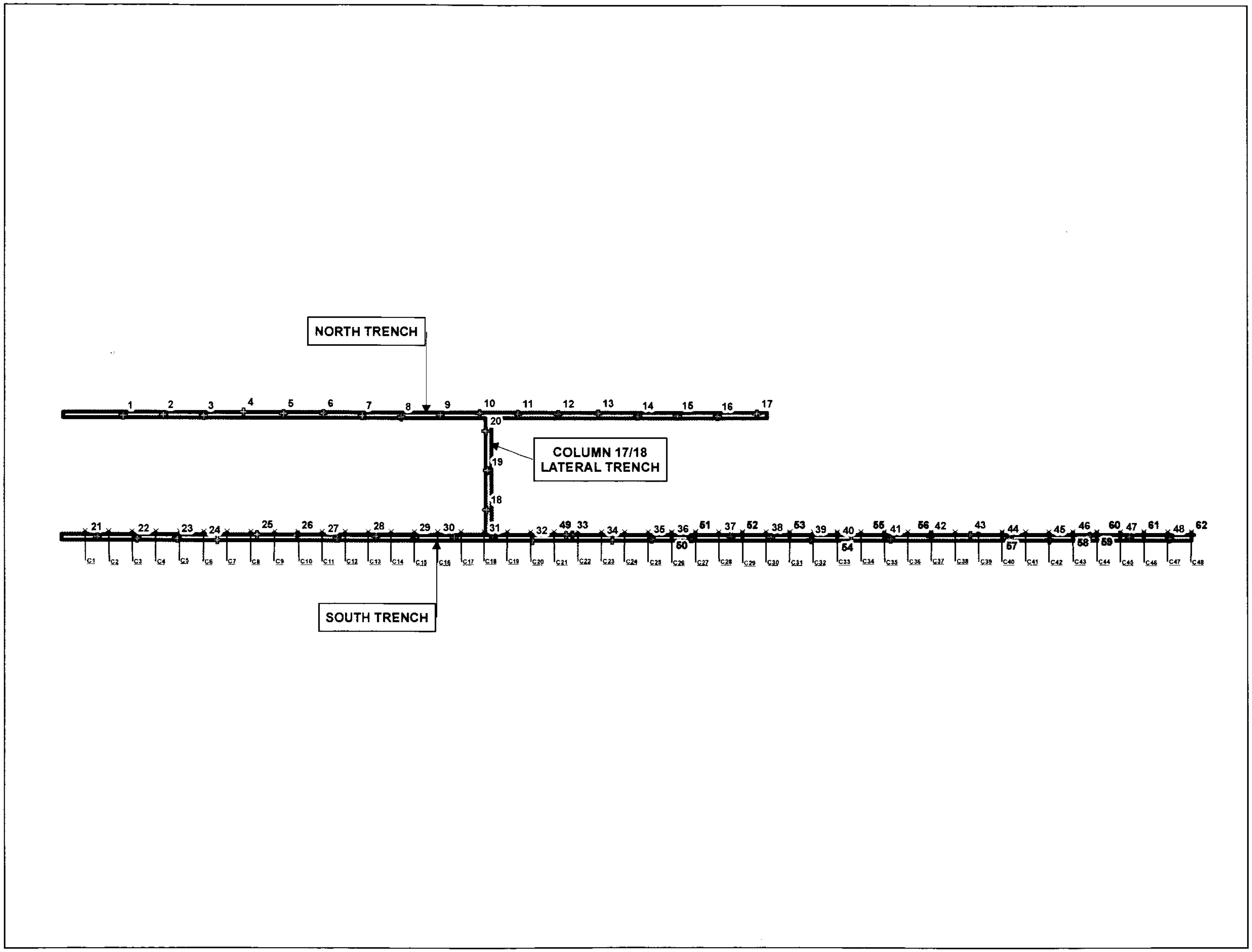

Legend

- × Columns
- Biased Samples
- Systematic Samples
- Trench Footprint

Feet
0 25 50 100

SAMPLE LOCATION MAP AND COORDINATES

**FORMER UNC FACILITY
NEW HAVEN
CONNECTICUT**

ATTACHMENT 4

CABRERA SERVICES
RADIOLOGICAL · ENVIRONMENTAL · REMEDIATION

ID	Easting (ft)	Northing (ft)	Type
1	42.03	85.28	Systematic
2	69.03	86.04	Systematic
3	96.03	85.32	Systematic
4	123.03	87.81	Systematic
5	150.03	86.86	Systematic
6	177.03	87.06	Systematic
7	204.03	85.57	Systematic
8	231.03	84.66	Systematic
9	258.03	86.15	Systematic
10	285.03	87.34	Systematic
11	312.03	86.81	Systematic
12	339.03	86.79	Systematic
13	366.03	87.28	Systematic
14	393.03	85.53	Systematic
15	420.03	85.69	Systematic
16	447.03	85.01	Systematic
17	474.03	86.98	Systematic
18	289.77	21.03	Systematic
19	290.44	47.95	Systematic
20	289.33	74.95	Systematic
21	24.38	2.26	Systematic
22	51.38	1.11	Systematic
23	78.38	1.10	Systematic
24	105.38	0.08	Systematic
25	132.38	3.93	Systematic
26	159.38	3.59	Systematic
27	186.38	1.46	Systematic
28	213.38	2.77	Systematic
29	240.38	2.00	Systematic
30	267.38	1.92	Systematic
31	294.38	1.75	Systematic
32	321.38	0.17	Systematic
33	348.38	3.98	Systematic
34	375.38	0.39	Systematic
35	402.38	0.88	Systematic
36	429.38	1.45	Systematic
37	456.38	2.79	Systematic
38	483.38	2.25	Systematic
39	510.38	0.66	Systematic
40	537.38	0.13	Systematic
41	564.38	1.24	Systematic
42	591.38	3.21	Systematic
43	618.38	3.93	Systematic
44	645.38	1.31	Systematic
45	672.38	0.69	Systematic
46	699.38	3.37	Systematic

47	726.38	2.38	Systematic
48	753.38	1.37	Systematic
49	344.00	5.00	Biased
50	416.00	5.00	Biased
51	432.00	5.00	Biased
52	464.00	5.00	Biased
53	496.00	5.00	Biased
54	528.00	5.00	Biased
55	560.00	5.00	Biased
56	592.00	5.00	Biased
57	640.00	5.00	Biased
58	688.00	5.00	Biased
59	704.00	5.00	Biased
60	720.00	5.00	Biased
61	736.00	5.00	Biased
62	768.00	5.00	Biased

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ATTACHMENT 5
MINIMUM DETECTABLE CONCENTRATIONS

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Estimation of Minimum Detectable Concentrations

The following technical approach for establishing the MDC for gamma-emitting radionuclides utilizes the methodology and approach utilized in MARSSIM Section 6.7.2.1 (NRC, 2000) and a modified NUREG-1507 (*Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions* [NRC, 1998]) method for determining the static and scan MDC for gamma-emitting radionuclides. Static and scan MDCs and scanning sensitivity utilizing both a Bicron G-5 FIDLER for core scanning and a Bicron G-1 one-by-one detector used in downhole gamma measurements were calculated for HEU below (as described briefly in Section 6.2).

