Final

Characterization and Final Status Survey Report: Radioactive Materials Handling Facility Holdup Pond (Site 4614)

Santa Susana Field Laboratory

Ventura County, California

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LIST OF ACRONYMS, ABBREVIATIONS, AND UNITS OF MEASUREMENT

Ac	Actinium (e.g., ^{228}Ac)
AI	Atomics International
Am	Americium (e.g., ^{241}Am)
ARARs	Applicable or Relevant and Appropriate Requirements
Bi	Bismuth (e.g., ^{214}Bi)
bgs	Below Ground Surface
CABRERA	Cabrera Services, Inc.
CFD	Cumulative Frequency Distribution
cm, cm^2	Centimeter, square centimeter
Co	Cobalt (e.g., ^{60}Co)
Cs	Cesium (e.g., ^{137}Cs)
D&D	Decontamination and Decommissioning
DCGL	Derived Concentration Guideline Level
$DCGL_{Cs,mod}$	Modified Derived Concentration Guideline Level
DOD	Department of Defense
DOE	U. S. Department of Energy
DQO	Data Quality Objectives
EDA	Exploratory Data Analysis
EPA	U. S. Environmental Protection Agency
ETEC	Energy Technology Engineering Center
Eu	Europium (e.g., ^{152}Eu)
Fe	Iron (e.g., ^{55}Fe)
ft, ft^2	Feet, Square Feet
FSP	Field Sampling Plan
GPS	Global Positioning System
GWS	Gamma Walkover Survey
HSA	Historical Site Assessment
ID	Identification
K	Potassium (e.g., ^{40}K)
kW	Kilowatt
LBGR	Lower Bound Gray Region
LCS	Laboratory Control Sample
m, m^2	Meter, Square Meter
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
mCi	Millicurie
MDC	Minimum Detectable Concentration
Mn	Manganese (e.g., ^{54}Mn)
µR/hr	Microroentgen per Hour
MW	Megawatt
NAD	North American Datum
NaI	Sodium Iodide
NASA	National Aeronautics and Space Administration
NELAP	National Environmental Laboratory Accreditation Program
Ni	Nickel (e.g., ^{59}Ni)

NIST	National Institute of Standards and Technology
NRC	Nuclear Regulatory Commission
pCi/g	Picocurie per Gram
PM	Project Manager
PRG	Preliminary Remediation Goal
Pu	Plutonium (e.g., ^{238}Pu)
QA	Quality Assurance
QC	Quality Control
RER	Relative (or Replicate) Error Ratio
RESRAD	Residual Radiation (Environmental Analysis)
RL	Reporting Limit
RMDF	Radioactive Materials Disposal Facility
RMHF	Radioactive Materials Handling Facility
RPD	Relative Percent Difference
SOF	Sum of Fractions
Sr	Strontium (e.g., ^{90}Sr)
SSFL	Santa Susana Field Laboratory
STIR	Shield Test Irradiation Reactor
Th	Thorium (e.g., ^{232}Th)
U	Uranium (e.g., ^{233}U)
U.S.C.	United States Code

EXECUTIVE SUMMARY

This report presents the results of the characterization and final status survey of the Radioactive Materials Handling Facility (RMHF) Holdup Pond at the Santa Susana Field Laboratory (SSFL) in Ventura County, California. This site includes the former pond as well as a drainage channel connecting the pond to the RMHF. The field work was performed from November 28, 2006, to December 15, 2006, by Cabrera Services, Inc. (CABRERA) in accordance with the *Field Sampling Plan: Final Status Survey, Radioactive Materials Handling Facility Holdup Pond* (FSP, CABRERA, 2006b).

The purpose of the final status survey was to provide recommendations for future use of the site. The survey was designed in accordance with Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) guidance such that collected survey data can be used to demonstrate compliance with the release criteria for unrestricted use.

Initial gamma walkover survey (GWS) measurements at the site identified elevated gross gamma activity in two areas at the site. On-site gamma spectroscopy measurements (provided by Boeing) revealed several samples with ^{137}Cs concentrations exceeding the DCGL. Based on these findings, the scope of the survey was revised to include the initial measurements as site characterization only. In addition, the classification of the Class 3 survey unit was revised to Class 1. A removal action was performed by Boeing prior to repeating the GWS survey and collecting soil samples for the final status survey. All initial GWS measurements and on-site laboratory results used for site characterization are provided in Section 3.0 and Appendix E. The area outside the drainage swale where biased samples 7 through 10 were collected during the characterization and removal action were not within the survey units 19 and 20 and did not receive final status verification. The final status survey data collected for survey units 19 and 20 after the removal action were evaluated using the project decision rules (see Table 1.1). These data are presented in Section 4.0.

The areas of interest included two survey units. Non-intrusive surface investigations, intrusive sample collection techniques, and off-site sample analyses were performed for each survey unit. Non-intrusive GWS were performed over 100% of accessible areas to identify the presence of elevated levels of radioactivity. Random-start systematic samples were collected from the Class 1 survey unit, and random samples were collected from the area initially classified as a Class 3 survey unit. Biased surface soil samples were collected at the location of the highest GWS result for each survey unit. Two subsurface soil samples were collected to support the assumption that contamination was restricted to the first 0.5 feet (ft) below ground surface (bgs).

Exploratory data analysis (EDA) was performed on the off-site laboratory analysis data to identify radionuclide distribution trends and potential outliers. EDA included visual inspection of measurement results using posting plots, cumulative frequency distributions (CFDs), histograms, and calculation of statistical quantities including mean, median, standard deviation, and range. The results of the EDA for individual radionuclides and survey units are presented in Appendix A. For each survey unit, the Sign test was performed for radionuclides of concern individually or using the sum of fractions (SOF) calculation. The results of the statistical tests are also presented in Appendix A.

Based on the results of the survey, CABRERA recommends the release of both survey units to unrestricted use.

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1.0 INTRODUCTION

This report presents the results of the characterization and final status survey of the RMHF Holdup Pond (i.e., Site 4614) at the SSFL in Ventura County, California. The report also makes recommendations for future use of the site based on the results of the survey. The field work was performed from November 28, 2006, to December 15, 2006, by CABRERA in accordance with the Field Sampling Plan (FSP) (CABRERA, 2006b).

The site is located in Area IV of the SSFL, shown in Figure 1.1. The SSFL is operated by Boeing for the United States Department of Energy (DOE). Under the authority of the Atomic Energy Act [42 United States Code (U.S.C.) 201 et seq.], DOE is responsible for establishing a comprehensive health, safety, and environmental program for managing facilities. As an Agreement State under the Atomic Energy Act, the State of California has jurisdiction over non-DOE radiological activities at the SSFL.

1.1 Purpose

The purpose of the survey was to determine final status for areas where the radionuclide concentrations were found to be below their respective DCGL based on individual radionuclides or multiple radionuclides using the SOF method (see Section 5.5.1). The survey was designed in accordance with MARSSIM guidance such that collected survey data could be used to demonstrate compliance with the release criteria for unrestricted use.

1.2 Scope

The scope of the survey included surface soil to a depth of 0.5 feet bgs within two survey units at Site 4614. Two subsurface soil samples were collected to support the assumption that contamination was restricted to the first 0.5 feet bgs. Figure 1.1 shows the location of the site within Area IV. Figures 1.2 – 1.4 of Attachment 1 show photos of the areas of interest at the site. The site was divided into two survey units. The boundaries and classifications of each survey unit are described in Section 4.1. No investigations of ground water, surface water, sediment, asphalt, concrete, or buildings were performed as part of the survey.

Initial GWS measurements revealed large areas of elevated activity in both the Class 1 and Class 3 survey unit. A removal action was performed and the Class 3 survey unit was reclassified as Class 1. The field efforts were revised to include characterization and removal actions and the survey design was re-evaluated (see Section 4.1.2) prior to performance of the final status survey.

1.3 Site History

In the late 1940's, North American Aviation acquired land in the Simi Hills between the Simi and San Fernando Valleys. That land, now known as SSFL, was used primarily for the testing of rocket engines. Atomics International (AI), a division of North American Aviation, was formed in 1955 and part of Area IV at SSFL was set aside and used for nuclear reactor development and testing. In 1984 AI merged with Rocketdyne. The Boeing Company purchased Rocketdyne in 1996. Area IV of the SSFL is used for DOE-sponsored activities. Boeing, the National Aeronautics and Space Administration (NASA), and the Department of Defense (DOD) have used the balance of the SSFL for rocket and laser testing.

Activities in Area IV started in the mid 1950s: until 1964 these activities were primarily related to sodium-cooled nuclear power plant development and development of space power systems with sodium and potassium as coolants. The Energy Technology Engineering Center (ETEC, originally known as the Liquid Metal Engineering Center) was formed in the mid 1960s as an Atomic Energy Commission (now DOE) laboratory for the development of liquid metal heat transfer systems in support of the Liquid Metal Fast Breeder Reactor Program. Nuclear operations at Area IV included 10 nuclear research reactors, 7 critical facilities, the Hot Laboratory, the Nuclear Materials Development Facility, the RMHF, and various test and nuclear material storage areas. All nuclear operations ended in 1988. Since that time, DOE-funded activities have focused on decontamination and decommissioning (D&D) of the ETEC facilities.

Site 4614 is a holdup pond located at the base of the drainage channel west of the RMHF complex. The pond was constructed in the middle 1960s for the nearby 4028 facility. The pond was converted for use by the RMHF by removal of the 4028 piping and construction of the drainage channel between the pond and the RMHF. This may have happened around 1976, when the remaining reactor at Building 4028 was decommissioned and removed. The site includes both the pond and the drainage channel. The pond and drainage channel were lined with asphalt until the fall of 2006, when the asphalt was removed as part of D&D operations. Neither the pond nor the drainage channel were backfilled or graded prior to this investigation.

The drainage channel and pond have been replaced with an above ground storage tank. The tank receives runoff from the RMHF via a drainage pipe (see Figure 1.2).

1.4 Project Data Quality Objectives

The general objectives of the survey were to provide sufficient information to:

- Confirm whether one or more radionuclides of concern exceed the DCGLs in areas with known or suspected radioactive contamination.
- Verify assumptions used to develop the survey design.
- Delineate areas where no radionuclide concentrations exceed the action levels and support recommendation for unrestricted release.

Quality assurance (QA) measures were implemented throughout the project to ensure data met known and suitable data quality criteria such as precision, accuracy, representativeness, comparability, and completeness. The quality of analytical data was also controlled through the performance of quality control (QC) measurements and the calibration of field and laboratory equipment. On-site radiological measurement techniques were used based on radiological characteristics of the potential contaminants and the reasonable implementation of best available technology. The measurement analysis results were reviewed, evaluated using EDA, and compared to the project DCGLs based on individual radionuclides or multiple radionuclides using the SOF method (see Section 5.5.1). Statistical comparisons to the DCGLs were performed using the Sign test.

1.4.1 Step 1 – State the Problem

The problem was the potential presence of concentrations of radionuclides of concern (i.e., those resulting from DOE activities) in surface soil exceeding the project action levels. The radionuclides of concern are discussed in Section 2.3. The project action levels are discussed in Section 2.4.

1.4.2 Step 2 – Identify the Decision

The principal study question for the survey was to determine if the activity of radionuclides of interest exceed established DCGLs. Each survey unit is considered to be suitable for release for unrestricted use if the average concentration of residual radioactivity for each source or uranium radionuclide of concern (see Table 2.3) is less than the established action level. For other radionuclides of concern, each survey unit is considered to be suitable for release for unrestricted use if the average concentration of residual radioactivity for each radionuclide of concern in the top 0.5 feet of soil results in a SOF less than the established action level. The following alternative actions resulted from resolution of the principle study question for this investigation:

- If the individual radionuclide concentration or SOF is below the action level, then no additional investigation will be performed and the survey unit will be recommended for unrestricted release.
- If the individual radionuclide concentration or SOF is greater than or equal to the established action level, then the primary decision maker will be consulted to determine further action. Potential actions included recommendations for remediation, additional survey data collection to define the nature and extent of the radioactivity, and/or the calculation of incremental risk or dose.

Based on the principal study question and alternative actions listed above, the decision statement for the final status survey is to determine whether the average concentrations of residual radioactivity for radionuclides of concern results in radionuclide concentrations and sums of fractions less than the action level.

1.4.3 Step 3 – Identify Inputs to the Decision

The following information will be utilized to support decisions

- Radionuclides of concern (Section 2.3)
- Project action levels (Section 2.4)
- Measurement inputs (Section 4.0)

1.4.4 Step 4 – Define the Study Boundaries

The vertical extent of the target population of interest was the radionuclide concentration in surface soil to a depth of 0.5 feet below ground surface (bgs) over the areas of interest within the site. Two subsurface soil samples were also collected to support the assumption that surface soil is the matrix of concern. The lateral extent of the target population was the geographical boundary of the site located in Area IV of the SSFL. Site 4614 included the former pond and drainage channel (3,693 ft^2) and a surrounding buffer zone (5,107 ft^2). The areas of concern were divided into two survey areas, or survey units (see Section 4.1). A separate decision concerning unrestricted release was made for each survey unit.

Data collection activities were sometimes constrained by manmade obstructions. A concrete drainage channel that prevented access to surface soil was present at the southwestern portion of the site in the Class 3 buffer zone (see Figures 1.3 and 4.3). A stormwater holdup tank was also present at the site. One hundred percent of accessible areas were surveyed. All surface soil samples were collected as planned.

1.4.5 Step 5 – Develop a Decision Rule

The decision rules, given in Table 1.1, were applied. Decisions on whether to perform additional investigations were made during performance of onsite field work based on the GWS data evaluation and after evaluation of the off-site analysis data. After the removal action, the GWS was performed a second time as part of the final status survey. Decisions were made on whether to release each of the two survey units for unrestricted use.

Table 1.1 – Survey Decision Rules

Parameter of Interest	***IF***	***THEN***	***Comments***
Gross Gamma Walkover			
Presence of Contamination	Contoured area with z-score greater than 3.0 is identified,	Collect a biased surface soil sample at the location having the highest z-score to investigate the nature of elevated radioactivity.	Z-score values greater than 3.0 are unexpected and potentially identify areas of elevated activity.
	No areas with z-score greater than 3.0 are identified,	Collect a biased surface soil sample to investigate the nature of elevated radioactivity at the location of the highest gross gamma result.	The maximum gross gamma value potentially identifies areas of elevated activity.
Small Area of Elevated Activity –Biased Surface Investigation			
Presence of Contamination	Analysis results for a biased surface soil sample do not exceed action levels,	Perform no further investigation at sample location.	No additional investigation to be performed.
	Analysis results for a biased surface soil sample exceed action levels,	Additional investigation will be coordinated with the Boeing Project Manager (PM) and directed by Boeing.	
Small Area of Elevated Activity –Biased Subsurface Investigation			

Parameter of Interest	***IF***	***THEN***	***Comments***
Presence of Contamination	Analysis results for a biased subsurface soil sample do not exceed action levels,	Perform no further investigation at sample location.	No additional investigation to be performed.
	Analysis results for a biased subsurface soil sample exceed action levels,	Additional investigation will be coordinated with the Boeing PM and directed by Boeing.	
Average Radionuclide Activity Concentration			
Average survey unit activity	The Cesium-137 (^{137}Cs) concentration for all systematic sample results from the off-site laboratory is less than 4.7 picocuries per gram (pCi/g) in a survey unit,	Recommend unrestricted release of survey unit.	Survey units that pass the MARSSIM statistical tests and do not contain small areas of elevated activity demonstrate compliance with the release criteria and are recommended for unrestricted release.
	The ^{137}Cs activity concentration for any systematic sample from the off-site laboratory exceeds 4.7 pCi/g in a survey unit,	Review the results of gross gamma walkover and biased results to determine if the area is uniformly contaminated or if there is a small area of elevated activity.	
	A survey unit is uniformly contaminated,	Additional investigation will be coordinated with the Boeing PM and directed by Boeing.	

