FINAL

Final Status Survey Report: Final Status Survey Post Historical Site Assessment Sites, Block 1

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
dpm	Disintegrations per Minute
DQO	Data Quality Objectives
EDA	Exploratory Data Analysis
EMC	Elevated Measurement Concentration
EPA	U. S. Environmental Protection Agency
ESG	Energy Systems Group
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
H	Hydrogen (e.g., ^{3}H)
HEPA	High-Efficiency Particulate Air
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
ORISE	Oak Ridge Institute for Science and Education
pCi/g	Picocurie per Gram
pCi/L	Picocurie per Liter
PM	Project Manager
PRG	Preliminary Remediation Goal
Pu	Plutonium (e.g., ^{238}Pu)
QA	Quality Assurance
QC	Quality Control
Ra	Radium (e.g., ^{226}Ra)
RER	Relative (or Replicate) Error Ratio
RESRAD	Residual Radiation (Environmental Analysis)
RL	Reporting Limit
RMHF	Radioactive Materials Handling Facility
RPD	Relative Percent Difference
SNAP	Systems for Nuclear Auxiliary Power
SOF	Sum of Fractions
Sr	Strontium (e.g., ^{90}Sr)
SRE	Sodium Reactor Experiment
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.	Unites States Code
Yard	(e.g., The Yard) Refers to Old ESG Salvage Yard

EXECUTIVE SUMMARY

This report presents the results of the characterization and final status survey of five sites within Area IV ("Block 1") at the Santa Susana Field Laboratory (SSFL) in Ventura County, California. This group of sites includes the footprints of the former buildings 4023, 4028, 4583, 4323 and 4030. The field work was performed from November 28, 2006, to December 15, 2006, by Cabrera Services, Inc. (CABRERA) in accordance with the *Final Field Sampling Plan: Final Status Survey, Post Historical Assessment Sites, Block 1* (FSP, CABRERA, 2006b).

The purpose of the survey was to determine final status for areas where radionuclide concentrations were found to be below their respective derived concentration guideline level (DCGL). 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.

The areas of interest included nine survey units. Non-intrusive surface investigations, intrusive sample collection techniques, and off-site sample analyses were performed for each survey unit. Non-intrusive gross gamma walkover surveys (GWS) were performed to identify the presence of elevated levels of radioactivity. Random-start systematic samples were collected from each Class 2 survey unit. Random sampling was performed in each 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 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, 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 all 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 five sites at the SSFL in Ventura County, California. The report also makes recommendations for future use of the five sites 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 FSP (CABRERA, 2006b).

The five sites are 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 the SOF method (see Section 4.4.1). 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 ft. bgs within five sites (4583, 4363, 4030, 4023, and 4028). Two subsurface soil samples were collected to support the assumption that contamination was restricted to the first 0.5 ft. bgs. Figure 1.1 shows the location of the five sites within Area IV. Figures 1.2 – 1.7 of Attachment 1 show photos of the areas of interest at the five sites. The five sites were divided into nine survey units. The boundaries and classifications of each survey unit are described in Section 3.1. No investigations of ground water, surface water, sediment, asphalt, concrete, or buildings were performed as part of the 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 Radioactive Materials Handling

Facility (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. At the time of this investigation, each of the five sites described below has been returned to a natural state.

Site 4023 is the former location of the Liquid Metals Component Test Building, and the Corrosion Test Loop. Building 4023 was a single story structure with galvanized steel walls and roof and a concrete slab floor. The sodium test loop was located in the western, or "old," portion of the building. The "new" building section held an analytical chemistry laboratory and a storage set-up room. The facility was approximately 20 feet below the general grade of the adjacent 12th Street. The site contained an exterior sub-grade open-top concrete vault that was used as a waste hold up tank. The majority of the contamination of Building 4023 was associated with drain lines and associated vent pipes, the holdup tank, the open top holdup tank pit, and a laboratory fume hood. The first section of Building 4023, constructed in 1962 (known as 023), housed a small sodium loop to conduct studies of radioactive contamination transport. The second section, constructed in 1976 (known as 23A), served as a storage and setup room as well as an analytical chemistry laboratory.