The basic parameters of the model consist of the following:

- Radionuclide mix and source activity (i.e., energy and yield of gamma emissions)
- Density of source media and physical size of source (i.e., areal dimensions of source)
- Relative distribution of potentially-impacted material (point versus distributed source and depth of elevated activity)
- The source to detector probe geometry
- Ambient background radiation of surveyed area
- Scan rate (observation interval)
- Index of sensitivity
- Efficiency related to surveyor

A general overview of the approach to determining scan MDCs follows:

- The model parameters described above provide an estimate for the exposure rate of the detector probe
- The relationship between the detector's net count rate and the net exposure rate (counts per minute per microrem per hour, [cpm/μR/hr]) is determined
- The sodium iodide (NaI) scintillation detector background level and scan rate (observation interval) are postulated, and the (MDCR) for the ideal observer, for a given level of performance, is obtained (note that both the Bicron G-5 and G-1 utilize sodium iodide scintillation crystals)
- A surveyor efficiency is selected, and then it is necessary to relate the survey MDCR ($MDCR_{surveyor}$) to a radionuclide concentration (in pCi/g)

The computer code Microshield® was used to model expected exposure rates from the radioactive source at the detector probe NaI crystal, and includes source to detector geometry and inter-dispersed shielding. The geometry and shielding are used to calculate the total flow of photons incident upon the detector crystal, called the gamma fluence rate, ultimately corresponding to a dose and countrate in the instrument. The overall approach provides the gamma fluence rate and hence instrument response to various photon energies based on the exposure rate from the radioactive material being measured (e.g., 15 keV, 20 keV, 30 keV, etc.). Each calculation in this process where the photon energy is a factor is therefore performed for each of these photon energies. The specific photon emission energies present within the source radionuclide(s) are modeled to establish the gamma fluence rate to exposure rate (FRER).

The amount of radioactivity the detector crystal is exposed to from the modeled source is used to determine the relationship between the detector's net count rate and the net exposure rate (counts per minute per microrem per hour, [cpm/μR/hr]). This methodology (NRC, 1998) correlates the radionuclide source to the minimum detectable net exposure rate, as the net exposure of the crystal varies with the energy of the photon emission. Typical background exposures are incorporated into the model.

Input parameters assume the presence of normalized concentrations of high-enriched uranium in soil. For core scanning using the Bicron G-5, the activity is assumed to be uniformly distributed over a disk-shaped area with a depth of six inches and a diameter of 22 inches. For downhole gamma measurements using the Bicron G-1, the activity is assumed to be uniformly distributed in a cylinder nine inches tall and a diameter of 14.25 inches; the height of the G-1 probe is nine inches, and the 14.25 inches is derived from a modeled six-inch thickness of soil surrounding the G-1 while placed into a direct push boring with a standard 2.25 inch diameter. Fifty years of in-growth of associated progeny was utilized in each of the two models, pertaining to the timeframe when fuel fabrication operations began at the Site circa 1959 (refer to Section 2.0). Arbitrary concentrations of one pCi/g of HEU is used for modeling purposes. This is consistent with the NUREG-1507 methodology and provides for a count rate to exposure ratio (cpm/μR/hr) to be calculated. The following text provides an overview of the NUREG-1507 factors and methodology used to calculate the HEU MDCs.

Step 1: Fluence Rate to Exposure Rate (FRER)

We begin by calculating the fluence rate to exposure rate (FRER, unitless), which may be calculated using the following equation from NUREG-1507 (refer to Attachment 5, Table 1, page 11 for G-5 and page 18 for G-1):

$$Fluence\ Rate\ (FRER) \approx \frac{1 \mu R/hr}{(E_\gamma)(\mu_{en}/\rho)_{air}}$$

Where:

E_γ energy of the gamma photon of concern (kiloelectron volts [keV])

$(\mu_{en}/\rho)_{air}$ mass energy absorption coefficient in air at the gamma photon energy of concern (centimeters squared per gram [cm^2/g])

The gamma energy photon data mass energy absorption coefficients have been applied to the 662 keV gamma photon for cesium-137 (^{137}Cs) for example:

$$(FRER) \approx \frac{1 \mu R/hr}{(E_\gamma)(\mu_{en}/\rho)_{air}} \approx \frac{1 \mu R/hr}{(662)(0.0294)} \approx 0.0514$$

Step 2: Probability of Interaction (P) Through Detector End for a Given Energy

Next, we make the reasonable assumption that the primary gamma interaction producing the detector response occurs through the end of the detector (as opposed to the sides); the probability of interaction (*P*) for a photon is calculated for each of the various photon energies including the 662 keV gamma photon for ^{137}Cs using the following equation (refer to Attachment 5, Table 2, page 11 for G-5 and page 18 for G-1):

$$P = 1 - e^{-(\mu/\rho)_{NaI}(x)(\rho_{NaI})}$$

Where:

P	probability of interaction (unitless)
$(\mu/\rho)_{NaI}$	mass absorption coefficient of NaI crystal at the energy of interest (cm^2/g)
x	thickness of the thin edge of the NaI crystal (0.063 inches for the G-5 and 1 inch for the G-1)
ρ	density of the NaI crystal (3.67 g/cm^3)

Step 3: Relative Detector Response (RDR)

The relative detector response (*RDR*) for each of the various photon energies including the 662 keV gamma photon for ^{137}Cs is determined by multiplying the FRER by the probability of interaction (*P*) (refer to Attachment 5, Table 3, page 12 for G-5 and page 19 for G-1):

$$RDR = (FRER) \times (P)$$

Step 4: Relationship Between Detector Response (cpm) and Exposure Rate (μR/hr)

Given the calculated values for the FRER, P, and RDR at the ^{137}Cs energy of 662 keV as determined in Steps 1, 2, and 3 above, the mass energy absorption coefficient for air and the mass attenuation coefficient for NaI are interpolated from tables on pages 139 and 140 in the Radiological Health Handbook (PHS, 1970).

Bicron provides an estimated response of both the G-5 and G-1 NaI crystals in a known radiation field for the ^{137}Cs energy of 662 KeV (1,287 and 300 cpm per μR/hr, respectively). The detector responses at this energy can be used to determine the response at all other energies of interest, using the following equation (refer to Attachment 5, Table 4, page 13 for G-5 and page 20 for G-1):

$$cpm / \mu R/hr \ at \ E_i = \left({}^{137}Cs \ cpm\right) \times \frac{RDR_{Ei}}{RDR_{^{137}Cs}}$$

Where:

E_i	energy of the photon of interest (keV)
^{137}Cs *cpm*	response of detector in cpm per μR/hr at the ^{137}Cs energy of 662 KeV (cpm)
RDR_{Ei}	RDR at the energy of interest
$RDR_{^{137}Cs}$	RDR for ^{137}Cs
cpm/μR/hr at E_i	response of the detector in each energy of interest

Step 5: Relationship Between Detector Response (cpm) and Con tamination Level (pCi/g)

The relationship between the detector response (i.e., *cpm/μR/hr* at E_i established in Step 4) and the contamination volume of soil modeled using Microshield® provides the inputs to determine the minimum detectable exposure rate, which in turn is used to determine the MDC. The weighted cpm per μR/hr response (weighted instrument sensitivity [WS_i]) is calculated for each of the various photon energies by multiplying the exposure rate (i.e., the Net Microshield® Exposure Rate with buildup [R_i], μR/hr at 1 pCi/g) by the corresponding *cpm/μR/hr* at E_i established in Step 4, and then dividing the result by the sum total μR/hr (at 1 pCi/g) for all photon energies (refer to Attachment 5, Table 5, page 13 for G-5 and page 20 for G-1):

$$Weighted \ Instrument \ Sensitivity \ (WS_i) = \frac{R_i \times (cpm \ per \ \mu R / hr)}{Sum \ Total \ R_i}$$

Note that three Microshield® models were prepared for the G-1 to allow modeling of soil with two air gaps, a thickness of PVC for the lining of each borehole, and a thickness of aluminum for the casing of the G-1 probe to establish the Net Microshield® Exposure Rate. The total radius of the space between the detector housing and the soil was 0.625 inches. Models were prepared as follows:

- Model 1) 0.48 inches of air and 0.145 inches of PVC
- Model 2) 0.625 inches of air,
- Model 3) 0.625 inches of air and 0.13 inches of aluminum

The net exposure rates at each of the various photon energies were calculated by adding the exposure rates at each of the various photon energies from Model 2 and Model 3, and subtracting the combined exposure rates at each of the various photon energies from Model 1 (refer to Table 5, page 13 for G-5 and page 20 for G-1).