Parameter of Interest	***IF***	***THEN***	***Comments***
	A small area of elevated activity is identified within a survey unit,	Additional investigation will be coordinated with the Boeing PM and directed by Boeing.	Small areas of elevated activity may exceed the DCGL values in Table 2.2 and not exceed the dose- and risk-based release criteria.
	The Cobalt-60 (^{60}Co) concentration for any systematic sample results from the off-site laboratory exceed the MDC,	Additional investigation will be coordinated with the Boeing PM and directed by Boeing.	Cobalt-60 is used as an indicator for the potential presence of difficult-to-detect activation products (i.e., Iron-55 (^{55}Fe), Nickel-59 (^{59}Ni), and ^{63}Ni)
SOF			
	Any ^{137}Cs result within a survey unit exceeds the modified ^{137}Cs DCGL ($DCGL_{Cs,mod}$)	Calculate the SOF	See decision rules below for SOF results
	All ^{137}Cs results within a survey unit are less than the $DCGL_{Cs,mod}$	Recommend unrestricted release of survey unit.	
	SOF < 1	Recommend unrestricted release of survey unit.	
	SOF ≥ 1	Calculate S+ (Sign Test)	See decision rules for sign test results below.
	S+ ≥ Critical Value	Additional investigation will be coordinated with the Boeing PM and directed by Boeing.	

Parameter of Interest	***IF***	***THEN***	***Comments***
	S+ < Critical Value	Recommend unrestricted release of survey unit.	Survey units that pass the MARSSIM statistical tests and do not contain small areas of elevated activity demonstrate compliance with the release criteria and are recommended for unrestricted release.

1.4.6 Step 6 – Specify Limits on Decision Errors

The survey was designed as a graded approach using a combination of gross gamma walkover survey data, on-site gamma analysis, and off-site laboratory analysis of surface soil samples to manage uncertainty. Sampling uncertainty was controlled by collecting additional samples from the area of interest. Analytical uncertainty was controlled by use of appropriate instruments, methods, techniques, and QC. Minimum detectable concentrations (MDCs) for individual radionuclides using specific analytical methods were established. Uncertainty in the decision to release areas for unrestricted use was controlled by the number of data points in each area and the uncertainty in the estimate of the mean radionuclide concentrations. The null hypothesis used to design the survey was the radioactivity in the survey unit exceeds the release criterion. A Type I decision error would occur if a decision was made to incorrectly release a survey unit that exceeds the release criterion. A Type II decision error would occur if a decision was made to incorrectly maintain control of a survey unit that demonstrated compliance with the release criterion. The error rate for both types of decision errors was set at 0.05, or 5%.

1.4.7 Step 7 – Optimize the Design for Obtaining Data

Sampling and analysis processes were designed to provide near real-time data during implementation of field activities. GWS provided information on which soil concentrations exceeded the scan MDC of 3.7 pC/g (^{137}Cs), and allowed appropriate selection of biased samples at the areas of highest gross gamma activity (see Section 4.3.1 and Appendix C). These data were evaluated and used to refine the scope of field activities to optimize implementation of the survey design and ensure the data quality objectives (DQOs) were met.

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2.0 RADIOLOGICAL OVERVIEW

A review of historical information, including previously collected radiological data, was performed as part of the survey design. The scope of the survey was determined based on the radioactive contamination scenarios identified. The survey was designed using the radionuclides of concern and the release criteria previously established for SSFL.

2.1 Historical Information

Two incidents occurred at the site that could have resulted in releases of radioactivity to the environment. Major events that resulted in potential releases of radioactivity, along with surveys that identified radioactivity in the environment, are summarized below. Incident numbers, where applicable, are shown in parentheses.

Site 4614: Former location of the RMHF Holdup Pond

Radioactive contamination exists in the pond as a result of known spills that have occurred at the Radioactive Materials Disposal Facility (RMDF)/RMHF:

- On January 17, 1979, leakage from the flocculation tower associated with Building 4021 contaminated the drainage ditch and the pond itself with less than 0.4 mCi of Strontium-90 (^{90}Sr) and ^{137}Cs (A0077).
- On January 9, 1980, a water hose broke, causing the Building 4021 tank to overflow, which then drained to the pond. This incident resulted in the released of about 100 gallons of liquid containing 1×10^{-2} millicuries (mCi) of mixed fission products (A0080).

2.2 Radioactive Contamination Scenarios

Radioactive contamination scenarios for Site 4614 include transport of radiological contaminants from the RMHF to the pond via a paved drainage channel. Prior to usage with the RMHF, the pond was connected to Building 4028, which contained a test reactor. The original reactor was the Shield Test Reactor, a 50 kilowatt (kW) swimming pool type reactor that operated from 1961 to 1964. The reactor was modified in 1964 to become the Shield Test Irradiation Reactor (STIR), a 1 megawatt (MW) reactor that operated from 1964 to 1972. There were no radiological incidents associated with Building 4028 that may have affected the pond. This scenario is based on the information provided in the historical site assessment (HSA) (Sapere, 2005).

2.3 Radionuclides of Concern

Boeing and DOE identified radionuclides of concern for the SSFL in *Approved Sitewide Release Criteria for Remediation of Radiological Facilities at the SSFL* (Boeing, 1998). Cobalt-60 is used as an indicator for the presence of other activation products for the final status surveys, therefore, radionuclide-specific analyses for ^{55}Fe, ^{59}Ni, or ^{63}Ni were not performed. Analysis for ^{3}H was not performed. Table 2.3 lists the radionuclides of concern identified for Site 4614.

Table 2.3 – Radionuclides of Concern

Transuranic	*Fission*	*Source/Uranium*	*Activation*
^{241}Am	^{134}Cs	^{228}Th	^{60}Co
^{238}Pu	^{137}Cs	^{232}Th	^{54}Mn
^{239}Pu	^{90}Sr	^{234}U	^{152}Eu
^{240}Pu		^{235}U	^{154}Eu
^{241}Pu		^{238}U	

2.4 Project Action Levels and DCGLs

Action levels are numerical values that cause the decision maker to choose one of the alternative actions. DCGLs are the action levels used for the final status survey of Site 4614. DCGLs are derived, radionuclide-specific activity concentrations within a survey unit corresponding to the release criterion. Gross gamma walkover survey data were compared to project action levels, and the results of off-site laboratory analysis of surface soil samples were compared to project DCGLs. The project action levels determined whether or not surface soil concentrations for radionuclides of concern required additional data collection to define the nature and lateral extent of the radioactivity. The project DCGLs determined whether or not a survey unit complied with the release criterion using SOF calculations.

The project action level for the gross gamma walkover survey data was primarily based on statistical probability and used contours of z-scores (number of standard deviations from the mean). Since 0.135% of normally distributed data are expected to exceed a z-score of 3.0, a z-score greater than 3.0 was used as an indicator for investigating areas with radioactivity potentially exceeding one or more DCGLs for surface soil.

The project DCGLs for surface soil are based on values which have been approved for use at the SSFL. The DCGLs for the radionuclides of concern, given in Table 2.4, are described in detail in *Approved Sitewide Release Criteria for Remediation of Radiological Facilities at the SSFL* (Boeing, 1998). The lower of the two radionuclide-specific DCGLs (shaded in Table 2.4) were used as the project action levels for soil sample results analyzed by the off-site laboratory. The individual DCGLs were only used for biased and ARAR-based radionuclides (Th, and U). Otherwise, the ^{137}Cs result was compared to the $DCGL_{Cs,mod}$.

Surface soil sample results analyzed by the off-site laboratory were compared to the $DCGL_{Cs,mod.}$ of 4.7 pCi/g (^{137}Cs). This value is the DCGL for ^{137}Cs modified to account for the other hard-to-detect or less abundant radionuclides of concern. It was calculated as a fraction of the $DCGL_{Cs,mod}$ used during the RMHF Perimeter Survey (CABRERA, 2006a), since the DCGL value for ^{137}Cs was revised downward for this investigation. The $DCGL_{Cs,mod}$ used during the RMHF Perimeter Survey (7.15 pCi/g) was multiplied by the ratio of the Boeing DCGL and Environmental Protection Agency (EPA) preliminary remediation goal (PRG) for residential soil at the 10-4 risk level (See Table 2.4) for ^{137}Cs ($6 \div 9.2 \times 7.15$).

The scan MDC of 3.7 pCi/g (see Section 4.3.1) was adequate to identify small areas of elevated activity less than the $DCGL_{Cs,mod}$.

Table 2.4 – DCGLs for Radionuclides of Concern

Constituent		***Residential Soil Concentration (pCi/g)***	
		Boeing DCGL[1]	*EPA PRG 10-4 Risk Level*[2]
Americium-241	(^{241}Am)	**5.44**[3]	187
Cobalt-60	(^{60}Co)	**1.94**	4
Cesium-134	(^{134}Cs)	**3.33**	16
Cesium-137	(^{137}Cs)	9.2	**6**
Europium-152	(^{152}Eu)	4.5	**4**
Europium-154	(^{154}Eu)	**4.1**	5
Manganese-54	(^{54}Mn)	**6.1**	69
Plutonium-238	(^{238}Pu)	**37.2**	297
Plutonium-239	(^{239}Pu)	**33.9**	259
Plutonium-240	(^{240}Pu)	**33.9**	-
Plutonium-241	(^{241}Pu)	**230**	40,600
Strontium-90	(^{90}Sr)	36	**23**
Thorium-228	(^{228}Th)	**5**	15
Thorium-232	(^{232}Th)	**5**	**5**
Uranium-234	(^{234}U)	**30**	401
Uranium-235	(^{235}U)	30	**20**
Uranium-238	(^{238}U)	**35**	74

1. Source: Boeing, 1998
2. Source: Based on EPA preliminary remediation guides (PRGs) for residential soil at a 10-4 risk level. OSWER 9355.01-83A. "Distribution of OSWER Radionuclide Preliminary Remediation Goals (PRGs) Superfund Electronic Calculator." February 7, 2002. http://epa-prgs.ornl.gov/radionuclides. Data retrieved October 26, 2006.
3. More restrictive standard for each constituent is bolded and shaded.

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3.0 SITE CHARACTERIZATION AND REMOVAL ACTION

The planned scope of the survey was revised based on initial GWS measurements, in accordance with the decision rules shown in Table 1.1. The revised scope designated the initial data as site characterization, and included a removal action. Sections 4 through 8 of this report, describe the final status survey that was performed after the characterization and removal activities.

3.1 Site Characterization

On November 30, 2007, a GWS of 100% of accessible areas was performed at Site 4614. The results of this survey showed large areas of elevated gross gamma readings in two areas of the sites (see Figure 3.2). The decision rules (see Table 3.1-1) required collection of biased surface soil samples. Ten soil samples were collected and analyzed by on-site gamma spectroscopy measurements (provided by Boeing). The results ranged from 1.1 to 9.0 pCi/g of ^{137}Cs. The first sample was near the top of the drainage channel and had a concentration of 2.2 pCi/g. Samples 2 – 6 were in the northern corner of the buffer zone and ranged from 3.0 to 9.1 pCi/g. Sample number six had estimated coordinates due to an error which occurred when recording the actual coordinates. The estimated location is known to have been between locations 5 and 7, which is where it was placed in Figure 3.2. Samples 7 – 10 were outside of the planned survey unit 20 in a drainage swale, running in a northerly direction outside the boundary of the survey unit and down a hill. Samples 7 – 10 ranged from 1.1 to 5.2 pCi/g ^{137}Cs, which are below the project approved DCGL. This area was not included within the final status surveys performed for survey units 19 and 20. The results of the onsite analysis of soil samples (see Table 3.1-2) resulted in a decision by the Boeing PM to perform a removal action.

Table 3.1-1 – Summary of Decision Rule Implementation

Parameter of Interest	***Criteria***	***Action Taken***
Gross Gamma Walkover		
Presence of Contamination	Area with z-score greater than 3.0 is identified.	Two areas with z-score > 3 were identified (see Figure 3.2)
	A gross gamma result is the highest result in a survey unit.	Not applicable. Biased surface samples were collected (see below)
Small Area of Elevated Activity – Highest and Biased Investigation		
Presence of Contamination	Gamma spectroscopy results for a surface soil sample do not exceed project action levels.	Not applicable. On-site gamma spectroscopy results revealed samples with results above the action level.
	Gamma spectroscopy results for a surface soil sample exceed project action levels.	The Boeing PM initiated a removal action.

Table 3.1-2 –Results of On-Site Soil Sample Analyses

Sample Number	Northing	Easting	Result (pCi/g)
1	581644	1934436	2.2
2	581644	1934401	3.1
3	581646	1934402	9.0
4	581648	1934404	6.2
5	581650	1934405	5.1
6	581653	1934407	4.1
7	581657	1934406	1.1
8	581663	1934407	0.0
9	581671	1934408	5.2
10	581678	1934417	5.1

3.2 Removal Action

Between December 7 and 8, 2006, a removal action was coordinated and performed by Boeing personnel to remove radiologically contaminated surface soil at Site 4614. A total of 346 cubic feet of soil was removed from two locations within the site (see Figures 1.2, 1.3 and 3.2). The majority of the soil was taken from the northern corner of the site. A small amount was taken from the top of the drainage channel. The materials were transferred to the RMHF for proper packaging and disposal.

The suspected source of the ^{137}Cs contamination near the top of the drainage channel was either a patch of contaminated asphalt, or soil that became contaminated prior to the application of the asphalt layer (since the asphalt that was removed was not surveyed, the actual source of the contamination could not be determined). The contaminated area in the drainage channel was first identified during a GWS during the RMHF Perimeter Survey (Cabrera, 2006a). As a result of the elevated results, the drainage channel was excluded from the RMHF Perimeter Survey for resurvey at a later date, which was included as part of the scope of this survey.

The origin of the contamination in the Class 3 buffer zone is suspected to be soil removed from the pond during excavation of the asphalt, and physically relocated to the area where it was identified during this survey. The survey unit was reclassified as Class 1 based on this removal action.

4.0 SUMMARY OF FINAL STATUS SURVEY ACTIVITIES

The area of interest was divided into two survey units. Gross gamma walkover surveys were performed and surface soil samples were collected and analyzed. Two subsurface soil samples were also collected and analyzed. Based on the results, the decision rules were applied and additional biased samples (based on GWS) were collected as required by decision rules. No additional surface samples or changes to the survey design were necessary; however, the Class 3 survey unit at 4614 was re-classified as Class 1 based on the removal action performed in this area.

4.1 Survey Units

Survey units were assigned to discrete geographical regions within each site for the purpose of planning appropriate survey designs. The following sections describe general features of each survey unit, the planned classification of each, and any changes made during the course of the investigation.

4.1.1 Survey Unit Descriptions

The areas of concern were the two survey units located in Area IV of the SSFL. Site 4614 is the location of the former RMHF holdup pond (3,693 ft^2), with a surrounding buffer zone (5,107 ft^2). Site 4614 was not graded, backfilled or landscaped since the removal of asphalt prior to the start of this project. The area of concern was divided into two survey areas, or survey units, numbered 19 and 20 (see Table 4.1). As originally planned, the survey units included impacted areas where potential for radioactive contamination exists (survey unit 19, Class 1), or impacted areas not expected to contain any residual radioactivity (survey unit 20, Class 3).

Table 4.1 – Survey Unit Classification

Survey Unit Number	*Site Number*	*Initial MARSSIM Classification*	*Final MARSSIM Classification*	*Planned Size (square feet)*	*Actual Size (square feet)*
19	4614	Class 1	Class 1	9,000	3,693
20	4614	Class 3	Class 1	9,000	5,107

*Shaded cells indicate changes to the survey design.

4.1.2 Survey Unit Changes and Reclassification

The initial survey unit sizes were based on the estimated size of the holdup pond. The boundary of the pond was staked, while the surrounding buffer zone extended to the limit of brush clearing. The perimeter of each survey unit was walked using a global positioning system (GPS), which recorded a sufficient number of points to define the survey unit boundaries. The final boundaries are shown in Figure 4.1.

The size of each survey unit is shown in Table 4.1. The actual size of the survey units was smaller than initially estimated by Boeing. The entire pond and surrounding buffer zone were surveyed, therefore the changes to the survey design (in terms of square footage) were considered to be acceptable.

The planned classification of each survey unit (see Table 4.1) was based on expected soil concentrations of the radionuclides of concern. Class 1 survey units are areas that had a potential for radioactive contamination prior to remediation. Class 3 survey units were not expected to contain any residual radioactivity. The pond and drainage channel were assigned as Class 1, while the buffer zone was initially assigned as Class 3. These assignments were reasonable based on the historical site assessment and coverage with asphalt. The site characterization data revealed gross gamma results with large areas of elevated activity, as well as on-site laboratory data exceeding the project $DCGL_{Cs,mod}$. Based on these data the Class 3 survey unit was reclassified as Class 1. As a result, the survey design was reviewed for adequacy.