Site 4363 is the former location of the Mechanical Component Development and Counting Building and Research and Development Building. Building 4363 was a 1,400 square-foot (ft^2) structure with four work bays (240 square feet each) placed side by side, a rest room and several small utility rooms. Concrete walls separated the bays. The north and south walls were sheet metal with partial wall panels on the inside wall surfaces. The roof was constructed from composition panels with asphalt base topping. The building sat on a concrete foundation, which extended around the building to form a perimeter walkway and loading dock. Building 4363 was used to support the Sodium Reactor Experiment (SRE). Site 4363 was transferred from the Rocketdyne Division to the AI Division in 1956-1957 to support expansion of the AI activities at SSFL.

Site 4028 is the former location of the Shield Test Irradiation Reactor (STIR) Facility, Shield Test Reactor, and Liquid Metal Fast Breeder Reactor Fuel Safety Building. Building 4028 was a 14-foot tall steel-framed structure covered with steel siding and roofing built on top of a concrete test vault. The test vault was 60 square meters (m^2) with a 6 foot ceiling. The building had a high-efficiency particulate air (HEPA) exhaust system and stack. Building 4028 included below-ground structures that were not directly below the main building. These structures were recessed into a sloped area such that they were not entirely underground. Building 4028 was constructed in 1960 to perform tests on space reactor shields. 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 STIR; a 1 megawatt (MW) reactor that operated from 1964 to 1972. Site 4811, which was located adjacent to Building 4028, became part of Building 4028 between 1962 and 1967. Site 4811 was a mechanical and electrical pad that held equipment directly supporting the STIR facility reactor. In March of 1976, STIR was decommissioned and removed from Building 4028. From 1977 to 1981, Building 4028 was used to conduct research on the behavior of molten uranium dioxide, causing the building to again become contaminated. Operations were terminated in 1984, and the building remained inactive until 1988 when cleanout and decontamination began. The process of D&D was conducted in 1988. Activities included the removal of surplus uranium oxide, decontamination and removal of equipment and electrical components, removal of the radioactive ducting system, decontamination of the building surfaces, miscellaneous cleanup operations and the final radiological survey of the facility. The above-ground structures were removed in 1989 and the below-ground structures were removed in 1998 or 1999. The removal of the below-ground structures did not require significant excavation, backfill and grading, since they were recessed into a slope adjacent to the main building.

Site 4030 is the former location of the AE-6 Counting Room and Workshop, and Particle Accelerator Facility. Building 4030 had a total enclosed area of 2,311 ft^2 (215 m^2) which consisted of two connected sections, each with steel framing, siding and roof. The western portion of Building 4030 was constructed at a right angle to the front office section. The front section of Building 4030 was known as Building 4035 before the rear section was added, and the two buildings were combined to form Building 4030. The rear section of Building 4030 was configured to house a Van de Graaf accelerator, which provided an adjustable energy proton beam to bombard a tritium (^3H) target to produce neutrons. Building 4030 was constructed in 1958 for research with a small accelerator neutron source. A Van de Graff accelerator was moved into the facility in 1960 and operated through 1964 in support of the Systems for Nuclear Auxiliary Power (SNAP) program. In 1966, the accelerator was removed. Beginning in 1972, the building was used as a purchasing office for the site and for traffic and warehousing. Building 4030 was demolished in 1999.

Site 4583 is the former location of the Old ESG Storage Yard and Conservation Yard (the Yard). The Yard was a three-acre area of mostly natural terrain in the northeastern corner of Area IV, north of C Street. This area has been used to support research and development work at the SSFL since the 1950s. The Yard was used extensively during the 1960s to late 1970s predominately in support of nuclear-related work. When the Yard ceased to be used to support nuclear-related projects around 1977, it was cleaned and all salvageable non-radioactive materials were moved to the New Salvage Yard. In the early 1980s, the Yard, which was no longer in use, became the Fuel Oil Tank Farm. The area was fenced in 1982.

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 using the SOF method (see Section 4.1.1). 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 radionuclide of concern in the top 0.5 ft. 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 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 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 sums of fractions less than the action level.