The percent of instrument response is then calculated by dividing the weighted instrument sensitivity by total weighted cpm per μR/hr and multiplying by 100 (refer to Table 5, page 13 for G-5 and page 20 for G-1):

$$Percent\ of\ instrument\ response = \frac{WS_i \times 100}{Sum\ Total\ WS_i}$$

Step 6: Calculation of Scan Minimum Detectable Count Rates

The core scanning model utilizes a scan speed of 0.5 meters per second (m/s) provides an observation interval of one second for the modeled disk-shaped contaminated area. The downhole gamma model utilizes an observation interval of 60 seconds because the measurements are one-minute static counts. The observation interval is expressed as follows:

$$b_i = b \times \frac{1\ \text{min.}}{60\ \text{sec.}} \times i$$

Where:

b	background count rate (counts per minute)
b_i	the average number of counts in the background interval (counts per second)
i	the observation interval length (one second)

The measured background at the GE UNC site is 10 μR/hr. Background gamma radiation generally resembles the 662 keV gamma particle emitted by ^{137}Cs, which will be used as our model for ambient background radiation. Using a conversion factor based upon field measurements of 1,287 cpm per μR/hr for ^{137}Cs with the G-5 results in an estimated background count rate of 12,870 cpm. Converting this value from cpm to counts per second (cps) results in a background of 214.5 cps. An actual average background value was available for use with the G-1 because a one-minute background count was performed at each downhole gamma location; the average of these one-minute background counts was 1,554 cpm or 25.9 cps.

The scan MDC is calculated using the methodology in NUREG-1507 (calculations for the G-5 are shown below for illustrative purposes). The MDCR and $MDCR_{surveyor}$ parameters utilize a counting error based upon the square root of the counts in the background interval (i.e., one second):

$$s_i = d\sqrt{b_i} = 1.38 \times \sqrt{214.5} = 20.21\ cps$$

$$s_{i,\,surveyor} = \frac{d'\sqrt{b_i}}{\sqrt{p}} = \frac{1.38\times\sqrt{214.5}}{\sqrt{0.5}} = 28.58\ cps$$

$$MDCR = s_i \times (60/i) = 20.21\times(60/1) = 1{,}212\ cpm$$

$$MDCR_{surveyor} = s_{i,\,surveyor} \times (60/i) = 28.58\times(60/1) = 1{,}715\ cpm$$

Where:

s_i	minimum detectable number of net source counts in the observation interval (cps)
d'	detectability index from Table 6.1 of NUREG-1507; a value of 1.38 was selected, which represents a true positive detection rate of 95% and a false positive detection rate of 60%
p	efficiency of a less than ideal surveyor, range of 0.5 to 0.75 (NUREG-1507); a value of 0.5 was chosen as a conservative value for the G-5; a value of 1 was chosen for the G-1 because it is a stationary count which eliminates the human error presented by scanning in the surveyor efficiency
$s_{i,surveyor}$	minimum detectable number of net source counts in the observation interval by a less than ideal surveyor (cps)
MDCR	minimum detectable count rate (cpm)
$MDCR_{surveyor}$	MDCR by a less than ideal surveyor (cpm)

Step 7: Calculation of Scan Minimum Detectable Concentration

The minimum detectable exposure rate (MDER) can be calculated using the previously calculated weighted instrument sensitivities (WS_i established in Step 5) (refer to Table 5, page 13 for G-5 and page 20 for G-1), in cpm per µR/hr, for HEU using the following equations:

$$MDER_i = \frac{MDCR_{surveyor}}{Sum\ Total\ WS_i}$$

$$Scan\ MDC_i = C_i \times \frac{MDER_i}{R_i}$$

$$Scanning\ Sensitivity = \frac{MDCR_{surveyor}}{Scan\ MDC_i}$$

Where:

$MDER_i$	MDER for the "i^th" source term, by a less than ideal surveyor, (µR/hr)

$MDCR_{surveyor}$	MDCR rate by a less than ideal surveyor (cpm)
WS_i	weighted instrument sensitivity for source term "i" (cpm per μR/hr) R_i exposure rate with buildup for the "ith" source term (μR/hr) C_i concentration of the "ith" source term (pCi/g)
Scan MDC_i	MDC for the "ith" source term (pCi/g)
Scanning Sensitivity	(cpm per pCi/g)

The calculated scan MDCs and scanning sensitivities are presented on page 14 for G-5 and page 21 for G-1, and in Table 6-1.

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FIDLER G-5 SCAN FOR HEU @ 1 pCi/g; NO SOIL COVER; 6 INCHES THICK × 22 INCHES DIAMETER; 50 yr decay

Step 1

Fluence rate to exposure rate (FRER, no units) = ~ (1 uR/h)/(Eγ)(u_{en}/ρ)air

TABLE 1

Energy$_{\gamma}$, keV	$(u_{en}/\rho)_{air}$, cm^2/g	FRER
15	1.29	0.0517
20	0.516	0.0969
30	0.147	0.2268
40	0.064	0.3906
50	0.0384	0.5208
60	0.0292	0.5708
80	0.0236	0.5297
100	0.0231	0.4329
150	0.0251	0.2656
200	0.0268	0.1866
300	0.0288	0.1157
400	0.0296	0.0845
500	0.0297	0.0673
600	0.0296	0.0563
800	0.0289	0.0433
1,000	0.0280	0.0357
1,500	0.0255	0.0261
2,000	0.0234	0.0214

Step 2

Probability of interaction (P) through end of detector for given energy is

Probability = $1\text{-}e^{-(\mu/\rho)NaI\ (x)\ (\rho NaI)}$

TABLE 2

Energy$_{\gamma}$, keV	$(\mu/\rho)_{NaI}$, cm^2/g	P
15	47.4	1.00
20	22.3	1.00
30	7.45	0.99
40	19.3	1.00
50	10.7	1.00
60	6.62	0.98
80	3.12	0.84
100	1.72	0.64
150	0.625	0.31
200	0.334	0.18
300	0.167	0.09
400	0.117	0.07
500	0.0955	0.05
600	0.0826	0.05
800	0.0676	0.04
1,000	0.0586	0.03
1,500	0.0469	0.03
2,000	0.0413	0.02

for Fidler G-5 12.7cm dia x 0.16 cm thick NaI crystal
x = 0.16 cm
ρ = 3.67 g/cm^3

FIDLER G-5 SCAN FOR HEU @ 1 pCi/g; NO SOIL COVER; 6 INCHES THICK × 22 INCHES DIAMETER; 50 yr decay

Step 3

Relative Detector Response (RDR) = relative fluence-to-exposure rate (FRER) times probability (P) of interaction

TABLE 3

$Energy_{\gamma}$, keV	FRER	P	RDR
15	0.0517	1.00	0.0517
20	0.0969	1.00	0.0969
30	0.2268	0.99	0.2239
40	0.3906	1.00	0.3906
50	0.5208	1.00	0.5199
60	0.5708	0.98	0.5591
80	0.5297	0.84	0.4449
100	0.4329	0.64	0.2752
150	0.2656	0.31	0.0816
200	0.1866	0.18	0.0332
300	0.1157	0.09	0.0108
400	0.0845	0.07	0.0056
500	0.0673	0.05	0.0037
600	0.0563	0.05	0.0027
800	0.0433	0.04	0.0017
1,000	0.0357	0.03	0.0012
1,500	0.0261	0.03	0.0007
2,000	0.0214	0.02	0.0005