Survey unit 20 was scanned at 100% coverage of accessible areas following the removal of radiologically contaminated soil. The retrospective power curve (Figure 5.18) showed that survey unit 20 was planned with an adequate number of soil samples (see Section 5.5.3). The only other change that could have been made would have been to assign the soil sample locations based on a random start triangular grid rather than a random grid. Review of the map of sample locations (see Figure 4.1) shows the samples were already spaced approximately equal distance from each other.

Based on this review, it was concluded that additional sampling efforts would not have been beneficial to improving the estimate of average activity within the second Class 1 survey unit. The characterization data adequately identified the extent of the areas of elevated activity, and the final status survey design was adequate for evaluating compliance with the release criterion for unrestricted use.

4.2 Sampling and Analysis Methods

Gross gamma measurements were performed and surface soil samples were collected in each survey unit and analyzed to verify the presence (or confirm the absence) of radioactive contamination and its nature and lateral extent. Two subsurface soil samples were collected to support the assumption that contamination was restricted to the first 0.5 feet bgs. Radiological data were collected in accordance with CABRERA radiological procedures as described in the FSP (CABRERA, 2006b). As part of the QC activities, instruments were checked on a daily basis and response found to be acceptable prior to their use (see Appendix C).

4.2.1 Gross Gamma Walkover Survey

Gross gamma walkover survey data were collected using a Ludlum Model 2221 scaler/ratemeter with a Ludlum Model 44-20 3 inch × 3 inch sodium iodide (NaI) gamma scintillation detector. The detector was suspended at a height of approximately 15 centimeters (cm) above the ground and moved in parallel lines 0.5 meters apart at a speed of 0.5 meters per second. The measurements were position correlated using a Trimble TDC1 GPS. Data were automatically logged with the measurement coordinates using the GPS. The GPS link tied survey data to spatial locations using state plane coordinates North American Datum (NAD) 1983, State Plane California V0405. The GPS was checked daily to ensure accuracy and repeatability (see Appendix C).

4.2.2 Soil Sample Collection

Surface soil was collected over an area of 100 cm^2 to a depth of approximately 0.5 ft at each sample location. Visually identifiable non-soil components such as stones, twigs, and foreign objects were manually separated from the sampled soil. The sampled soil was mixed to homogenize it and approximately 1,000 grams of soil was collected in a one-gallon plastic bag. The container was labeled with the sample identification (ID), date and time of collection, and initialed by the surveyor. The samples were shipped to an off-site laboratory for analysis by gamma spectroscopy, liquid scintillation analysis, and alpha spectrometry.

Subsurface soil samples were excavated using a hand auger and processed as described above.

4.2.3 Exposure Rate Measurements

Exposure rate measurements were performed as a qualitative health and safety check at all sample locations using a Ludlum® Model 19 MicroR meter, which was source checked daily (see Appendix C). The detector was positioned approximately one meter above the sample location and allowed to stabilize prior to recording the measurement. Results for biased sample locations (which would be expected to have the highest readings) are shown in Table 4.2. Both results were 17 microRoentgens per hour (μR/hr). Daily QC readings in a low background area averaged 8 μR/hr. Readings in other areas of the SSFL ranged from 15 to 17 μR/hr (Cabrera 2007). Based on these readings, neither health and safety issues nor unusual exposure rate conditions were determined to exist. The results are provided for informational purposes only and cannot be readily correlated with reported radionuclide concentrations at the given sample location.

Table 4.2 – Exposure Rate Measurements Summary

Site	*Biased Sample Number*	*Date/Time of Reading*	*Reading (μR/hr)*
4614	19SSS03000	12/14/07 10:35	17
4614	20SSS01600	12/14/07 10:45	17

4.2.4 Off-site Laboratory Analysis of Surface Soil Samples

The soil samples were double bagged in one-gallon Zip Lock® bags, numbered, logged, and transferred to the off-site laboratory for further analysis. The off-site laboratory, Severn Trent Laboratories (St. Louis, Missouri), is certified by a state that is authorized to provide National Environmental Laboratory Accreditation Program (NELAP) certification. A chain of custody form was used to transfer custody of the sample to the off-site laboratory.

The off-site laboratory performed gamma spectroscopy analysis of the soil samples. Samples were also analyzed for uranium and plutonium isotopes by alpha spectroscopy as well as radionuclide-specific ^{90}Sr by gas proportional beta and ^{241}Pu analysis by liquid scintillation. Duplicates, laboratory control samples (LCS), and blanks were performed as part of the off-site laboratory QC activities (see Section 6.2 and Appendix C).

4.3 Survey Data Collection

The survey was designed to provide sufficient data to support a release decision for MARSSIM Class 1 survey units, or to determine if additional data were required prior to making a release decision for each survey unit. The gross gamma walkover survey was performed to identify the potential presence of small areas of radioactive contamination. Surface soil samples were collected on either a random-start systematic grid (Class 1) or randomly (buffer zone) to provide an estimate of the average radionuclide concentrations in each survey unit. Additional samples were collected at biased sample locations which were selected based on the results of the gross gamma walkover survey. Two subsurface soil samples were collected.

4.3.1 Gross Gamma Walkover Survey

The gross gamma walkover survey was designed to cover 100% of the accessible areas in each Class 1 survey unit, and at least 10% of the buffer zone. Due to the small coverage area and high degree of accessibility, the actual coverage was 100% in both units. Inaccessible areas such as the stormwater holdup tank and concrete drainage channel (which were within the planned boundaries of the buffer zone) were not surveyed and appear as gaps in the survey coverage. Figures 1.2 and 1.3 show photos of these obstructions.

The *a priori* scan MDC of 3.7 pCi/g was calculated using Microshield® in accordance with methods described in MARSSIM. The calculation is based on a normalized 1 pCi/g of ^{137}Cs in soil with density of 1.6 grams per centimeter cubed (g/cm^3), using a 3 × 3 inch NaI detector suspended at a height of 15 cm. Discussion of the GWS MDC based on *a posteriori* results is located in Section 6.1.3.

The GWS was performed in the field by suspending the 3 × 3 inch NaI detector a height of 15 cm above the surface of the soil, and moving the detector in parallel lines spaced 1 meter apart, at a walking speed of 0.5 meters per second. A height of 10 cm was specified in the FSP (CABRERA, 2006b); however, this value was not consistent with the assumptions used in the scan MDC calculation and a value of 15 cm was used instead. This change to the work plan was considered necessary and acceptable.

4.3.2 Surface Soil Samples

The survey design required a minimum of 15 surface soil sample locations in survey unit 20, and a minimum of 29 surface soil sample locations in the survey unit 19. The sample locations, shown in Figure 4.1 for the respective survey units, were selected based on a random-start systematic (triangular) grid (survey unit 19), or random locations (survey unit 20). The minimum number of samples collected from each survey unit was based on the $DCGL_{Cs,mod}$ of 4.7 pCi/g ^{137}Cs and was calculated in the FSP (Section 4.4.3) using MARSSIM guidance. The surface area of each Class 1 survey unit was used to calculate the sample spacing for the triangular grid. The actual sample locations were determined in the field using the programmed GPS coordinates of the selected sample locations. A total of 44 surface soil samples were collected from either random-start systematic or random locations. Two biased samples were collected based on the results of the GWS, one sample in each survey unit.

4.3.3 Subsurface Soil Samples

Two subsurface soil samples were planned and collected to check the assumption that any residual radioactivity would be located in the top six inches of soil. One was collected near the top of the drainage channel, and the other was collected near the center of the pond. Both of these samples were at depths of one foot bgs.

4.4 Real-Time Implementation of Decision Rules

Gross gamma walkover survey data was used to provide real-time implementation of the decision rules, given in Table 1.1, to determine if additional data were required. Where potential radioactive contamination was identified, additional surface soil samples were collected and analyzed to verify its presence (or confirm its absence) and to define its nature and lateral extent. Where no potential contamination was identified, no additional data were collected.

4.4.1 Gross Gamma Walkover Survey Data Evaluation

Gross gamma walkover survey data (i.e., gross gamma count rate data logged using the GPS) were utilized to identify biased sample locations. Count rate data were evaluated by survey unit. The data were evaluated with EDA (i.e., CFDs, summary statistics, and z-score calculation) prior to presentation as color-coded contour plots for biased sample selection. The following description generally presents the data evaluation and biased sample selection process.

Data files were plotted on a cumulative frequency diagram (see Appendix A) to obtain information on the general shape of the data distribution. Figure 4.2 shows the plotted data file from Site 4614. The plot reveals one distinct population with no outliers. The straight-line data represents the background count rate (i.e., non-hot spot) relative to the survey unit. Any outliers would be apparent on the right side of the plot in a pattern that deviates upward from the straight-line data. This site yielded results consistent with a normal background distribution.

Gross gamma count rate data from the relative background population were used to calculate an average and a standard deviation. The standard deviation was used to compute z-scores (number of standard deviations from the mean), which were used to create map contours. A z-score contour greater than 3.0 was used as an action level indicating elevated gamma radiation levels. Approximately 0.135% of normally distributed data are expected to exceed a z-score of 3.0.

A contour map of the overall survey area was created once z-scores were calculated. The contouring process involves creating a regularly spaced grid and assigning values to every spot on the grid. The grid spacing and the values assigned at the grid nodes determine what the contour plot looks like. Grid node values are assigned using a weighted average based on the inverse square law, which is generally used to describe how radiation levels drop off with distance from a source. Once the grid is complete, contour lines are drawn to connect the dots with the same values.

The results of the gross gamma walkover survey in z-score contours is represented in Figure 4.3. The four color divisions represent various ranges of z-score values with red being the highest values, followed by green, then light blue, with dark blue being the lowest values.

The contour maps were used to select biased sample locations from z-score contours greater than 3.0 (see Figure 4.3). A small area with z-scores greater than 3.0 was identified in the northern portion of the survey unit 20 in the area of the removal action. One bias sample was collected from this area. No contours greater than 3.0 were identified in survey unit 19, so one biased sample location was selected at the point of the highest gross gamma count rate. GPS data were used to locate each biased sample location (northing and easting point) in the field. A total of 2 samples were collected from biased sample locations at Site 4614.

4.5 Subsequent Implementation of Decision Rules

The off-site laboratory analysis of soil samples by gamma spectroscopy was used to determine whether radionuclide-specific analysis for hard-to-detect radionuclides of concern would be performed, and for final status when the SOF results were below the DCGL.

4.5.1 Off-site Laboratory Analysis

The off-site laboratory performed gamma spectroscopy, alpha spectrometry (isotopic uranium and plutonium), liquid scintillation counting (^{241}Pu), and gas flow proportional counting (^{90}Sr) of the surface soil samples. None of the 48 samples exceeded the project action level for ^{137}Cs. Therefore, no additional sampling was required.

Analysis for ^{228}Th and ^{232}Th were accomplished by gamma spectroscopy analysis for Actinium-228 (^{228}Ac), rather than by separate alpha analyses. The alpha analysis performed during a previous investigation (CABRERA, 2006a) showed that a separate alpha analysis was unnecessary because these components of the thorium natural decay series are in equilibrium at SSFL. Therefore, ^{228}Ac can be used as a surrogate for estimating the concentration of ^{228}Th and ^{232}Th.

4.5.2 Radionuclide-Specific Analyses for Other Activation Products

The gamma spectroscopy analysis performed by the off-site laboratory did not detect ^{60}Co above the MDC in any of the surface soil samples. Since ^{60}Co was not detected above the MDC, radionuclide-specific analyses for other activation products (^{55}Fe, ^{59}Ni, and ^{63}Ni) were not performed.

4.6 Summary of Decision Rule Implementation

A summary of the results of the implementation of the decision rules established in the survey design is presented in Table 4.6.

Table 4.6 – Summary of Decision Rule Implementation

Parameter of Interest	***Criteria***	***Action Taken***
Gross Gamma Walkover		
Presence of Contamination	Area with z-score greater than 3.0 is identified.	One biased sample location selected for sampling from areas with z-score greater than 3.0 (survey unit 20).
	A gross gamma result is the highest result in a survey unit.	One biased sample location was selected where the z-score did not exceed three, and the highest gross gamma result was used instead (survey unit 19).
Small Area of Elevated Activity – Highest and Biased Investigation		
Presence of Contamination	Gamma spectroscopy results for a surface soil sample do not exceed project action levels.	None of the gamma spectroscopy results for highest or biased samples exceeded the project action levels, so no further action was taken.
	Gamma spectroscopy results for a surface soil sample exceed project action levels.	None of the gamma spectroscopy results for highest or biased samples exceeded the project action levels, so no further action was taken.
Average Radionuclide Activity Concentration		
Average survey unit Radioactivity	The ^{137}Cs concentration for all systematic sample results from the off-site laboratory is less than 4.7 pCi/g in a survey unit.	None of the average ^{137}Cs results within a survey unit exceeded the project action level of 4.7 pCi/g.

Parameter of Interest	***Criteria***	***Action Taken***
	The ^{137}Cs concentration for any systematic sample results from the off-site laboratory exceeds 4.7 pCi/g in a survey unit.	None of the average ^{137}Cs results within a survey unit exceeded the project action level of 4.7 pCi/g.
	A survey unit is uniformly contaminated.	No survey unit identified as uniformly contaminated; therefore, no action taken.
	A small area of elevated activity is identified within a survey unit.	No small areas of elevated activity were identified within a survey unit; therefore, no action taken.
	The ^{60}Co concentration for any systematic sample results from the off-site laboratory exceed the MDC.	No ^{60}Co concentration exceeded MDC; therefore, no option was presented to the Boeing Project Manager (PM) to perform analysis for the presence of hard-to-detect activation products.
SOF		
	Any ^{137}Cs result within a survey unit exceeds the $DCGL_{Cs,mod}$	None of the ^{137}Cs results exceeded the $DCGL_{Cs,mod}$, therefore, no further action was taken.

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5.0 SURVEY RESULTS

Four types of measurements were performed as part of the survey:

- Gross gamma walkover measurements,
- Gamma spectroscopy of surface soil samples,
- Alpha spectrometry of surface soil samples for uranium and plutonium isotopes, and
- Radionuclide-specific analyses for ^{90}Sr, and ^{241}Pu.

These measurement techniques were selected based on the radionuclides of concern assuming surface soil as the media to be measured or sampled. Exposure rate measurements were also collected for health and safety purposes (see Section 4.2.3). The GWS was used to provide near real-time feedback for confirming the presence and defining the nature and lateral extent of gamma-emitting radioactivity. Decision rule implementation using near real-time feedback is addressed in Section 4.4. The off-site laboratory performed gamma spectroscopy and alpha spectrometry analyses of the soil samples. Radionuclide-specific analyses for ^{90}Sr, and ^{241}Pu were also performed by the off-site laboratory to identify and measure these beta-emitting radionuclides of concern.

5.1 Data Quality Assessment

Survey data were verified to be authentic, appropriately documented, and technically defensible. Specifically, the following conclusions were made:

- The instruments used to collect the data were capable of detecting the radiation types and energies of interest at or below project action levels and/or the target MDCs.
- The calibration of the instruments used to collect the data was current and radioactive sources used for calibration were traceable to the National Institute of Standards and Technology (NIST).
- Instrument response was checked before and, where required, after instrument use each day data were collected.
- The MDCs and the assumptions used to develop them were appropriate for the instruments and the survey methods used to collect the data.
- The survey methods used to collect the data were appropriate for the media and types of radiation being measured.
- The custody of samples collected for off-site laboratory analysis was tracked from the point of collection until final results were obtained.
- The survey data consist of measurement results that are representative of the area of interest and collected as prescribed by the survey design.

5.2 Data Analyses by Radionuclide

EDA was performed on the off-site laboratory analysis data to identify radionuclide distribution trends and potential outliers. EDA included visual inspection of measurement results using posting plots, CFDs, histograms, and calculation of statistical quantities including mean, median, standard deviation, and range. The complete off-site laboratory analysis results are found in Appendix B, while EDA files are found in Appendix A.

Based on the evaluation of the combined project data set, potential outliers were identified for several radionuclides. None of these outliers exceeded their respective DCGL. These radionuclides were: ^{137}Cs, ^{238}Pu, $^{239/240}Pu$, ^{241}Pu, ^{90}Sr, ^{234}U, $^{235/236}U$, and ^{238}U. These radionuclides are discussed individually in the sections below. CFDs and frequency plots for each of these radionuclides are shown in Figures 5.1 – 5.16. CFDs and frequency plots for the remainder of the radionuclides of concern are provided in Appendix A.

Summary statistics by radionuclide are provided in Table 5.6 below for both random-start systematic, random, and biased samples. Results are reported as pCi/g dry weight.