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 (Sections 3.4, 3.5, and 4.0)

1.4.3 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 ft. bgs over the areas of interest within the five sites. Subsurface soil samples were also collected at Sites 4023 and 4028 to support the assumption that surface soil is the matrix of concern. The lateral extent of the target population was the geographical boundaries of the five sites located in Area IV of the SSFL. Sites 4023, 4363, 4028, and 4030 included the former building footprints, ranging in size from 1,500 – 11,250 ft^2 (139 – 1,045 m^2) with approximate square or rectangular boundaries, and a surrounding buffer zone of equal area. The fifth site (4583) had an area of 130,680 ft^2 (12,141 m^2). The areas of concern were divided into nine total survey areas, or survey units (see Section 3.1). A separate decision concerning unrestricted release was made for each survey unit.

Data collection activities were sometimes constrained by natural or manmade obstructions. In survey unit 4583, most areas were covered by either brush or natural rock outcroppings (see

Figures 1.6 and 1.7); and 100% of accessible areas were surveyed. At survey unit 4028, a planned surface soil sample was not collected due to the steep grade at the planned sample location which prevented access by the GeoProbe® vehicle. Furthermore, the desired depth of subsurface sampling was not obtained at either 4023 or 4028 due to a bedrock layer. See sections 4.3.1 and 4.3.3 for additional information on sample collection activity at sites 4023 and 4028. All surface soil samples and GWS were collected as planned.

1.4.4 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. In no case was additional data collection required. Decisions were made on whether to release each of the nine survey units for unrestricted use.

Table 1.1 – Survey Decision Rules

Parameter of Interest	***IF***	***THEN***	***Comments***
Gross Gamma Walkover			
Presence of Contamination	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.

Parameter of Interest	***IF***	***THEN***	***Comments***
	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			
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.	

Parameter of Interest	***IF***	***THEN***	***Comments***
	A survey unit is uniformly contaminated,	Additional investigation will be coordinated with the Boeing PM and directed by Boeing.	
	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), ^{63}Ni, and ^{3}H)
SOF			
	Any ^{137}Cs result within a survey unit exceeds the $DCGL_{Cs,mod}$	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.

Parameter of Interest	***IF***	***THEN***	***Comments***
	S+ ≥ Critical Value	Additional investigation will be coordinated with the Boeing PM and directed by Boeing.	
	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.

1.4.5 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.

1.4.6 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 3.3.1 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.

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 design was built using the radionuclides of concern and the release criteria which were previously established for SSFL.

2.1 Historical Information

Multiple incidents occurred at the five sites 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 4023: Former location of the Liquid Metals Component Test Building, and the Corrosion Test Loop

- On December 18, 1980, water reacted with non-neutralized sodium and surged out of the loop. The water leak resulted in contamination of the ceiling, walls and floor with maximum contamination levels of 1,000 disentegrations per minute (dpm) per 100 square centimeters (cm^2) of Manganese-54 (^{54}Mn) (A0084).
- On April 28, 1981, there was a minor sodium leak and fire, with ^{137}Cs, ^{54}Mn and ^{60}Co as the principal radioactive isotopes contained in the loop at the time. The fire was extinguished with calcium carbonate. Smears of the loop and the floor showed no radioactive contamination (A0257).
- In 1993, Rockwell/Rocketdyne conducted a final radiological survey to ensure compliance with acceptable contamination limits for activation products and mixed fission products and for ambient exposure rate. The scope of the survey included only the interior rooms of the building. Initial surface scans indicated an area within Building 4023 with elevated levels of ^{137}Cs requiring additional decontamination. The decontamination efforts lowered surface activity to below release limits.
- In 1994, the Oak Ridge Institute for Science and Education (ORISE) conducted a verification survey using surface scans to confirm that remedial actions have been effective in meeting established guidelines. No soil samples were taken, because the entire area around Building 4023 was paved. Scans inside the Building 4023 Control Room identified elevated direct radiation in two areas that required additional investigation. Decontamination efforts lowered beta surface activity to background levels.