Estimated Fidler G-5 12.7cm dia x 0.16cm thick NaI response for Cs-137 is 1287 cpm/uR/hr

Use same methodology and interpolating for Cs-137 response have:

$Energy_{\gamma}$, keV	$(u_{en}/\rho)_{air}$, cm^2/g		
662	0.0294	FRER ~	0.0514
$Energy_{\gamma}$, keV	$(\mu/\rho)_{NaI}$, cm^2/g		
662	0.0780	Probability =	0.04
		RDR =	0.0023

For this detector the response to another energy is based on the ratio of the relative detector response, RDR to the Cs-137 energy
cpm/μR/h, E_i = $(cpm_{cs-137})*(RDR_{Ei})/(RDR_{Cs-137})$

FIDLER G-5 SCAN FOR HEU @ 1 pCi/g; NO SOIL COVER; 6 INCHES THICK × 22 INCHES DIAMETER; 50 yr decay

Step 4

Relationship Between Detector Response (cpm) and Exposure Rate (μR/hr)

TABLE 4

Energy$_\gamma$, keV	RDR_{Ei}	Fidler NaI Detector, E_i, cpm per μR/hr
15	0.0517	28934
20	0.0969	54250
30	0.2239	125355
40	0.3906	218695
50	0.5199	291052
60	0.5591	313006
80	0.4449	249068
100	0.2752	154090
150	0.0816	45680
200	0.0332	18602
300	0.0108	6053
400	0.0056	3140
500	0.0037	2056
600	0.0027	1493
662	0.0023	1287
800	0.0017	942
1,000	0.0012	676
1,500	0.0007	398
2,000	0.0005	287

Step 5

Relationship Between Detector Response (cpm) and Contamination Level (pCi/g)

Table 5

keV	MicroShield Exposure Rate, μR/hr (with buildup)	cpm/μR/hr	cpm/μR/hr (weighted)	Percent of NaI detector response
15	2.234E-08	28934	0	0.0%
20	1.797E-10	54250	0	0.0%
30	1.310E-05	125355	891	2.3%
40	3.911E-10	218695	0	0.0%
50	7.716E-06	291052	1219	3.2%
60	1.505E-06	313006	256	0.7%
80	5.979E-05	249068	8082	21.0%
100	9.233E-05	154090	7721	20.1%
150	2.394E-04	45680	5935	15.4%
200	1.422E-03	18602	14356	37.3%
300	1.479E-06	6053	5	0.0%
400	1.022E-06	3140	2	0.0%
500	4.456E-08	2056	0	0.0%
600	6.320E-07	1493	1	0.0%
800	6.960E-07	942	0	0.0%
1000	1.910E-06	676	1	0.0%
1500	5.476E-10	398	0	0.0%
2000	8.999E-07	287	0	0.0%
Total	1.843E-03		38469	100%

FIDLER G-5 SCAN FOR HEU @ 1 pCi/g; NO SOIL COVER; 6 INCHES THICK × 22 INCHES DIAMETER; 50 yr decay

Step 6

Calculation of Scan Minimum Detectable Count Rates

MDC for Cs-137 energy

Assume 10 μR/hr bkg then have 12,870 cpm

b_i =	214.5	counts
MDCR =	1212.67	cpm
$MDCR_{surveyor}$ =	1715	cpm

Step 7

Calculation of Scan Minimum Detectable Concentration

Minimum Detectable Exposure Rate =

MDCR surveyor/(cpm/μr/hr)
0.045 μr/hr

and MDC for total uranium and 50-year equilibrium progeny based on a normalized 1 pCi/g total uranium

Scan MDC = (Assumed MDC U_{TOTAL}Conc) x (Exposure Rate $MDCR_{Surveyor}$)/(Exposure $Rate_{assumed\ U\ Conc}$)

Scan MDC = 24.2 pCi/g

MicroShield 8.02
Cabrera Services, Inc. (8.02-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
HEU.MS5	October 9, 2012	12:02:51 PM	00:00:09

Project Info

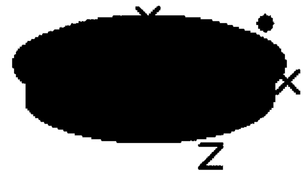
Case Title	50y HEU at U 1 pCi/g
Description	0.03%U238,97%U234,2.97%U235 act frac;15 cm nosoilcov, Al shi
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions

Height	15.0 cm (5.9 in)
Radius	28.0 cm (11.0 in)

Dose Points

A	X	Y	Z
#1	0.0 cm (0 in)	25.211 cm (9.9 in)	0.0 cm (0 in)
#2	50.0 cm (1 ft 7.7 in)	25.211 cm (9.9 in)	0.0 cm (0 in)



Shields

Shield N	Dimension	Material	Density
Source	2254.53 in³	Concrete	1.6
Shield 2	.02 in	Aluminum	2.7
Air Gap		Air	0.00122
Wall Clad	8.661 in	Concrete	1.6
Immersion		Air	0.00122

Source Input: Grouping Method - Standard Indices
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Ac-227	9.2752e-013	3.4318e-002	2.5105e-011	9.2890e-007
Bi-210	1.0162e-013	3.7601e-003	2.7507e-012	1.0178e-007
Bi-211	9.2403e-013	3.4189e-002	2.5011e-011	9.2540e-007
Bi-214	2.7723e-013	1.0257e-002	7.5037e-012	2.7764e-007
Fr-223	1.2800e-014	4.7359e-004	3.4645e-013	1.2819e-008
Pa-231	1.8562e-012	6.8678e-002	5.0241e-011	1.8589e-006
Pa-234	2.8374e-014	1.0498e-003	7.6800e-013	2.8416e-008
Pa-234m	1.7734e-011	6.5615e-001	4.8000e-010	1.7760e-005
Pb-210	1.0173e-013	3.7641e-003	2.7536e-012	1.0188e-007
Pb-211	9.2403e-013	3.4189e-002	2.5011e-011	9.2540e-007
Pb-214	2.7723e-013	1.0257e-002	7.5037e-012	2.7764e-007
Po-210	9.8693e-014	3.6516e-003	2.6713e-012	9.8839e-008
Po-211	2.5226e-015	9.3336e-005	6.8279e-014	2.5263e-009
Po-214	2.7717e-013	1.0255e-002	7.5021e-012	2.7758e-007
Po-215	9.2403e-013	3.4189e-002	2.5011e-011	9.2540e-007
Po-218	2.7728e-013	1.0259e-002	7.5052e-012	2.7769e-007
Ra-223	9.2403e-013	3.4189e-002	2.5011e-011	9.2540e-007

Ra-226	2.7745e-013	1.0266e-002	7.5098e-012	2.7786e-007
Rn-219	9.2403e-013	3.4189e-002	2.5011e-011	9.2540e-007
Rn-222	2.7728e-013	1.0259e-002	7.5052e-012	2.7769e-007
Th-227	9.1257e-013	3.3765e-002	2.4701e-011	9.1392e-007
Th-230	2.5800e-011	9.5461e-001	6.9834e-010	2.5839e-005
Th-231	1.7556e-009	6.4958e+001	4.7520e-008	1.7582e-003
Th-234	1.7734e-011	6.5615e-001	4.8000e-010	1.7760e-005
Tl-207	9.2150e-013	3.4096e-002	2.4943e-011	9.2287e-007
U-234	5.7331e-008	2.1212e+003	1.5518e-006	5.7416e-002
U-235	1.7556e-009	6.4958e+001	4.7520e-008	1.7582e-003
U-238	1.7734e-011	6.5615e-001	4.8000e-010	1.7760e-005