Table 5.2 – Summary Statistics by Radionuclide

Includes Systematic, Random and Biased Samples

Radionuclide	*Analysis Method*	*Samples Reported*	*Samples Exceeding DCGL*	*Reported Activity (pCi/g)*				*Average MDC (pCi/g)*
				Average	*Standard Deviation*	*Maximum*	*Minimum*	
Americium-241	901.1 MOD	48	0	0.013	0.044	0.14	-0.084	0.18
Cesium-134	901.1 MOD	48	0	-0.0056	0.025	0.034	-0.085	0.073
Cesium-137	901.1 MOD	48	0	0.47	0.53	2.1	-0.005	0.099
Cobalt-60	901.1 MOD	48	0	-0.00054	0.023	0.051	-0.051	0.096
Europium-152	901.1 MOD	48	0	-0.021	0.044	0.090	-0.10	0.15
Europium-154	901.1 MOD	48	0	-0.024	0.17	0.28	-0.49	0.10
Manganese-54	901.1 MOD	48	0	0.0085	0.026	0.072	-0.045	0.090
Plutonium-238	A-01-R MOD[2]	48	0	0.0027	0.010	0.039	-0.026	0.041
Plutonium-239/40	A-01-R MOD	48	0	0.0021	0.013	0.076	-0.026	0.029
Plutonium-241	STL-RC-0245[3]	48	0	-0.49	0.8	1.0	-2.8	3.5
Strontium-90	905 MOD[4]	48	0	0.35	0.28	1.3	-0.010	0.59
Thorium-228, 232[6]	901.1 MOD	48	0	1.2	0.17	1.5	0.63	0.35
Uranium-234	A-01-R MOD	48	0	0.98	0.22	1.7	0.67	0.048
Uranium-235/236	A-01-R MOD	48	0	0.056	0.031	0.19	0.0090	0.041
Uranium-238	A-01-R MOD	48	0	0.86	0.16	1.5	0.51	0.038

[1]Gamma Spectroscopy
[2]Alpha Spectroscopy
[3]Liquid Scintillation Counting
[4]Gas Flow Proportional Counting
[5]Distillation and Liquid Scintillation Counting
[6]As identified by ^{228}Ac.

5.2.1 Gamma Spectroscopy Results

Surface soil samples were analyzed by gamma spectroscopy. The gamma spectroscopy analysis library included the radionuclides of concern and is included with reported data in Appendix B.

No samples reported concentrations of ^{137}Cs above the $DCGL_{Cs,mod}$ of 4.7 pCi/g. The population is skewed towards a maximum value of 2.1 pCi/g (see Figures 5.1 and 5.2). The average and maximum are 0.47 and 2.1 pCi/g, respectively. The distribution is not consistent with a normally distributed background population.

Cesium-137 was detected above the MDC (0.1 pCi/g) in 36 samples. The highest result was 2.1 pCi/g in sample 19SSS02700 (surface soil sample from location 027 in survey unit 19, located at the eastern end, or top, of the drainage channel close to the RMHF).

All of the other radionuclides of concern that were analyzed by gamma spectroscopy showed a distribution consistent with a normally distributed background population, with no outliers. Figures showing the CFDs and frequency plots are provided in Appendix A.

5.2.2 Alpha Spectrometry Results

Surface soil samples were analyzed by alpha spectrometry for uranium and plutonium isotopes. All of the samples reported concentrations for the naturally occurring isotopes ^{234}U and ^{238}U above the MDC. Two samples of $^{235/236}$U were reported above the MDC, one of which was considered an outlier based on the CFD (see Figure 5.7) and histogram (see Figure 5.8). This sample (20SSS00100) was also elevated for ^{137}Cs although the result was below the $DCGL_{Cs,mod}$.

One sample containing ^{238}U was considered to be an outlier, although it was below its DCGL (see Figures 5.5 and 5.6). This sample was also an outlier for ^{90}Sr (19SSS02500). Since the maximum values were below the DCGLs for these radionuclides, additional sampling was not performed.

Three samples were identified as potential outliers for plutonium isotopes: one for $^{239/240}$Pu (20SSS00600) and two for ^{238}Pu (19SSS02600, 20SSS00300, see Figures 5.9 – 5.11). One sample result exceeded (0.076 pCi/g) the average MDC (0.029 pCi/g) for the $^{239/240}$Pu analytical method. No sample results exceeded the average MDC (0.041 pCi/g) for the ^{238}Pu analytical method. None of these samples exceeded their respective DCGL, and were not investigated further.

No analyses were performed for ^{242}Pu, which was used as a tracer for off-site laboratory analysis.

5.2.3 Results of Radionuclide-Specific Analyses for ^{90}Sr and ^{241}Pu

Surface soil samples were analyzed by gas proportional beta analysis for ^{90}Sr and liquid scintillation analysis for ^{241}Pu. No samples reported ^{241}Pu above the MDC, however, two were identified as potential outliers (19SSS01800, 1.0 pCi/g; 19SSS02700, 1.0 pCi/g, see Figures 5.13 and 5.14). Otherwise the ^{241}Pu data are consistent with a normally distributed background population. The outliers were below the DCGL for ^{241}Pu and were not investigated further.

Two of the samples reported ^{90}Sr concentrations above the MDC. The average concentration of ^{90}Sr was 0.35 ± 0.28 pCi/g. The ^{90}Sr data are skewed towards a maximum value of 1.3 pCi/g with at least five potential outliers (see Figures 5.15 and 5.16). The ^{90}Sr results were all well below the DCGL.

5.2.4 Uranium Enrichment Ratio Calculations

The $^{234}U/^{238}U$ ratio was analyzed for potential ^{235}U enrichment or depletion different from natural soil composition, which would be indicative of uranium contamination. The $^{234}U/^{238}U$ ratio for naturally occurring uranium is approximately 1.0. Analysis of the project $^{234}U/^{238}U$ sample results showed an average ratio of approximately 1.0 which is indicative of natural uranium. Individual ratios for each sample location are within this ratio at the 95% confidence level and represent natural soil composition as shown in Figure 5.2. Thus, no uranium contamination was identified.

5.3 Off-site Laboratory MDCs - Target vs. Achieved

Target MDC values, given in Table 5.3, were established in the FSP (CABRERA, 2006b) and assumed a sample size of 500 grams and a count time of 120-300 minutes. MDCs for gamma-emitting radionuclides were based on achieving 10% of the ^{137}Cs DCGL or less.

The average MDC for all radionuclides was less than the target MDC, and none of the MDCs exceeded 10% of the associated DCGL. A total of 14 analyses reported MDCs greater than the target MDC. Thirteen of these were for ^{137}Cs (target MDC 0.1 pCi/g, range 0.11 – 0.15 pCi/g), and one for ^{234}U (target MDC 0.1 pCi/g, measured MDC 0.11 pCi/g). No data were rejected based on these findings.

Table 5.3 – Target vs. Achieved Off-site Laboratory MDCs

Constituent	Analysis Method	No. Samples results > Target MDC	Target MDC	Samples Reported	Achieved MDC (pCi/g)		
					Average MDC	Max MDC	Minimum MDC
Americium-241	901.1 MOD[1]	0	2.5	48	0.18	0.21	0.14
Cesium-134	901.1 MOD	0	0.3	48	0.073	0.094	0.051
Cesium-137	901.1 MOD	36	0.1	48	0.099	0.15	0.062
Cobalt-60	901.1 MOD	0	0.2	48	0.096	0.13	0.051
Europium-152	901.1 MOD	0	1	48	0.15	0.18	0.11
Europium-154	901.1 MOD	0	1.3	48	0.10	0.12	0.080
Manganese-54	901.1 MOD	0	0.5	48	0.090	0.11	0.071
Plutonium-238	A-01-R MOD[2]	0	0.1	48	0.041	0.088	0.019
Plutonium-239/40	A-01-R MOD	0	0.1	48	0.029	0.069	0.012
Plutonium-241	STL-RC-0245[3]	0	20	48	3.5	8.2	1.6
Strontium-90	905 MOD[4]	2	1	48	0.59	1.0	0.35
Thorium-228, 232[5]	901.1 MOD	39	1	48	0.35	0.83	0.22
Uranium-234	A-01-R MOD	48	0.1	48	0.048	0.11	0.020
Uranium-235/236	A-01-R MOD	2	0.1	48	0.041	0.079	0.011
Uranium-238	A-01-R MOD	48	0.1	48	0.038	0.080	0.0090

[1]Gamma Spectroscopy
[2]Alpha Spectroscopy
[3]Liquid Scintillation Counting
[4]Gas Flow Proportional Counting
[5]As identified by ^{228}Ac.

5.4 Data Evaluation by Survey Unit

None of the sample results exceeded their respective DCGLs for any radionuclide at either of the two survey units.

A total of 48 soil samples were collected from 29 random-start systematic locations, 15 random locations, and two biased locations based on results of the GWS. The total of 48 also includes the two biased subsurface samples.

Exploratory data analysis (EDA) was performed on the results of the off-site laboratory analysis of all samples to identify radionuclide distribution trends and potential outliers. EDA included visual inspection of results using posting plots, CFDs, histograms, and calculation of statistical quantities including mean, median, standard deviation, and range. The statistical comparisons and graphical representations of the data by survey unit are found in Appendix A. The summary statistics by survey unit for selected radionuclides are shown in Table 5.4. These radionuclides were selected based on the distribution of the CFDs (see Figures 5.1 and 5.15), which were not consistent with a normally distributed background population, but below the respective DCGL.

Table 5.4 – Survey Unit Sampling and Summary Statistics for Selected Nuclides

Site	***4614***	***4614***	***Total***
Class	1	1	
Survey Unit Number	19	20	
#Systematic Samples	29	0	29
#Random Samples	0	15	15
#Biased Surface Samples	1	1	2
#Biased Subsurf. Samples	2	0	2
Total	32	16	48
	^{137}Cs, pCi/g		
Average	0.40	0.60	0.47
Standard Deviation	0.48	0.62	0.53
Maximum	2.1	2.0	2.1
Minimum	-0.0050	0.070	-0.005
	^{90}Sr, pCi/g		
Average	0.38	0.29	0.35
Standard Deviation	0.29	0.26	0.28
Maximum	1.3	0.99	1.3
Minimum	0.020	-0.010	-0.010

5.4.1 Survey Units 19 and 20

Samples were collected from 29 random-start systematic sample locations in survey unit 19, and 15 random locations in survey unit 20. The GWS was performed over 100% of survey units 19 and 20, and the data were combined. Twenty-four out of 5,967 measurements exceeded a z-score of 3 (<1%). The highest GWS results in both survey units were investigated with biased surface soil samples (see Figures 4.1 and 4.3). Two subsurface samples were collected in survey unit 19 to support the assumption that contamination was limited to the first 0.5 feet bgs. None of the samples reported radionuclide concentrations above their respective DCGLs.

5.5 Statistical Test

The off-site laboratory analysis results for the random-start systematic surface soil samples were evaluated using the statistical tests in MARSSIM.

5.5.1 Sum-of-Fractions Calculations

Since there are multiple radionuclides of concern, the SOF was calculated for each sample by summing the concentration of each radionuclide of concern divided by its corresponding DCGL. The release criterion is met where the SOF is less than unity, as illustrated:

$$\frac{C_1}{DCGL_1} + \frac{C_2}{DCGL_2} + \ldots \frac{C_n}{DCGL_n} < 1$$

where:

C_n	=	Concentration of radionuclide n
$DCGL_n$	=	DCGL for radionuclide n

SOF calculations do not include ^{40}K (see Section 2.3). They also do not include Th, and U radionuclides (see Section 5.5.2).

None of the SOF calculations exceeded unity (1). The sum of fractions results are shown with all sample data in Appendix A.

5.5.2 Sign Test

The Sign test was applied to the random-start systematic and random sample data (non-biased). The Sign test assumes the data are independent random measurements and statistically independent. The Sign test is based on the hypothesis that the radionuclide concentration in the survey unit exceeds the DCGL. This is referred to as the null hypothesis. There must be sufficient survey data with radionuclide concentrations below the DCGL to reject the null hypothesis and conclude the radionuclide concentration in the survey unit does not exceed the DCGL. Normally, the Sign test is applied where the radionuclide of concern is not present in background. However, the Sign test may also be used if the radionuclide is present in background at a small fraction of the DCGL. In other words, background is considered insignificant. In this case, the background concentration of the radionuclide is included with the residual radioactivity (in other words, the entire amount is attributed to facility operations). Thus, the total radionuclide concentration (including background) was compared to the DCGL. This option was used since it was expected that ignoring the background concentration would not affect the outcome of the statistical test and makes the test conservative. The advantage of ignoring a small background concentration is that no background reference area is needed.

The Sign test was performed by survey unit for the radionuclides of concern using the SOF calculation (see preceding section). It was also performed for individual Th, and U radionuclides of concern. The Sign test was applied individually for these radionuclides because their DCGLs are based on DOE Applicable or Relevant and Appropriate Requirements (ARARs) and not on dose-based, Residual Radiation (RESRAD) derived soil concentrations.

The results of the SOF and ARAR Sign tests are summarized in Table 5.5-1. The test statistic S+ is the number of samples where the SOF is less than unity or where the sample concentration is below the DCGL. The critical value, from MARSSIM Appendix I.3, is the minimum number of such samples needed to reject the null hypothesis. The results of the individual radionuclides are presented in Appendix A.

Table 5.5-1 – Survey Unit SOF and ARAR Sign Test Results

Survey Unit	*Number of Samples*	*S+, SOF*	*S+, ^{228}Th*	*S+, ^{232}Th*	*S+, ^{234}U*	*S+, $^{235/236}$U*	*S+, ^{238}U*	*Critical Value*	*Result*
19	29	29	29	29	29	29	29	19	PASS
20	15	15	15	15	15	15	15	11	PASS

The decision error rates α and β were established by the FSP (CABRERA, 2006b) at 0.05 (see Section 1.4.6). Since the test statistic S+ is greater than the critical value in all cases, sufficient statistical evidence exists to reject the hypothesis that the radionuclide concentration in the survey unit is greater than or equal to the DCGL for both survey units.

The four biased samples were treated by comparing the activity in each sample to its respective DCGL. None of the biased samples had activity exceeding the DCGLs, so no further investigation was performed.

5.5.3 Retrospective Power Analysis

A retrospective power analysis was performed as described in MARSSIM Appendix I.9. Normally it is performed only when the statistical test fails to reject the null hypothesis, since it demonstrates whether the number of samples collected provided sufficient statistical power to the test. Where the test concludes the null hypothesis can be rejected, the number of samples collected is moot. Basically, the power of the test (i.e., the probability of rejecting the null hypothesis) increases with increasing sample size and declines with increasing sampling variance. In all cases, the null hypothesis was rejected.

The utility of a retrospective power analysis is found in verifying a sufficient number of samples were collected in the event a statistical test is not performed. The statistical test provides no useful information when all of the sample results are less than the DCGL. The probability of rejecting the null hypothesis is always 100% and the question regarding whether a sufficient number of samples were collected will remain unless answered by a power analysis.

Calculation assumptions used to construct the power analysis, given in Table 5.5-2, are from the FSP (CABRERA, 2006b) and are based on the concentration of ^{137}Cs in the surface soil.

Table 5.5-2 – Retrospective Power Analysis Assumptions

Parameter	*Value, 19*	*Value, 20*
^{137}Cs $DCGL_{Cs,mod}$	4.7 pCi/g	4.7 pCi/g
Assumed Standard Deviation (σ)	2.35 pCi/g	1.84 pCi/g
Lower Bound of Gray Region (LBGR)	2.35 pCi/g	0.92 pCi/g
False Positive Decision Error (α)	0.05	0.05
False Negative Decision Error (β)	0.05	0.05

The results, shown in Table 5.5-3, indicate that the number of samples collected per survey unit was greater than the minimum number required to assure sufficient statistical power to the test. This is expected since the actual standard deviations are less than the standard deviation assumed in the survey design upon which the number of samples to be collected was based.

Table 5.5-3 – Retrospective Power Analysis by Survey Unit

Analysis Parameter	***19***	***20***
Actual Std Dev (pCi/g), ^{137}Cs	0.49	0.61
Required Number	14	14
Number Collected	29	15
Result	Pass	Pass

A retrospective power curve for survey units 19 and 20 are shown in Figures 5.17 and 5.18. The curve shows the probability of rejecting the null hypothesis versus the concentration of radioactivity. In the case of survey unit 19, where the average concentration is less than 1 pCi/g, the power is equal to approximately 1, providing a high degree of confidence that the decision to reject the null hypothesis was a correct one.