Site 4363: Former location of the Mechanical Component Development and Counting Building and Research and Development Building

- Contamination of Building 4363 resulted from work on a component containing contaminated sodium from the SRE Core I accident, which occurred in Building 4143 in 1959. The SRE accident dispersed low enriched uranium and mixed fission products in the sodium, which was the same type of contamination found at Building 4363.
- In 1992, stored equipment was removed from Bay 4 and fixed beta contamination was detected on the floor. A more comprehensive survey conducted in 1993 detected additional radioactive contamination on the west wall and overhead horizontal

surfaces in Bay 4 (i.e., ducting, piping and light fixtures). This investigation included gamma spectrometry of wall scrapings and removable surface contamination counting for alpha and beta that was limited to the interior portions of the former building. This investigation revealed the presence of 137Cs and low enrichment uranium (2.75%), and presumed Strontium-90 (90Sr) activity. Detectable activity on the floor ranged from 25,000 to 142,000 dpm/100 cm2 beta, and hot spots on the west wall ranged from 25,000 to 730,000 dpm/100 cm2 beta.

Site 4028: Former location of the STIR Facility, Shield Test Reactor, and Liquid Metal Fast Breeder Reactor Fuel Safety Building

- On July 17, 1963, an unmarked irradiated fission foil was moved in a private car to a clean office (A0447).
- On June 17, 1965, an employee received an extremity beta exposure resulting from the handling of a plastic bag sealed with green tape containing chemical samples which were irradiated for 1000 seconds at 1 MW (A0279).
- On January 10, 1978, there was a small Uranium fire in the arc-melting furnace (A0065).
- On January 30, 1979, increased radioactivity was found in runoff water from Radioactive Materials Disposal Facility. The estimated total activity released to the pond was approximately 0.36 millicuries (mCi) of gross beta activity (A0232). This incident is not believed to have directly impacted Building 4028; however, the activity released to the RMHF pond (Site 4614) may have contributed to activity in downstream piping and underlying soil that will be investigated at a later date.
- On July 24, 1981, a contaminated crucible stored outside was exposed to elements (A0087).

Site 4030: Former location of the AE-6 Counting Room and Workshop, and Particle Accelerator Facility

- There are no Incident Reports associated with Building 4030.
- Tritium Smear Survey on Building 4030 and associated equipment, March 29, 1966. The maximum sample was 75,000 dpm. Areas of contamination were decontaminated.
- General Rocketdyne Survey, 1988. In 1988, Rocketdyne performed a survey to clarify and identify areas at SSFL requiring further radiological inspection or remediation. Radiological contamination quantities were compared against unrestricted-use acceptable contamination prescribed by DOE 5400.1. Building 4030 was included and the scope of the survey, which included ambient gamma exposure rate measurements, “indication” beta surveys of the accelerator room and outside paved area (palletized-container storage area). Exterior soil samples were checked for ^{3}H content. The average ^{3}H activity in soil was 5.31 picocuries per liter (pCi/L), with a maximum acceptable concentration of 366 pCi/L. Survey results were below acceptable limits.
- ORISE conducted an independent verification survey for Building 4030 in 1995. Surface scans for alpha, beta and gamma activity and single-point direct measurements for total alpha and total beta activity were performed on floors, walls, equipment and outside soil. These levels were compared to the guidelines specified in DOE 5400.1. One sample of total ^{3}H activity exceeded the average guideline for

beta-gamma emitters, and ORISE recommended additional sampling be performed in this area.

Site 4583: Former location of the Old ESG Storage Yard and Conservation Yard

- Deliberate dumping or placing of materials did not occur, but contaminated items (uranium and mixed fission products) were occasionally found during routine radiation surveys. These discoveries would have occurred during the Yard's use as a storage facility during the 1960's, until 1977 when all materials were removed.

2.2 Radioactive Contamination Scenarios

Radioactive contamination scenarios for each site include transport of radiological contaminants from the former building structures to the environment through inadvertent storage, spills, or tracking of radioactive material from the structures. These scenarios are based on the information provided in the Historical Site Assessment (HSA, Sapere, 2005). The demolition of the buildings may have released hidden or trapped contaminants not identified during gamma survey or surveys for loose contamination on the interior building surfaces.

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 performed at Site 4030 only. Table 2.1 lists the radionuclides of concern identified for the five sites at SSFL.

Table 2.1 – 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	^{3}H

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 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 2.2, are described in detail in *Approved Sitewide Release Criteria for Remediation of Radiological Facilities at the SSFL* (Boeing, 1998).