Buildup: The material reference is Source

Integration Parameters

Radial	49
Circumferential	49
Y Direction (axial)	49

Results - Dose Point # 1 - (0,9.93e+00,0) in

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.015	1.222e-01	2.496e-10	2.605e-10	2.141e-11	2.234e-11
0.02	3.115e-04	4.790e-12	5.189e-12	1.659e-13	1.797e-13
0.03	9.524e+00	1.089e-06	1.322e-06	1.080e-08	1.310e-08
0.04	1.813e-04	6.191e-11	8.844e-11	2.738e-13	3.911e-13
0.05	2.507e+00	1.718e-06	2.896e-06	4.576e-09	7.716e-09
0.06	3.380e-01	3.721e-07	7.577e-07	7.390e-10	1.505e-09
0.08	7.641e+00	1.533e-05	3.778e-05	2.426e-08	5.979e-08
0.1	7.686e+00	2.248e-05	6.035e-05	3.439e-08	9.233e-08
0.15	1.012e+01	5.317e-05	1.454e-04	8.756e-08	2.394e-07
0.2	4.009e+01	3.097e-04	8.058e-04	5.466e-07	1.422e-06
0.3	2.547e-02	3.354e-07	7.795e-07	6.361e-10	1.479e-09
0.4	1.290e-02	2.476e-07	5.244e-07	4.825e-10	1.022e-09
0.5	4.472e-04	1.151e-08	2.270e-08	2.259e-11	4.456e-11
0.6	5.337e-03	1.744e-07	3.238e-07	3.405e-10	6.320e-10
0.8	4.521e-03	2.153e-07	3.659e-07	4.095e-10	6.960e-10
1.0	1.018e-02	6.485e-07	1.036e-06	1.195e-09	1.910e-09
1.5	2.100e-03	2.259e-07	3.255e-07	3.801e-10	5.476e-10
2.0	2.764e-03	4.278e-07	5.819e-07	6.615e-10	8.999e-10
Totals	**7.810e+01**	**4.062e-04**	**1.058e-03**	**7.131e-07**	**1.843e-06**

Results - Dose Point # 2 - (1.97e+01,9.93e+00,0) in

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.015	1.222e-01	1.916e-12	2.021e-12	1.644e-13	1.734e-13
0.02	3.115e-04	1.161e-13	1.280e-13	4.023e-15	4.433e-15
0.03	9.524e+00	5.249e-08	6.589e-08	5.202e-10	6.530e-10
0.04	1.813e-04	3.659e-12	5.502e-12	1.618e-14	2.433e-14
0.05	2.507e+00	1.122e-07	2.034e-07	2.990e-10	5.419e-10
0.06	3.380e-01	2.593e-08	5.814e-08	5.151e-11	1.155e-10

0.08	7.641e+00	1.158e-06	3.331e-06	1.833e-09	5.270e-09
0.1	7.686e+00	1.781e-06	5.873e-06	2.724e-09	8.986e-09
0.15	1.012e+01	4.497e-06	1.629e-05	7.406e-09	2.683e-08
0.2	4.009e+01	2.729e-05	9.726e-05	4.817e-08	1.717e-07
0.3	2.547e-02	3.138e-08	1.020e-07	5.952e-11	1.935e-10
0.4	1.290e-02	2.428e-08	7.205e-08	4.731e-11	1.404e-10
0.5	4.472e-04	1.174e-09	3.221e-09	2.304e-12	6.322e-12
0.6	5.337e-03	1.841e-08	4.712e-08	3.593e-11	9.197e-11
0.8	4.521e-03	2.406e-08	5.533e-08	4.577e-11	1.052e-10
1.0	1.018e-02	7.595e-08	1.611e-07	1.400e-10	2.970e-10
1.5	2.100e-03	2.891e-08	5.329e-08	4.864e-11	8.966e-11
2.0	2.764e-03	5.817e-08	9.852e-08	8.996e-11	1.523e-10
Totals	**7.810e+01**	**3.518e-05**	**1.237e-04**	**6.147e-08**	**2.151e-07**

G-1 DOWNHOLE SCAN FOR HEU @ 1 pCi/g; 9 INCHES THICK × 14.25 INCHES DIAMETER; 50 yr decay

Step 1

Fluence rate to exposure rate (FRER, no units) = ~ (1 uR/h)/(Eγ)(u_{en}/ρ)air

TABLE 1

Energy$_\gamma$, keV	$(u_{en}/\rho)_{air}$, cm^2/g	FRER
15	1.29	0.0517
20	0.516	0.0969
30	0.147	0.2268
40	0.064	0.3906
50	0.0384	0.5208
60	0.0292	0.5708
80	0.0236	0.5297
100	0.0231	0.4329
150	0.0251	0.2656
200	0.0268	0.1866
300	0.0288	0.1157
400	0.0296	0.0845
500	0.0297	0.0673
600	0.0296	0.0563
800	0.0289	0.0433
1,000	0.0280	0.0357
1,500	0.0255	0.0261
2,000	0.0234	0.0214

Step 2

Probability of interaction (P) through end of detector for given energy is

Probability = $1\text{-}e^{-(\mu/\rho)\text{NaI}\,(x)\,(\rho\text{NaI})}$

TABLE 2

Energy$_\gamma$, keV	$(\mu/\rho)_{NaI}$, cm^2/g	P
15	47.4	1.00
20	22.3	1.00
30	7.45	1.00
40	19.3	1.00
50	10.7	1.00
60	6.62	1.00
80	3.12	1.00
100	1.72	1.00
150	0.625	1.00
200	0.334	0.96
300	0.167	0.79
400	0.117	0.66
500	0.0955	0.59
600	0.0826	0.54
800	0.0676	0.47
1,000	0.0586	0.42
1,500	0.0469	0.35
2,000	0.0413	0.32

for 1 x 1 NaI crystal: x = 2.54 cm
ρ = 3.67 g/cm^3

G-1 DOWNHOLE SCAN FOR HEU @ 1 pCi/g; 9 INCHES THICK × 14.25 INCHES DIAMETER; 50 yr decay

Step 3

Relative Detector Response (RDR) = relative fluence-to-exposure rate times probability of interaction

TABLE 3

Energy$_\gamma$, keV	FRER	P	RDR
15	0.0517	1.00	0.0517
20	0.0969	1.00	0.0969
30	0.2268	1.00	0.2268
40	0.3906	1.00	0.3906
50	0.5208	1.00	0.5208
60	0.5708	1.00	0.5708
80	0.5297	1.00	0.5297
100	0.4329	1.00	0.4329
150	0.2656	1.00	0.2648
200	0.1866	0.96	0.1783
300	0.1157	0.79	0.0913
400	0.0845	0.66	0.0561
500	0.0673	0.59	0.0397
600	0.0563	0.54	0.0302
800	0.0433	0.47	0.0202
1,000	0.0357	0.42	0.0150
1,500	0.0261	0.35	0.0093
2,000	0.0214	0.32	0.0068

Based on a Ludlum 44-2 1x1 NaI response for Cs-137 is 300 cpm/uR/hr

Use same methodology and interpolating for Cs-137 response have:

Energy$_\gamma$, keV	$(u_{en}/\rho)_{air}$, cm^2/g		
662	0.0294	FRER ~	0.0514
Energy$_\gamma$, keV	$(\mu/\rho)_{NaI}$, cm^2/g		
662	0.0780	Probability =	0.52
		RDR =	0.0265