6.0 QUALITY CONTROL

Portable and laboratory instrumentation capable of detecting the radiation types and energies of interest were selected, calibrated, and maintained for survey data collection (see Appendix C). QC measures, discussed in the following sections, were implemented throughout the project to ensure data met known and suitable data quality criteria such as precision, accuracy, representativeness, comparability, and completeness.

Variables related to data precision and accuracy were monitored by field and laboratory response checks designed to monitor the performance of the instrumentation used to collect the data. Duplicate analyses were performed by the off-site laboratory and compared to verify key decision parameters (i.e., decision rule implementation).

The representativeness of the data was ensured by adherence to the survey design set forth in the FSP (CABRERA, 2006b) and the use of standardized data collection methods and techniques established in written procedures. Surveyors were trained on these documents, copies of which were maintained on-site and referenced as needed.

Routine monitoring of surveyor performance and environmental factors was performed to ensure data comparability. Where comparability issues were identified, measures were instituted to avoid future problems. Data were reviewed and, where necessary, discarded and re-collected.

The type and quantity of collected data were reviewed against survey design requirements to ensure data completeness.

6.1 Portable Instrumentation

Table 6.1 lists the types of portable instrumentation that were used during the course of this investigation. Calibration certificates are provided in Appendix D.

Table 6.1 – Portable Instrumentation

Instrument	*Detector*	*Detector Type*	*Radiation Type*
Ludlum Model 2221	Ludlum Model 44-20	3” x 3” NaI Scintillation	gamma
Ludlum Model 2360	Ludlum Model 43-93	Alpha/Beta Scintillation	alpha, beta
Ludlum Model 2929	Ludlum Model 43-10-1	Scintillation	alpha, beta
Ludlum Model 19	n/a	1” x 1” (NaI)Tl	gamma
Trimble TDC1 GPS	n/a	n/a	n/a

6.1.1 Calibration and Maintenance

Survey instruments were calibrated for the radiation types and energies of interest. Radionuclide mixture ratios and varying energies were accounted for during calibration by using a calibration source with a conservative average energy as compared to the weighted average energy of the radionuclide mixture. Radioactive sources used for calibration purposes are traceable to NIST.

6.1.2 Instrument Response

Survey instrument response was checked before and after instrument use each day. A check source was used that emitted the same type of radiation (alpha, beta, or gamma) as the radiation being measured and that gave a similar instrument response. The response check was performed using a specified source-detector alignment that could easily be repeated. Results within 20% of the expected values were considered acceptable. Expected values were calculated as the average of at least 10 initial checks of the instrument. If the instrument failed its response check, it was not used until the problem was resolved.

The Trimble GPS units were checked daily against a calibration point. The calibration point was selected upon commencement of fieldwork and consisted of a stable site feature unlikely to move during the project (e.g., fencepost, pavement intersection, etc.). Prior to initial GPS use, ten static positional readings were obtained at the calibration point. From these positional readings, a mean position was determined. Thereafter, the GPS units were checked against the calibration point at least daily. The acceptance criterion for GPS daily checks was within one meter of the calibration point, as calculated using the Pythagorean Theorem. GPS units exhibiting positional error in excess of one meter were not used until corrective action was taken.

6.1.3 Minimum Detectable Concentration

An MDC was determined using the methods described in MARSSIM for instruments used to perform the gross gamma walkover survey, as described in Section 5.1 of the FSP (CABRERA, 2006b). The scan speed, distance above ground surface, radionuclides of concern, and detector characteristics were considered in the calculation. The ^{137}Cs scan MDC for the gross gamma walkover survey was estimated to be 3.7 pCi/g. This value is approximately 90% of the project action level (i.e., the ^{137}Cs $DCGL_{Cs,mod}$). To evaluate whether the MDC was achieved, surface soil sample results for ^{137}Cs were reviewed.

No sample locations (both random-start systematic or biased) within Site 4614 were identified with ^{137}Cs concentrations above 2.1 pCi/g, which is the maximum value measured by the off-site laboratory. This sample point (19SSS02700) was in survey unit 19 near the top of the drainage channel. The GWS contour data (see Figure 4.3) did not identify this area as having z-score greater than 3.0 and the ^{137}Cs results was below the calculated instrument MDC. Sample 20SSS00100 had a concentration of 1.8 pCi/g and the contour data shows several isolated areas near this sample location where the z-score was greater than 3.0. This data was therefore inconclusive in determining whether the scan MDC was met.

Biased sample locations selected based on the gross gamma walkover survey data reported surface soil ^{137}Cs concentrations of 0.43 pCi/g (19SSS03000) and 1.4 pCi/g (sample 20SSS01600). No surface soil samples reported ^{137}Cs concentrations above the project action level in areas not previously identified by gross gamma walkover survey data, which provided confidence that the scan MDC was acceptable.

Preliminary GWS data at this site (prior to the removal action) revealed large areas having z-scores greater than 3.0. These areas were investigated with soil sampling and onsite analysis[1], from which the ^{137}Cs concentrations were found to be between 1.1 and 9.0 pCi/g. The GWS was therefore able to identify elevated areas with soil concentrations less than the scan MDC of 3.7 pCi/g, which provided confidence that the scan MDC was acceptable.

[1] Onsite analysis was provided by the Boeing Company's analytical laboratory using a high purity germanium detector. Soil samples consisting of approximately 500 - 1000 grams of sifted, dry soil were counted for 1000 seconds, and reported in pCi/g on a dry weight basis. Results were used during scoping surveys only.

6.2 Laboratory Instrumentation

Three types of QC samples were analyzed to evaluate laboratory performance:

- Duplicate samples to evaluate the reproducibility of counting equipment.
- Laboratory control samples to evaluate the accuracy of the measurements.
- Reagent blank samples to evaluate the potential for laboratory contamination.

One of each type of sample was analyzed for QC purposes for every 20 project samples analyzed off-site.

Table 6.2 presents a summary of the laboratory QC analyses, their frequency, and the acceptance criteria that were used.

Table 6.2 – Laboratory Quality Control

QC Check	***Minimum Frequency***	***Acceptance Criteria***
Off-site Laboratory (Gamma Spectroscopy, Alpha Spectrometry, Gas Proportional, Liquid Scintillation)		
LCS	One per 20 samples (5%) or one per batch, whichever is more frequent	Recovery 70-130% of expected value
Reagent Blank	One per 20 samples (5%) or one per batch, whichever is more frequent	Less than or equal to the Reporting Limit (RL)
Duplicates	One duplicate count per 20 samples (5%) or one per batch, whichever is more frequent	Relative Percent Difference (RPD) ≤ 35%, or Relative Error Ratio (RER) ≤ 1

6.2.1 Off-site Laboratory Duplicate Analyses

The off-site laboratory performed duplicate sample counts in three different samples of 46 measured (6.5%), meeting the required frequency of 5% or one per 20. The total number of results that were not qualified as U (<MDC) was 31. None of these 31 results had RPD exceeding 35%. Therefore, the results were considered acceptable, and no results were rejected based on RPD results. The full table showing the 31 results is provided electronically in Appendix C.

6.2.2 Off-site Laboratory LCS Analyses

The LCS analyses were performed at the required frequency. Two LCS samples had recoveries marginally outside of the acceptance criteria. The first sample, F7A040000124C in batch F6L200244, had a ^{241}Pu recovery of 69, and the second sample, F6L190000570C in batch F6L190219, had a ^{90}Sr recovery of 132. No data were rejected based on LCS results.

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7.0 SUMMARY AND CONCLUSIONS

The general objectives of the survey were to provide sufficient information to:

- Confirm whether one or more radionuclides of concern exceed the project action levels in areas with known or suspected radioactive contamination.
- Define the nature and lateral extent of areas (i.e., areas of surface soil) where radionuclide concentrations exceed the project action levels.
- Verify assumptions used to develop the survey design.
- Delineate areas where no radionuclide concentrations exceed the project action levels and support recommendation for unrestricted release.

7.1 Presence of Radioactive Contamination

The presence of radioactive concentration (i.e., concentrations of one or more radionuclides greater than or equal to their respective DCGLs) was identified during the site characterization measurements. A removal action was performed, and the final status survey did not identify the presence of radioactive contamination, showing the removal action was effective.

7.2 Nature and Lateral Extent of Radioactive Contamination

Since radionuclide concentrations did not exceed the project action levels, it was not necessary to determine the lateral extent of radioactive contamination at either of the two survey units.

7.3 Verification of Survey Design Assumptions

The survey was designed as a graded approach for thorough characterization with the intensity of a Class 1 and Class 3 MARSSIM final status surveys. The gross gamma walkover survey was based on the assumption that gamma-emitters were indicative of potential small areas of elevated concentrations of radionuclides of concern. Biased sampling confirmed that the gross gamma walkover survey found elevated gamma-emitters below the ^{137}Cs $DCGL_{Cs,mod}$. Subsurface samples supported the use of surface soil as the primary matrix of concern.

Off-site laboratory analysis did not identify any non-gamma emitting radionuclides of concern above their DCGLs. The random-start systematic or random sampling approach to survey homogeneous or wide spread contamination was successful in determining the average concentration of radionuclides in each survey unit.

7.4 Areas Where Data Support Recommendation for Unrestricted Release

The data collected in both survey units 19 and 20 are of sufficient quantity and quality to support a recommendation for unrestricted release. The area outside the drainage swale where biased samples 7 through 10 were collected during the characterization and removal action were not within the survey units 19 and 20 and did not receive final status verification.

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8.0 RECOMMENDATIONS

Based on the results and conclusions of this report, CABRERA recommends releasing both survey units 19 and 20 for unrestricted use.

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9.0 REFERENCES

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Attachment 1

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Figure 1.1 SSFL Area IV

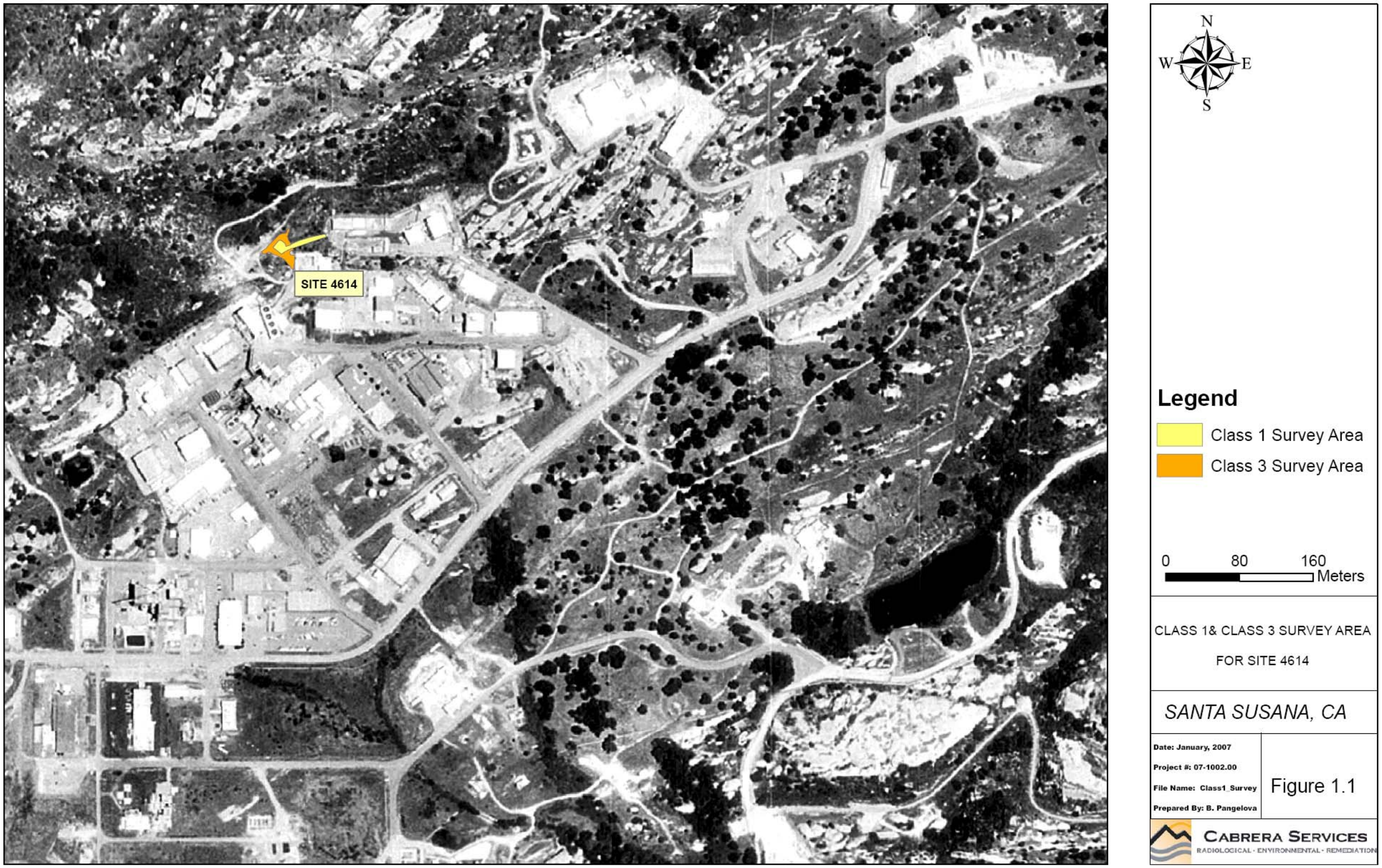


Figure 1.2 Site 4614 (View of Drainage Channel)

The removal action was perfomed in the circled area. The dotted white line shows an inaccessible area where GWS was not performed.

Figure 1.3 Site 4614 (West View)

The removal action was performed in the boxed area. The dotted line shows the concrete drainage channel that was not surveyed during GWS.

Figure 1.4 Site 4583 (SE View)

Figure 3.1 GWS Characterization Data for Site 4614

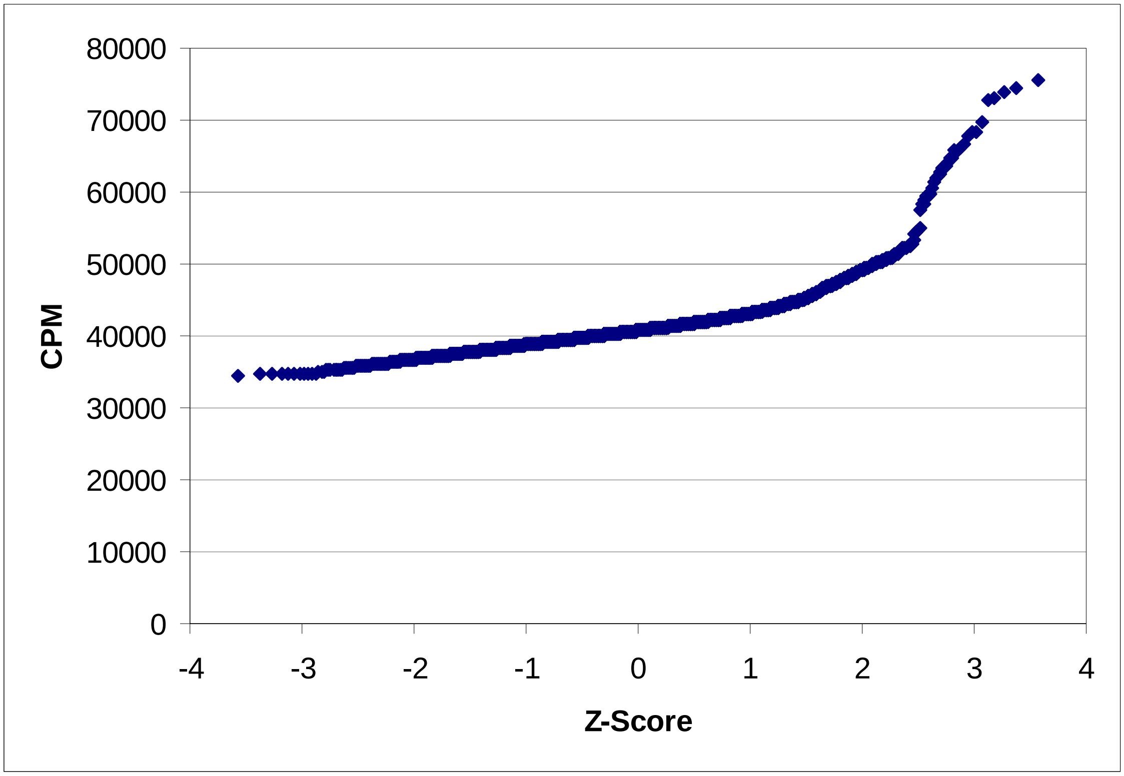
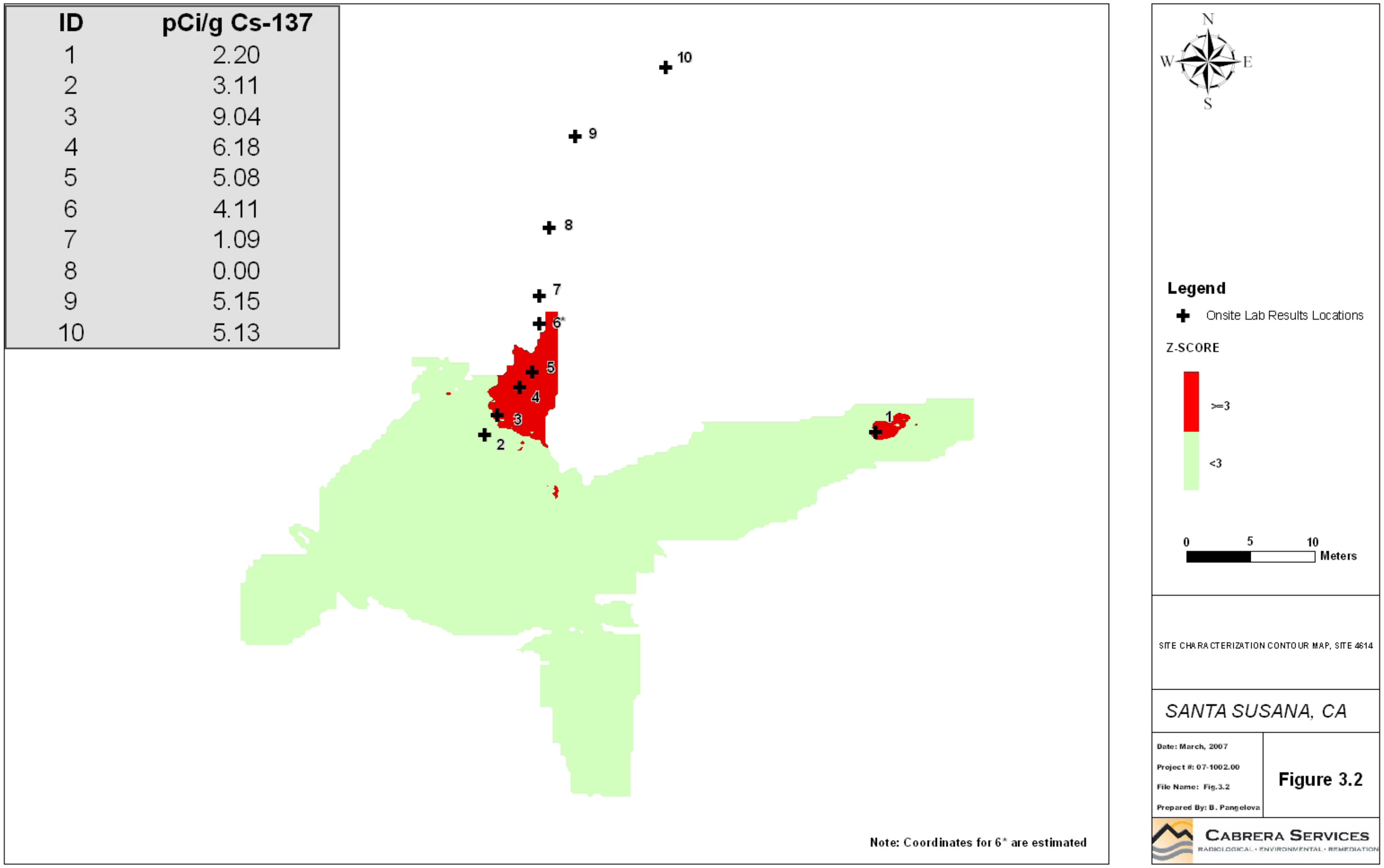


Figure 3.2 Site Characterization Contour Map, Site 4614



ID	pCi/g Cs-137
1	2.20
2	3.11
3	9.04
4	6.18
5	5.08
6	4.11
7	1.09
8	0.00
9	5.15
10	5.13

Figure 4.1 Soil Sample Locations, Site 4614

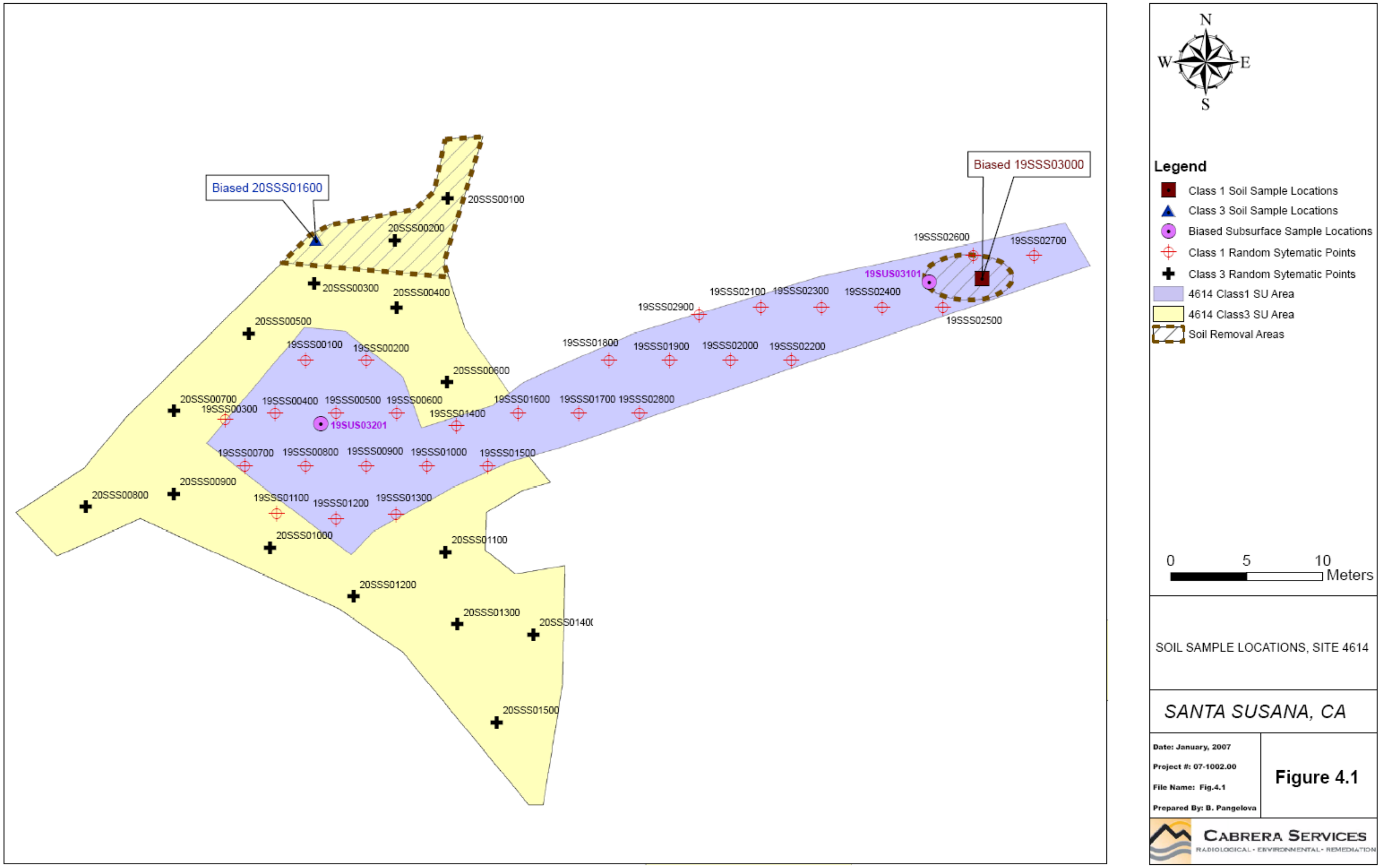


Figure 4.2 Cumulative Frequency Distribution For Site 4614

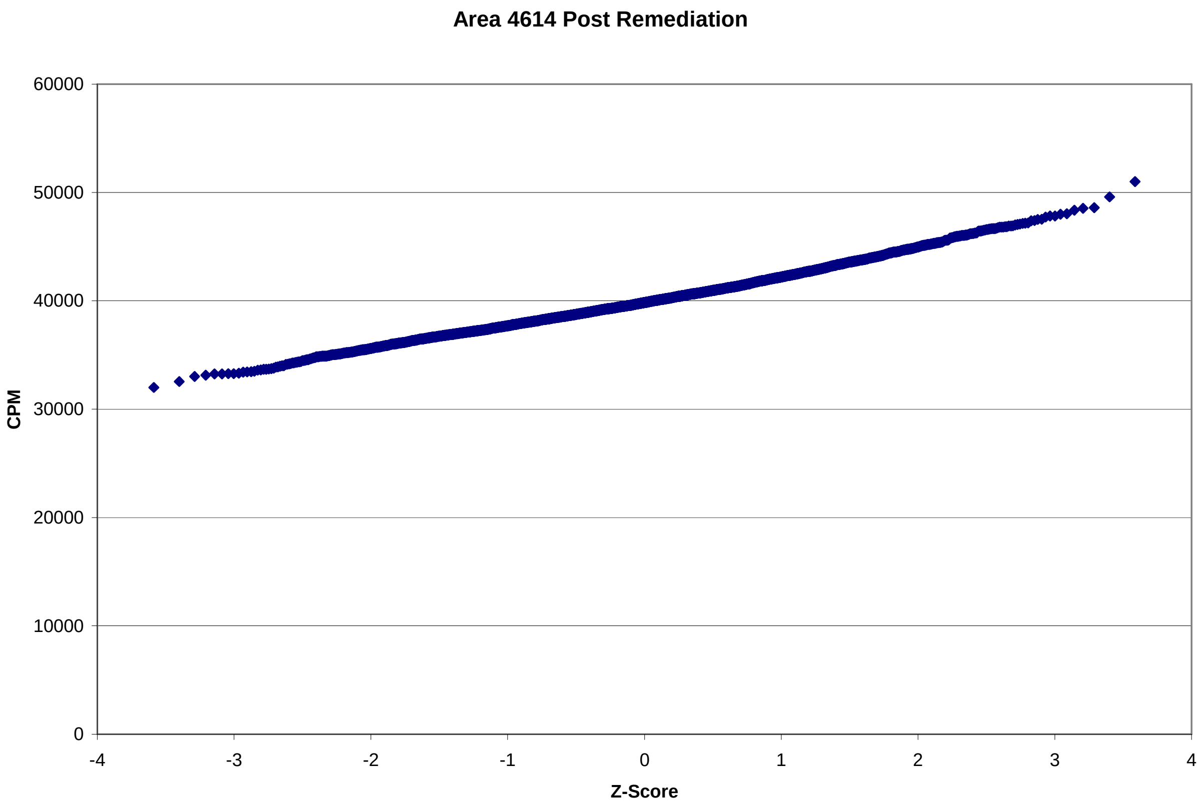


Figure 4.3 Survey Unit 19, 20 Z-Score Contour Map (Site 4614)