For this detector the response to another energy is based on the ratio of the relative detector response, RDR to the Cs-137 energy
cpm/μR/hr, E_i = $(cpm_{cs\text{-}137})$*(RDR_{Ei})/$(RDR_{Cs\text{-}137})$

G-1 DOWNHOLE SCAN FOR HEU @ 1 pCi/g; 9 INCHES THICK × 14.25 INCHES DIAMETER; 50 yr decay

Step 4

Relationship Between Detector Response (cpm) and Exposure Rate (μR/hr)

TABLE 4

Energy$_\gamma$, keV	RDR_{Ei}	1" x 1" NaI Detector, cpm per μR/hr
15	0.0517	584
20	0.0969	1,095
30	0.2268	2,564
40	0.3906	4,416
50	0.5208	5,888
60	0.5708	6,453
80	0.5297	5,988
100	0.4329	4,894
150	0.2648	2,994
200	0.1783	2,015
300	0.0913	1,033
400	0.0561	634
500	0.0397	449
600	0.0302	342
662	0.0265	300
800	0.0202	229
1,000	0.0150	170
1,500	0.0093	105
2,000	0.0068	77

Step 5

Relationship Between Detector Response (cpm) and Contamination Level (pCi/g)

Table 5

keV	Net MicroShield Exposure Rate, μR/hr (with buildup)	cpm/μR/hr	cpm/μR/hr (weighted)	Percent of NaI detector response	0.48" Air and 0.145" PVC MicroShield Exposure Rate, mR/hr (with buildup)	0.625" Air MicroShield Exposure Rate, mR/hr (with buildup)	0.625" Air and 0.13" Aluminum MicroShield Exposure Rate, mR/hr (with buildup)
15	9.744E-09	584	0	0.0%	4.42E-14	1.45E-10	1.55E-10
20	0.000E+00	1,095	0	0.0%	1.27E-14	4.77E-13	1.53E-14
30	0.000E+00	2,564	0	0.0%	7.28E-09	2.24E-08	7.34E-09
40	1.513E-10	4,416	0	0.0%	4.05E-13	6.39E-13	3.85E-13
50	7.460E-06	5,888	14	0.6%	1.083E-08	1.350E-08	1.013E-08
60	1.872E-06	6,453	4	0.2%	2.35E-09	2.67E-09	2.19E-09
80	9.154E-05	5,988	181	7.5%	1.05E-07	1.12E-07	9.83E-08
100	1.504E-04	4,894	243	10.1%	1.68E-07	1.75E-07	1.58E-07
150	4.006E-04	2,994	396	16.4%	4.38E-07	4.51E-07	4.13E-07
200	2.368E-03	2,015	1,574	65.2%	2.57E-06	2.64E-06	2.43E-06
300	2.440E-06	1,033	1	0.0%	2.64E-09	2.70E-09	2.50E-09
400	1.685E-06	634	0	0.0%	1.82E-09	1.86E-09	1.72E-09
500	7.329E-08	449	0	0.0%	7.92E-11	8.08E-11	7.49E-11
600	1.039E-06	342	0	0.0%	1.12E-09	1.14E-09	1.06E-09
800	1.148E-06	229	0	0.0%	1.24E-09	1.26E-09	1.17E-09
1000	3.145E-06	170	0	0.0%	3.39E-09	3.44E-09	3.20E-09
1500	9.070E-07	105	0	0.0%	9.74E-10	9.89E-10	9.23E-10
2000	1.495E-06	77	0	0.0%	1.60E-09	1.62E-09	1.52E-09
Total	3.032E-03		2,413	100%	3.319E-06	3.426E-06	3.131E-06

G-1 DOWNHOLE SCAN FOR HEU @ 1 pCi/g; 9 INCHES THICK × 14.25 INCHES DIAMETER; 50 yr decay

Step 6

Calculation of Scan Minimum Detectable Count Rates

MDC for Cs-137 energy

Actual average background from downhole measurements 1554 cpm	b_i =	25.9	counts
	MDCR =	421.4	cpm
	$MDCR_{surveyor}$ =	421	cpm

Step 7

Calculation of Scan Minimum Detectable Concentration

Minimum Detectable Exposure Rate =

MDCR surveyor/(cpm/μr/hr)
0.175 μr/hr

and MDC for high-enriched uranium and 50-year equilibrium progeny based on a normalized 1 pCi/g total uranium

Scan MDC = (Assumed MDC U_{TOTAL}Conc) x (Exposure Rate $MDCR_{Surveyor}$)/(Exposure $Rate_{assumed\ U\ Conc}$)

Scan MDC = 57.6 pCi/g

MicroShield 8.02
Cabrera Services, Inc. (8.02-0000)

Date	By	Checked

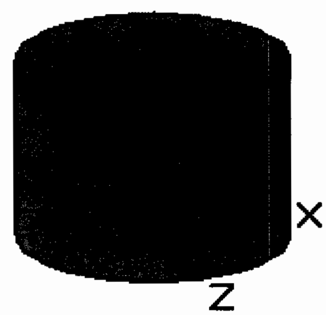
Filename	Run Date	Run Time	Duration
UNC Downhole G-1 HEU Air 0.48 PVC 0.145.msd	October 9, 2012	12:53:19 PM	00:00:08

Project Info

Case Title	Case 1
Description	Reference Filename
Geometry	11 - Annular Cylinder - Internal Dose Point

Source Dimensions

Height	22.86 cm (9.0 in)
Inner Cyl Radius	0.368 cm (0.1 in)
Inner Cyl Thickness	1.219 cm (0.5 in)
Source	15.24 cm (6.0 in)



Dose Points

A	X	Y	Z
#1	0.0 cm (0 in)	0.0 cm (0 in)	0.0 cm (0 in)

Shields

Shield N	Dimension	Material	Density
Cyl. Radius	.145 in	PVC	1.38
Shield 1	.48 in	Air	0.00122
Source	1229.934 in³	FGR 12 Soil	1.6

Source Input: Grouping Method - Standard Indices
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Excluded
Library: Grove

Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Ac-227	5.0600e-013	1.8722e-002	2.5105e-011	9.2890e-007
Bi-210	5.5433e-014	2.0510e-003	2.7503e-012	1.0176e-007
Bi-211	5.0409e-013	1.8651e-002	2.5011e-011	9.2540e-007
Bi-214	1.5122e-013	5.5951e-003	7.5027e-012	2.7760e-007
Fr-223	6.9828e-015	2.5836e-004	3.4645e-013	1.2819e-008
Pa-231	1.0126e-012	3.7467e-002	5.0241e-011	1.8589e-006
Pa-234	1.5479e-014	5.7272e-004	7.6800e-013	2.8416e-008
Pa-234m	9.6744e-012	3.5795e-001	4.8000e-010	1.7760e-005
Pb-210	5.5492e-014	2.0532e-003	2.7533e-012	1.0187e-007
Pb-211	5.0409e-013	1.8651e-002	2.5011e-011	9.2540e-007
Pb-214	1.5122e-013	5.5951e-003	7.5027e-012	2.7760e-007
Po-210	5.3834e-014	1.9918e-003	2.6710e-012	9.8826e-008
Po-211	1.3762e-015	5.0918e-005	6.8279e-014	2.5263e-009
Po-214	1.5119e-013	5.5939e-003	7.5012e-012	2.7754e-007
Po-215	5.0410e-013	1.8652e-002	2.5011e-011	9.2540e-007
Po-218	1.5125e-013	5.5962e-003	7.5043e-012	2.7766e-007
Ra-223	5.0410e-013	1.8652e-002	2.5011e-011	9.2540e-007
Ra-226	1.5134e-013	5.5996e-003	7.5088e-012	2.7783e-007

Rn-219	5.0410e-013	1.8652e-002	2.5011e-011	9.2540e-007
Rn-222	1.5125e-013	5.5962e-003	7.5043e-012	2.7766e-007
Th-227	4.9784e-013	1.8420e-002	2.4701e-011	9.1392e-007
Th-230	1.4073e-011	5.2071e-001	6.9825e-010	2.5835e-005
Th-231	9.5777e-010	3.5437e+001	4.7520e-008	1.7582e-003
Th-234	9.6744e-012	3.5795e-001	4.8000e-010	1.7760e-005
Tl-207	5.0272e-013	1.8600e-002	2.4943e-011	9.2287e-007
U-234	3.1272e-008	1.1571e+003	1.5516e-006	5.7408e-002
U-235	9.5777e-010	3.5437e+001	4.7520e-008	1.7582e-003
U-238	9.6744e-012	3.5795e-001	4.8000e-010	1.7760e-005

Buildup: The material reference is Source

Integration Parameters

Radial	49
Circumferential	49
Y Direction (axial)	49

Results

Energy (MeV)	**Activity (Photons/sec)**	**Fluence Rate MeV/cm²/sec No Buildup**	**Fluence Rate MeV/cm²/sec With Buildup**	**Exposure Rate mR/hr No Buildup**	**Exposure Rate mR/hr With Buildup**
0.015	6.666e-02	4.707e-13	5.157e-13	4.038e-14	4.423e-14
0.02	1.699e-04	3.128e-13	3.660e-13	1.084e-14	1.268e-14
0.03	5.196e+00	5.212e-07	7.343e-07	5.165e-09	7.277e-09
0.04	9.889e-05	5.189e-11	9.161e-11	2.295e-13	4.051e-13
0.05	1.367e+00	1.822e-06	4.065e-06	4.854e-09	1.083e-08
0.06	1.844e-01	4.472e-07	1.182e-06	8.883e-10	2.348e-09
0.08	4.168e+00	2.084e-05	6.639e-05	3.298e-08	1.051e-07
0.1	4.193e+00	3.230e-05	1.098e-04	4.942e-08	1.680e-07
0.15	5.522e+00	8.062e-05	2.660e-04	1.328e-07	4.381e-07
0.2	2.187e+01	4.794e-04	1.458e-03	8.462e-07	2.574e-06
0.3	1.390e-02	5.302e-07	1.393e-06	1.006e-09	2.643e-09
0.4	7.036e-03	3.969e-07	9.352e-07	7.734e-10	1.822e-09
0.5	2.439e-04	1.863e-08	4.033e-08	3.657e-11	7.917e-11
0.6	2.911e-03	2.846e-07	5.745e-07	5.556e-10	1.121e-09
0.8	2.466e-03	3.557e-07	6.501e-07	6.766e-10	1.237e-09
1.0	5.551e-03	1.081e-06	1.836e-06	1.993e-09	3.385e-09
1.5	1.145e-03	3.827e-07	5.788e-07	6.439e-10	9.738e-10
2.0	1.508e-03	7.316e-07	1.035e-06	1.131e-09	1.601e-09
Totals	**4.260e+01**	**6.198e-04**	**1.914e-03**	**1.079e-06**	**3.318e-06**

MicroShield 8.02
Cabrera Services, Inc. (8.02-0000)

Date	By	Checked

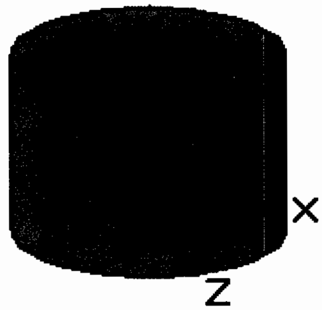
Filename	Run Date	Run Time	Duration
UNC Downhole G-1 HEU Air 0.625.msd	October 11, 2012	3:29:58 PM	00:00:09

Project Info

Case Title	Case 1
Description	Reference Filename
Geometry	11 - Annular Cylinder - Internal Dose Point

Source Dimensions

Height	22.86 cm (9.0 in)
Inner Cyl Radius	1.588 cm (0.6 in)
Inner Cyl Thickness	0.0 cm (0 in)
Source	15.24 cm (6.0 in)



Dose Points

A	X	Y	Z
#1	0.0 cm (0 in)	0.0 cm (0 in)	0.0 cm (0 in)

Shields

Shield N	Dimension	Material	Density
Cyl. Radius	.625 in	Air	0.00122
Source	1229.934 in³	FGR 12 Soil	1.6

Source Input: Grouping Method - Standard Indices
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Excluded
Library: Grove

Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Ac-227	5.0600e-013	1.8722e-002	2.5105e-011	9.2890e-007
Bi-210	5.5433e-014	2.0510e-003	2.7503e-012	1.0176e-007
Bi-211	5.0409e-013	1.8651e-002	2.5011e-011	9.2540e-007
Bi-214	1.5122e-013	5.5951e-003	7.5027e-012	2.7760e-007
Fr-223	6.9828e-015	2.5836e-004	3.4645e-013	1.2819e-008
Pa-231	1.0126e-012	3.7467e-002	5.0241e-011	1.8589e-006
Pa-234	1.5479e-014	5.7272e-004	7.6800e-013	2.8416e-008
Pa-234m	9.6744e-012	3.5795e-001	4.8000e-010	1.7760e-005
Pb-210	5.5492e-014	2.0532e-003	2.7533e-012	1.0187e-007
Pb-211	5.0409e-013	1.8651e-002	2.5011e-011	9.2540e-007
Pb-214	1.5122e-013	5.5951e-003	7.5027e-012	2.7760e-007
Po-210	5.3834e-014	1.9918e-003	2.6710e-012	9.8826e-008
Po-211	1.3762e-015	5.0918e-005	6.8279e-014	2.5263e-009
Po-214	1.5119e-013	5.5939e-003	7.5012e-012	2.7754e-007
Po-215	5.0410e-013	1.8652e-002	2.5011e-011	9.2540e-007
Po-218	1.5125e-013	5.5962e-003	7.5043e-012	2.7766e-007
Ra-223	5.0410e-013	1.8652e-002	2.5011e-011	9.2540e-007
Ra-226	1.5134e-013	5.5996e-003	7.5088e-012	2.7783e-007
Rn-219	5.0410e-013	1.8652e-002	2.5011e-011	9.2540e-007

Rn-222	1.5125e-013	5.5962e-003	7.5043e-012	2.7766e-007
Th-227	4.9784e-013	1.8420e-002	2.4701e-011	9.1392e-007
Th-230	1.4073e-011	5.2071e-001	6.9825e-010	2.5835e-005
Th-231	9.5777e-010	3.5437e+001	4.7520e-008	1.7582e-003
Th-234	9.6744e-012	3.5795e-001	4.8000e-010	1.7760e-005
Tl-207	5.0272e-013	1.8600e-002	2.4943e-011	9.2287e-007
U-234	3.1272e-008	1.1571e+003	1.5516e-006	5.7408e-002
U-235	9.5777e-010	3.5437e+001	4.7520e-008	1.7582e-003
U-238	9.6744e-012	3.5795e-001	4.8000e-010	1.7760e-005