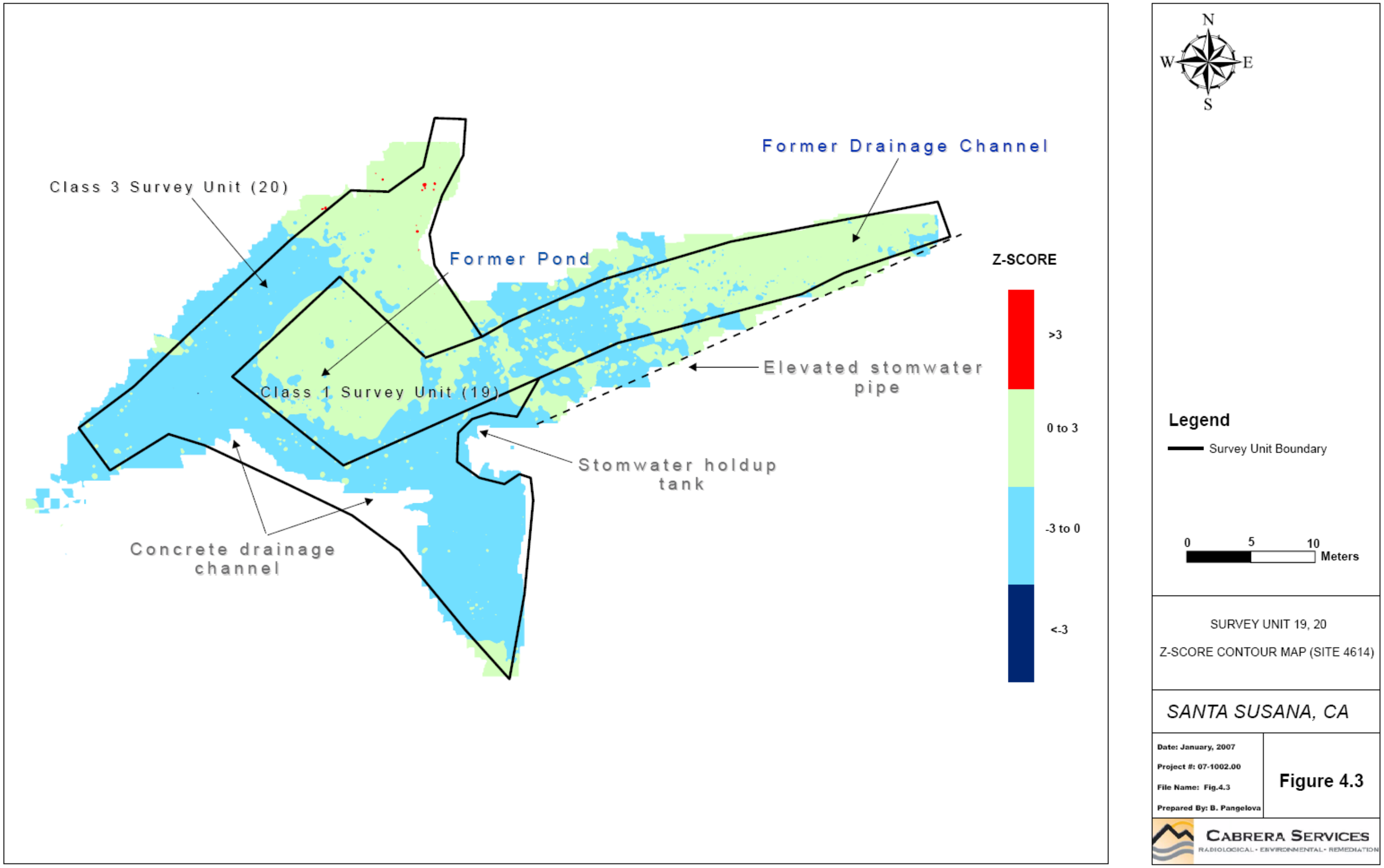


Figure 5.1 Cumulative Frequency Distribution, Area IV, ^{137}Cs

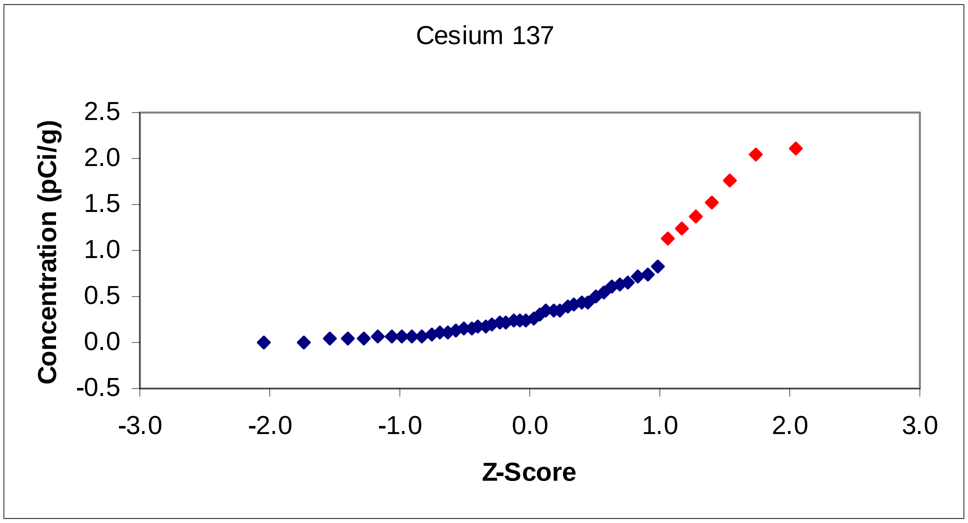


Figure 5.2 Frequency Plot, Area IV, ^{137}Cs

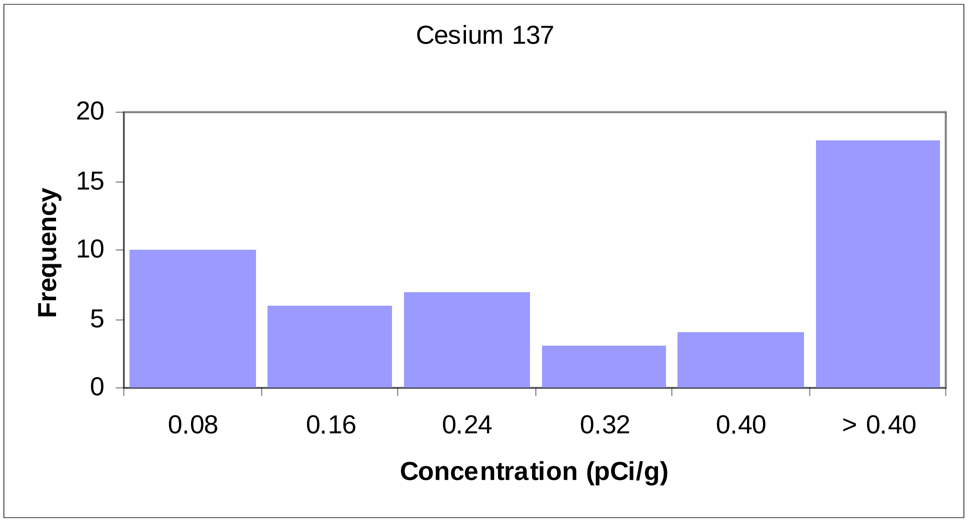


Figure 5.3 Cumulative Frequency Distribution, Area IV, ^{234}U

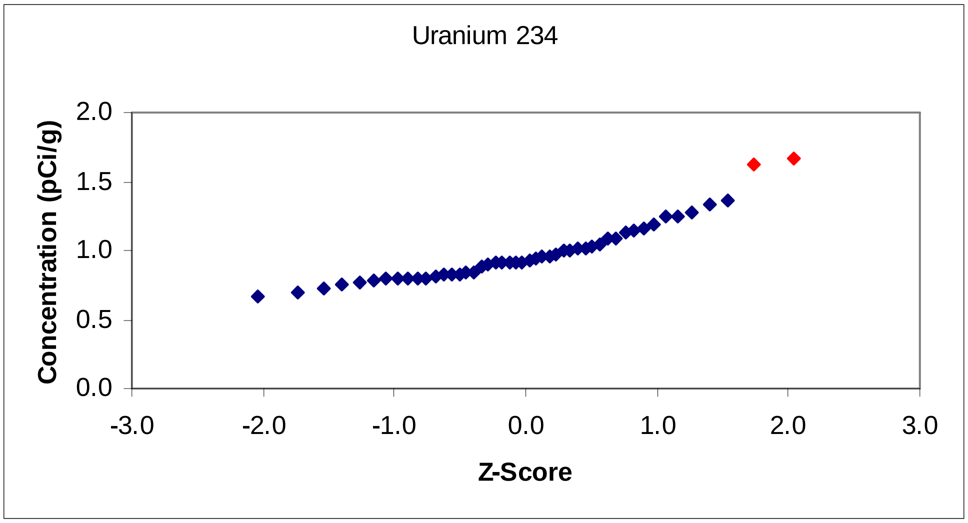


Figure 5.4 Frequency Plot, Area IV, ^{234}U

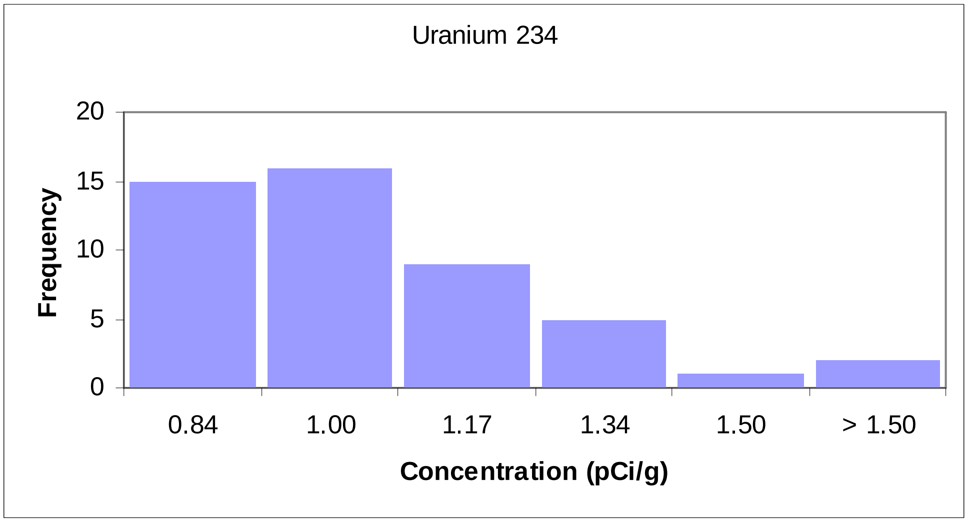


Figure 5.5 Cumulative Frequency Distribution, Area IV, ^{238}U

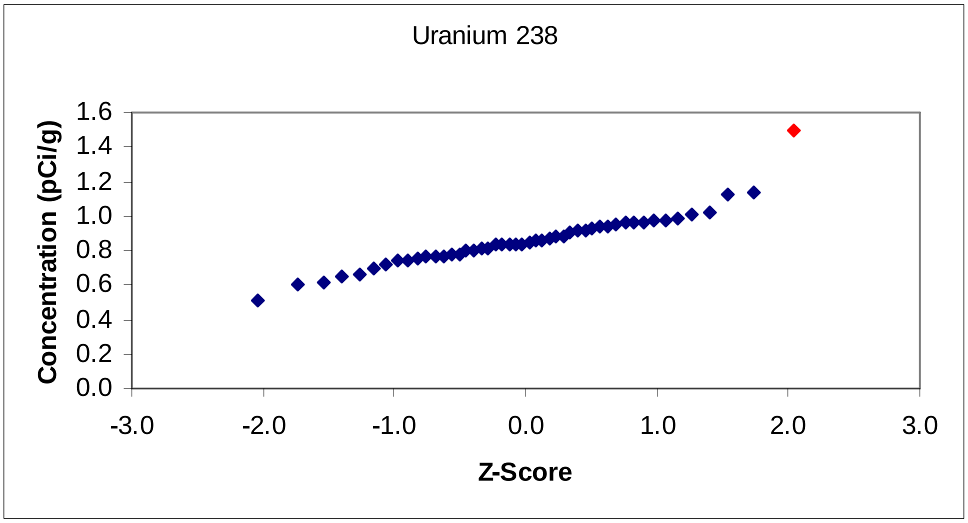


Figure 5.6 Frequency Plot, Area IV, ^{238}U

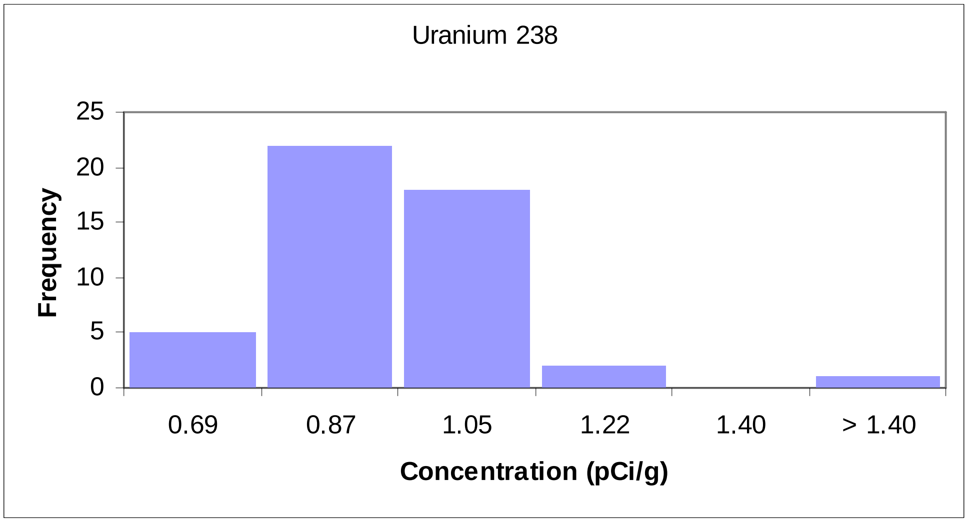


Figure 5.7 Cumulative Frequency Distribution, Area IV, ^{235}U

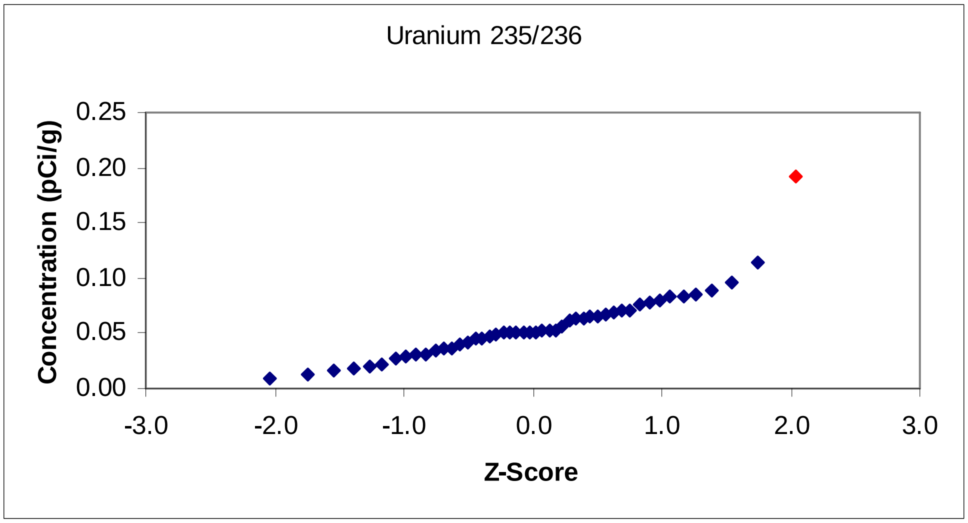


Figure 5.8 Frequency Plot, Area IV, ^{235}U

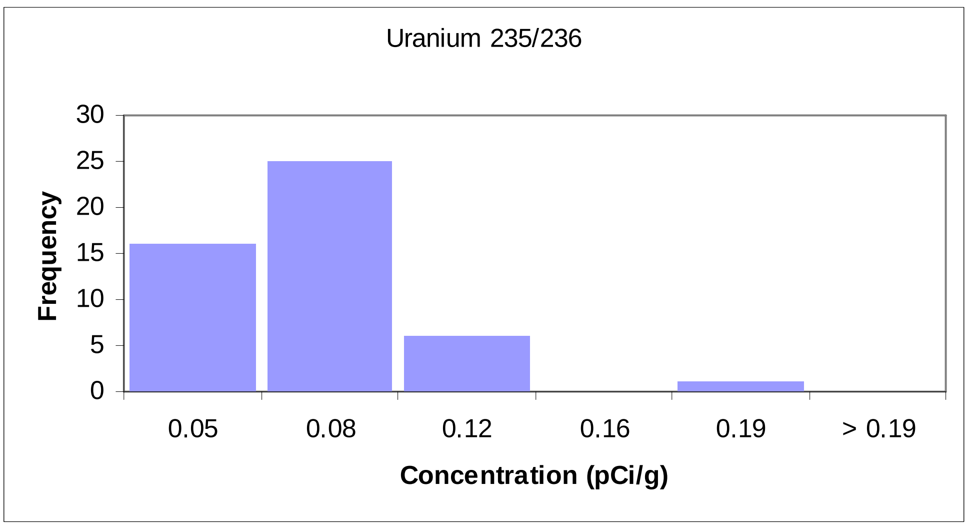


Figure 5.9 Cumulative Frequency Distribution, Area IV, ^{238}Pu

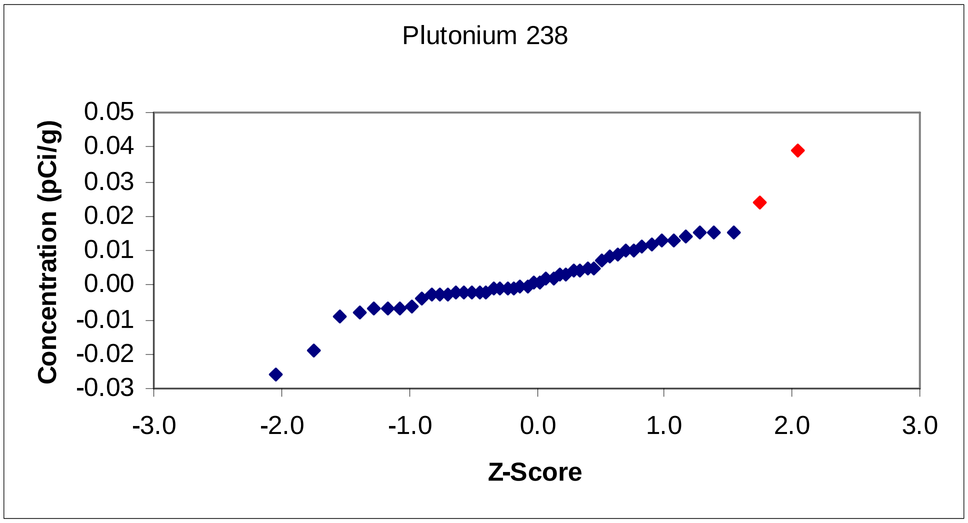


Figure 5.10 Frequency Plot, Area IV, ^{238}Pu

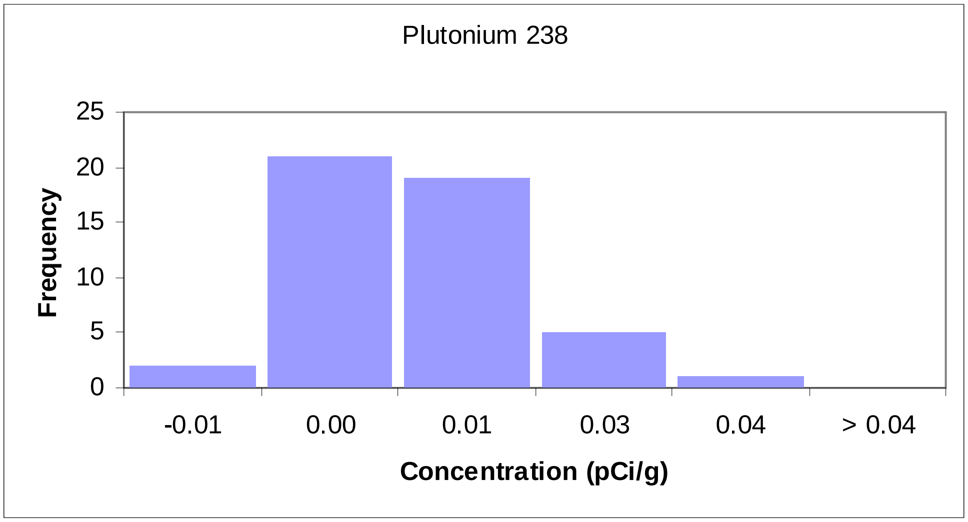


Figure 5.11 Cumulative Frequency Distribution, Area IV, $^{239/40}$Pu

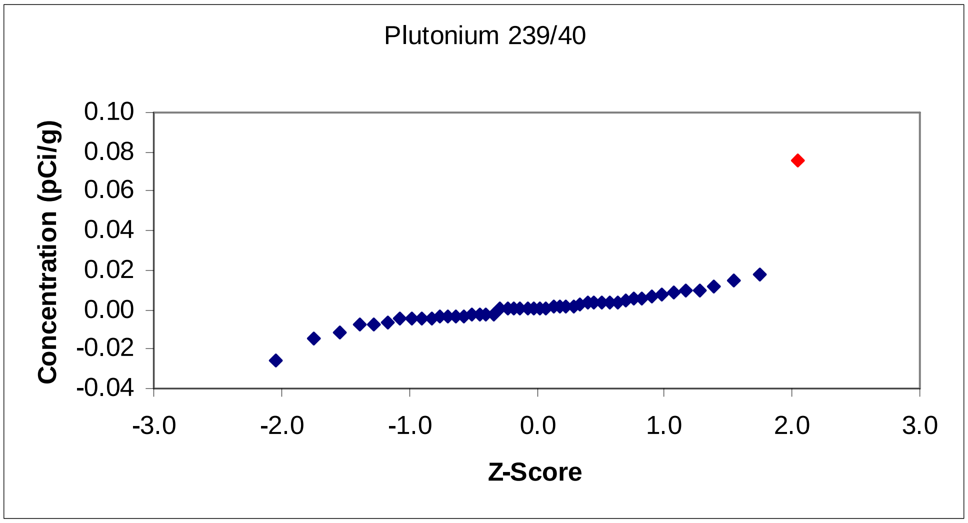


Figure 5.12 Frequency Plot, Area IV, $^{239/40}$Pu

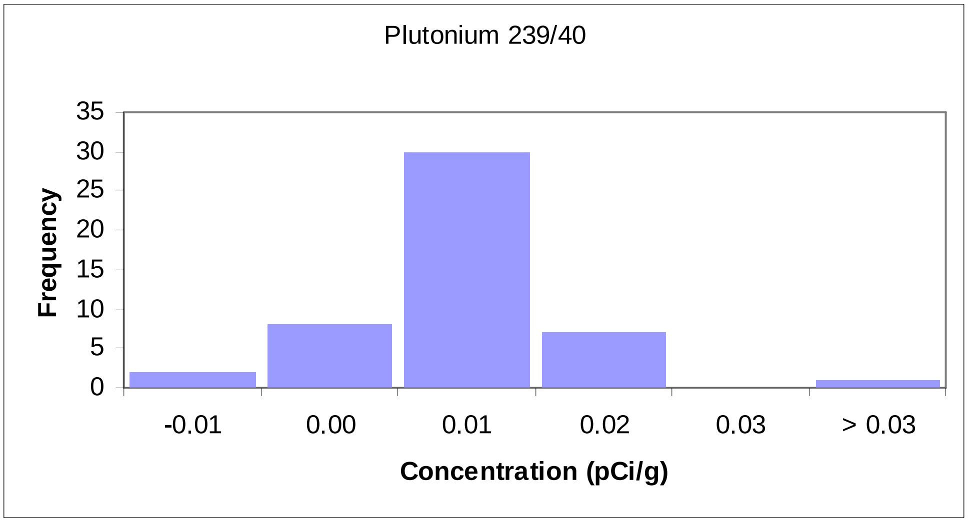


Figure 5.13 Cumulative Frequency Distribution, Area IV, ^{241}Pu

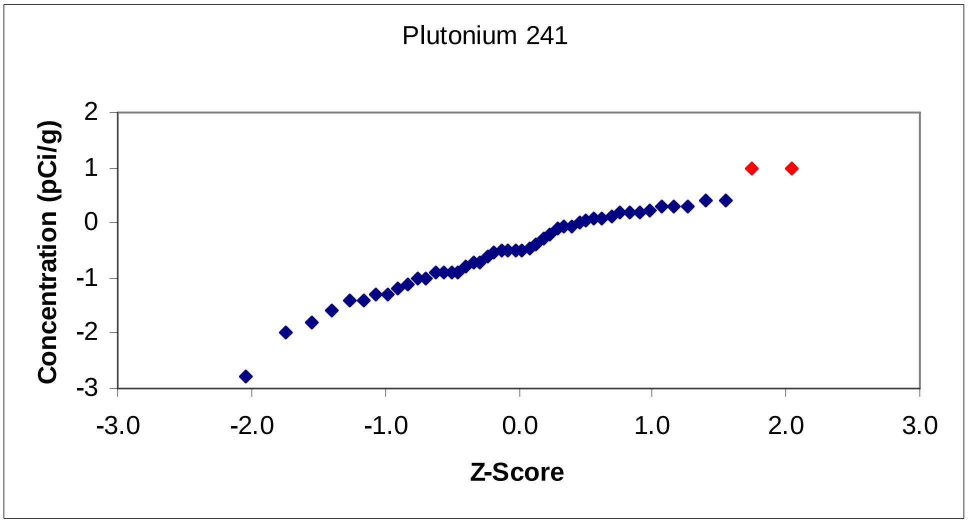


Figure 5.14 Frequency Plot, Area IV, ^{251}Pu

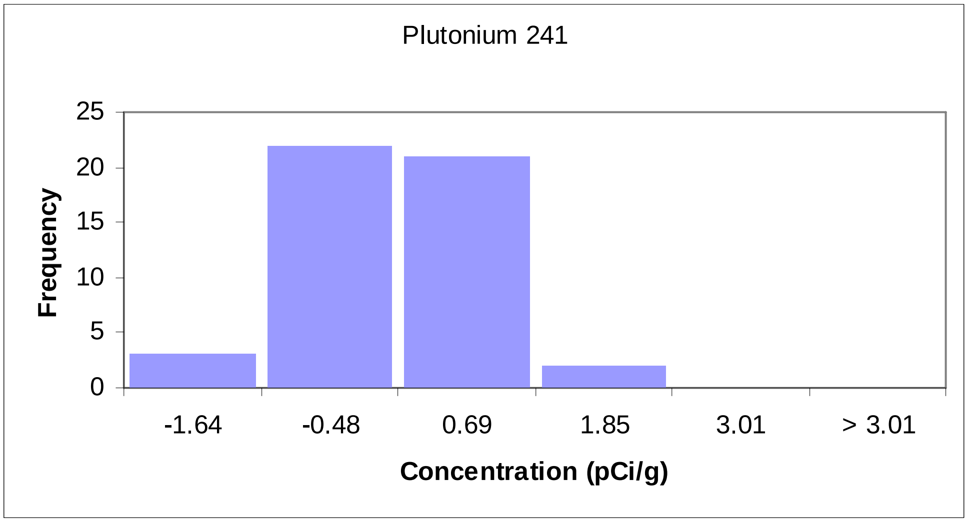


Figure 5.15 Cumulative Frequency Distribution, Area IV, ^{90}Sr

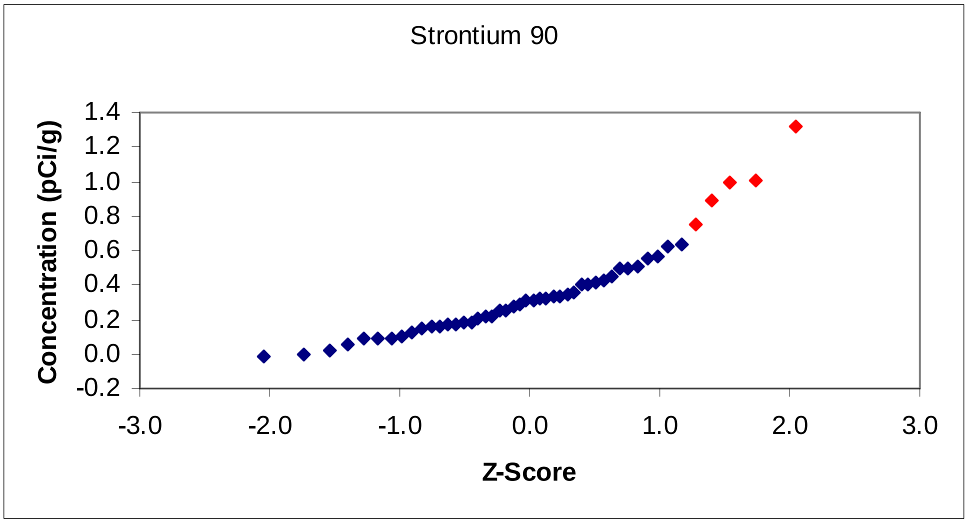


Figure 5.16 Frequency Plot, Area IV, ^{90}Sr

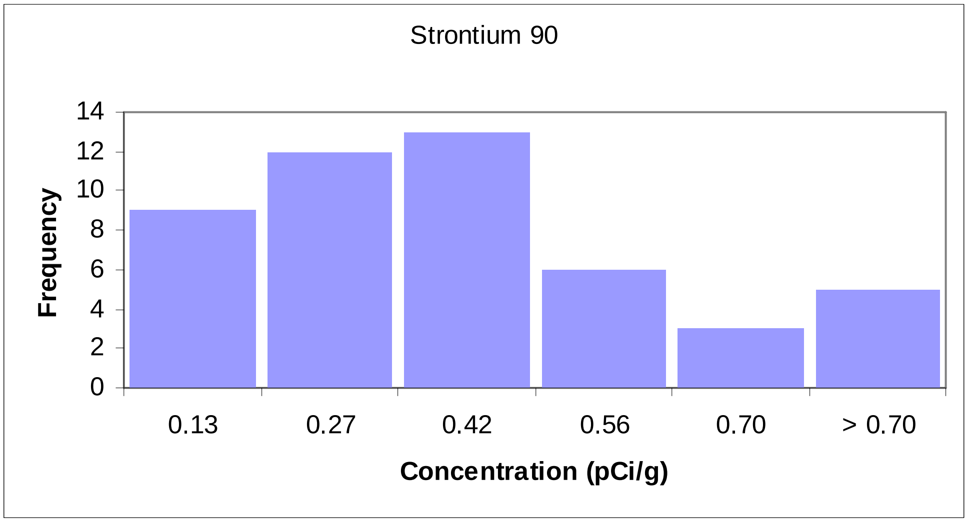


Figure 5.17 Retrospective Power Curve for ^{137}Cs, survey unit 19

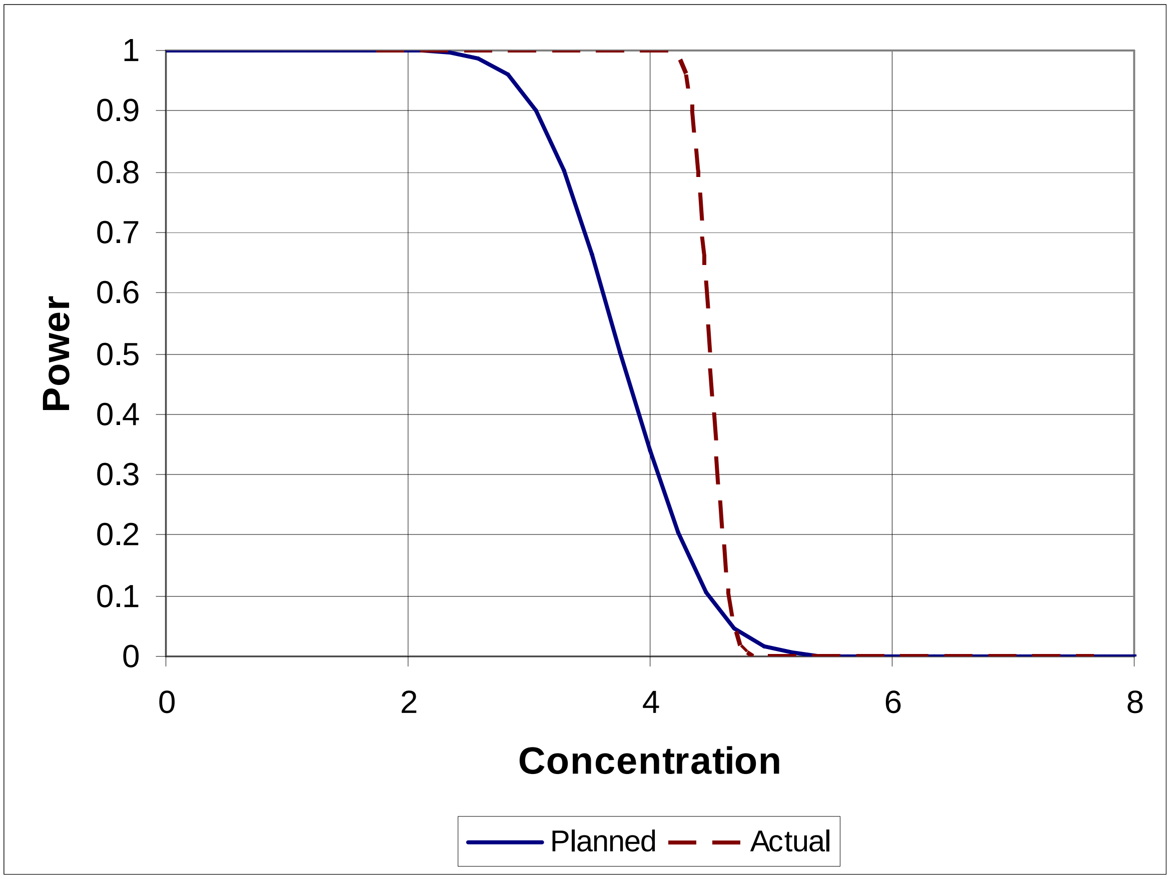


Figure 5.18 Retrospective Power Curve for ^{137}Cs, survey unit 20

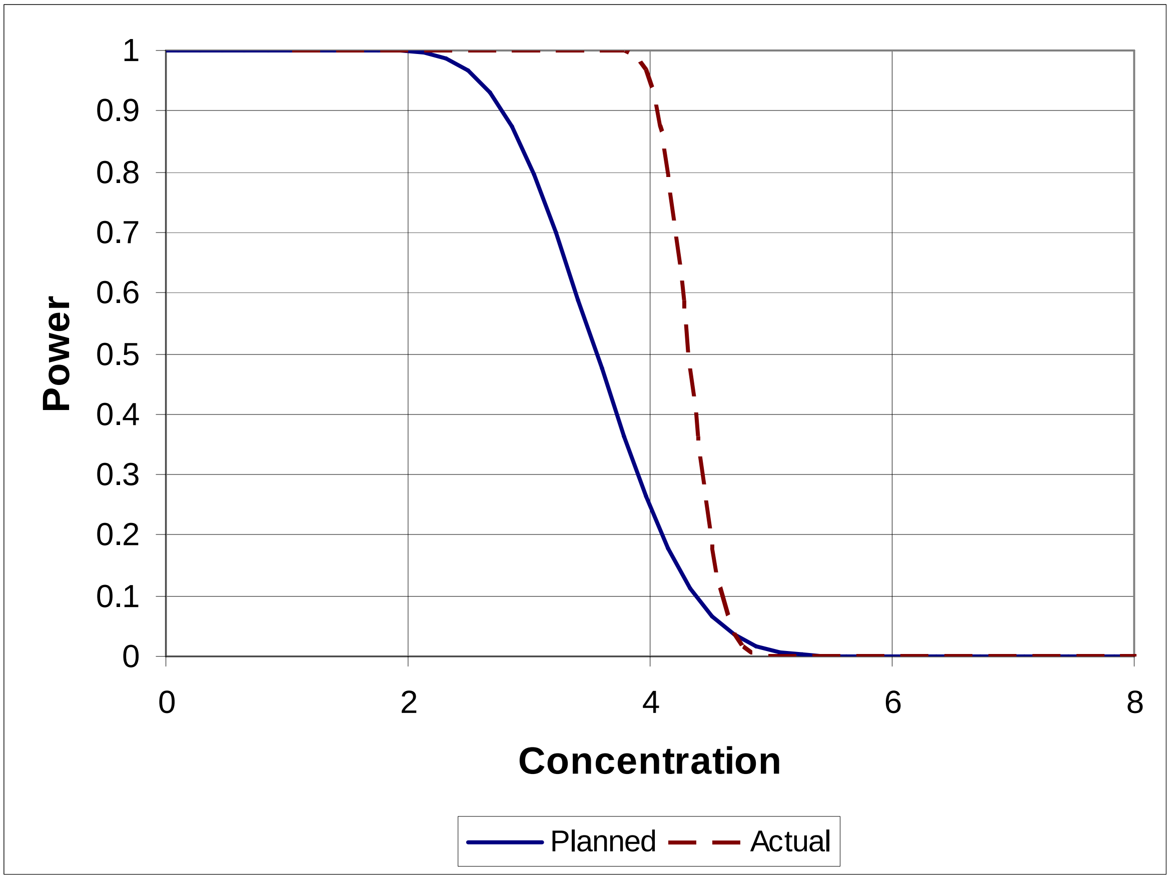


Figure 5.2 Uranium Enrichment Scatter Plot