Buildup: The material reference is Source

Integration Parameters

Radial	49
Circumferential	49
Y Direction (axial)	49

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.015	6.666e-02	1.644e-09	1.694e-09	1.410e-10	1.453e-10
0.02	1.699e-04	1.288e-11	1.378e-11	4.461e-13	4.773e-13
0.03	5.196e+00	1.835e-06	2.263e-06	1.818e-08	2.243e-08
0.04	9.889e-05	9.557e-11	1.445e-10	4.227e-13	6.390e-13
0.05	1.367e+00	2.637e-06	5.068e-06	7.024e-09	1.350e-08
0.06	1.844e-01	5.799e-07	1.343e-06	1.152e-09	2.668e-09
0.08	4.168e+00	2.469e-05	7.072e-05	3.908e-08	1.119e-07
0.1	4.193e+00	3.698e-05	1.146e-04	5.657e-08	1.753e-07
0.15	5.522e+00	8.946e-05	2.736e-04	1.473e-07	4.505e-07
0.2	2.187e+01	5.253e-04	1.494e-03	9.271e-07	2.636e-06
0.3	1.390e-02	5.731e-07	1.424e-06	1.087e-09	2.701e-09
0.4	7.036e-03	4.254e-07	9.544e-07	8.290e-10	1.860e-09
0.5	2.439e-04	1.985e-08	4.114e-08	3.895e-11	8.075e-11
0.6	2.911e-03	3.018e-07	5.856e-07	5.890e-10	1.143e-09
0.8	2.466e-03	3.745e-07	6.621e-07	7.123e-10	1.259e-09
1.0	5.551e-03	1.132e-06	1.869e-06	2.087e-09	3.444e-09
1.5	1.145e-03	3.974e-07	5.881e-07	6.687e-10	9.894e-10
2.0	1.508e-03	7.559e-07	1.050e-06	1.169e-09	1.624e-09
Totals	**4.260e+01**	**6.855e-04**	**1.968e-03**	**1.204e-06**	**3.426e-06**

MicroShield 8.02
Cabrera Services, Inc. (8.02-0000)

Date	By	Checked

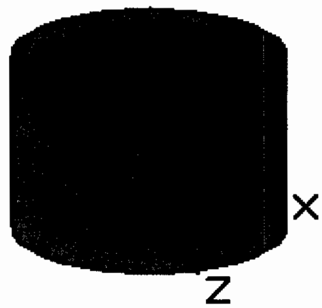
Filename	Run Date	Run Time	Duration
UNC Downhole G-1 HEU Air 0.625 Al 0.13.msd	October 9, 2012	3:18:35 PM	00:00:08

Project Info

Case Title	Case 1
Description	Reference Filename
Geometry	11 - Annular Cylinder - Internal Dose Point

Source Dimensions

Height	22.86 cm (9.0 in)
Inner Cyl Radius	0.33 cm (0.1 in)
Inner Cyl Thickness	1.588 cm (0.6 in)
Source	15.24 cm (6.0 in)



Dose Points

A	X	Y	Z
#1	0.0 cm (0 in)	0.0 cm (0 in)	0.0 cm (0 in)

Shields

Shield N	Dimension	Material	Density
Cyl. Radius	.13 in	Aluminum	2.7
Shield 1	.625 in	Air	0.00122
Source	1274.042 in³	FGR 12 Soil	1.6

Source Input: Grouping Method - Standard Indices
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Excluded
Library: Grove

Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Ac-227	5.0600e-013	1.8722e-002	2.4236e-011	8.9674e-007
Bi-210	5.5433e-014	2.0510e-003	2.6551e-012	9.8240e-008
Bi-211	5.0409e-013	1.8651e-002	2.4145e-011	8.9336e-007
Bi-214	1.5122e-013	5.5951e-003	7.2430e-012	2.6799e-007
Fr-223	6.9828e-015	2.5836e-004	3.3446e-013	1.2375e-008
Pa-231	1.0126e-012	3.7467e-002	4.8502e-011	1.7946e-006
Pa-234	1.5479e-014	5.7272e-004	7.4141e-013	2.7432e-008
Pa-234m	9.6744e-012	3.5795e-001	4.6338e-010	1.7145e-005
Pb-210	5.5492e-014	2.0532e-003	2.6579e-012	9.8344e-008
Pb-211	5.0409e-013	1.8651e-002	2.4145e-011	8.9336e-007
Pb-214	1.5122e-013	5.5951e-003	7.2430e-012	2.6799e-007
Po-210	5.3834e-014	1.9918e-003	2.5785e-012	9.5405e-008
Po-211	1.3762e-015	5.0918e-005	6.5916e-014	2.4389e-009
Po-214	1.5119e-013	5.5939e-003	7.2415e-012	2.6793e-007
Po-215	5.0410e-013	1.8652e-002	2.4145e-011	8.9337e-007
Po-218	1.5125e-013	5.5962e-003	7.2445e-012	2.6805e-007
Ra-223	5.0410e-013	1.8652e-002	2.4145e-011	8.9337e-007
Ra-226	1.5134e-013	5.5996e-003	7.2488e-012	2.6821e-007

Rn-219	5.0410e-013	1.8652e-002	2.4145e-011	8.9337e-007
Rn-222	1.5125e-013	5.5962e-003	7.2445e-012	2.6805e-007
Th-227	4.9784e-013	1.8420e-002	2.3845e-011	8.8228e-007
Th-230	1.4073e-011	5.2071e-001	6.7408e-010	2.4941e-005
Th-231	9.5777e-010	3.5437e+001	4.5875e-008	1.6974e-003
Th-234	9.6744e-012	3.5795e-001	4.6338e-010	1.7145e-005
Tl-207	5.0272e-013	1.8600e-002	2.4079e-011	8.9092e-007
U-234	3.1272e-008	1.1571e+003	1.4979e-006	5.5421e-002
U-235	9.5777e-010	3.5437e+001	4.5875e-008	1.6974e-003
U-238	9.6744e-012	3.5795e-001	4.6338e-010	1.7145e-005

Buildup: The material reference is Source

Integration Parameters

Radial	49
Circumferential	49
Y Direction (axial)	49

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.015	1.578e+02	1.653e-09	1.808e-09	1.418e-10	1.550e-10
0.02	1.699e-04	3.790e-13	4.420e-13	1.313e-14	1.531e-14
0.03	5.196e+00	5.276e-07	7.408e-07	5.229e-09	7.342e-09
0.04	9.889e-05	4.916e-11	8.709e-11	2.174e-13	3.852e-13
0.05	1.367e+00	1.678e-06	3.802e-06	4.471e-09	1.013e-08
0.06	1.844e-01	4.065e-07	1.103e-06	8.073e-10	2.192e-09
0.08	4.168e+00	1.875e-05	6.214e-05	2.968e-08	9.834e-08
0.1	4.193e+00	2.902e-05	1.031e-04	4.439e-08	1.577e-07
0.15	5.522e+00	7.264e-05	2.508e-04	1.196e-07	4.130e-07
0.2	2.187e+01	4.339e-04	1.377e-03	7.658e-07	2.430e-06
0.3	1.390e-02	4.833e-07	1.317e-06	9.168e-10	2.498e-09
0.4	7.036e-03	3.637e-07	8.842e-07	7.086e-10	1.723e-09
0.5	2.439e-04	1.713e-08	3.814e-08	3.363e-11	7.487e-11
0.6	2.911e-03	2.626e-07	5.434e-07	5.125e-10	1.061e-09
0.8	2.466e-03	3.297e-07	6.152e-07	6.270e-10	1.170e-09
1.0	5.551e-03	1.005e-06	1.738e-06	1.853e-09	3.204e-09
1.5	1.145e-03	3.578e-07	5.484e-07	6.020e-10	9.226e-10
2.0	1.508e-03	6.861e-07	9.815e-07	1.061e-09	1.518e-09
Totals	**2.003e+02**	**5.604e-04**	**1.805e-03**	**9.764e-07**	**3.131e-06**

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