Surface soil sample results analyzed by the off-site laboratory were compared to a modified DCGL ($DCGL_{Cs,mod}$) 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 $DCGL_{Cs\text{-}mod}$ 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 2.2) for ^{137}Cs ($6 \div 9.2 \times 7.15$). The scan MDC of 3.7 pCi/g (see Section 3.3.1) was expected to identify small areas of elevated activity less than the $DCGL_{Cs,mod}$. The lower of the two radionuclide-specific DCGLs (shaded in Table 2.2) were used as the project action levels for soil sample results analyzed by the off-site laboratory.

Table 2.2 – 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
Tritium	(^{3}H)	31,900	**228**
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 SUMMARY OF SURVEY ACTIVITIES

The areas of interest were divided into nine survey units. Gross gamma walkover surveys were performed and surface soil samples were collected and analyzed. Two subsurface soil samples were collected and analyzed. Based on the results, the decision rules were applied and additional biased samples 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 4583 was re-classified as Class 2 based on one unexpected outlier that was not consistent with a normally distributed background population, but did not exceed the DCGLs.

3.1 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.

3.1.1 Survey Unit Descriptions

The areas of concern were the five sites located in Area IV of the SSFL. Sites 4023, 4363, 4028, and 4030 included both the former building footprints, ranging in size from 1,400 – 11,250 ft^2 (139 – 1,045 m^2) with approximate square or rectangular boundaries, and a surrounding buffer zone of equal area. The fifth site (4583) had an area of 130,680 ft^2 (12,141 m^2). Sites 4023, 4363, 4028 and 4583 have been restored to a natural state including reseeding with native grasses. Site 4030 had recently been restored, as evidenced by a green layer of hydro-seed mulch present in an even layer over the entire site. The areas of concern were divided into nine total survey areas, or survey units, numbered 10 – 18 (see Table 3.1). They included impacted areas where neither measurements above the DCGL, nor areas of elevated activity are expected. Based on this assessment, these areas were initially assigned as either MARSSIM Class 2 or Class 3 areas (see Table 3.1)

Table 3.1 – Survey Unit Classification

Survey Unit Number	*Site Number*	*Initial MARSSIM Classification*	*Final MARSSIM Classification*	*Planned Size (square feet)*	*Actual Size (square feet)*
10	4023	Class 2	Class 2	11,250	9,699
11	4023	Class 3	Class 3	11,250	5,598
12	4363	Class 2	Class 2	1,400	5,760
13	4363	Class 3	Class 3	1,400	12,119
14	4028	Class 2	Class 2	4,000	6,229
15	4028	Class 3	Class 2*	4,000	9,370
16	4030	Class 2	Class 2	2,500	5,430
17	4030	Class 3	Class 3	2,500	7,668
18	4583	Class 3	Class 2	130,680	151,296

*Shaded cells indicate changes to the survey design.

3.1.2 Survey Unit Changes and Reclassification

The initial survey unit sizes were based on the sizes of the former buildings as described in the HSA (Sapere, 2005). During the initial walk down of each site, stakes were identified which marked the corners of each buffer zone; however, none of the building footprints had been defined. With the assistance of the Boeing PM, the boundaries were established in the field using aerial photos as well as natural and man-made landmarks still present at each site (e.g., trees, adjacent buildings, roads, etc.). A global positioning system (GPS) was used to record a sufficient number of points to define the survey unit boundaries. The final boundaries are shown in Figures 3.1 – 3.5.

The size of each survey unit is shown in Table 3.1. In general, the absence of the former buildings made the exact placement of the former building footprints difficult. In all cases, the survey area of the building footprint was larger than the planned area. Adjacent buildings and other landmarks provided confidence that the building footprints were encapsulated by the boundaries defined in the field. For survey unit 11, the buffer zone was smaller than planned due to physical constraints on the boundaries of the site (e.g., roads) and all land areas were included. For these reasons, the changes to the survey design were considered to be acceptable.

The planned classification of each survey unit (see Table 3.1) was based on expected soil concentrations of the radionuclides of concern. Class 2 survey units had a potential for radioactive contamination, but were not expected to exceed the DCGL. Class 3 survey units were not expected to contain any residual radioactivity. In general, the building footprints were assigned Class 2, while the buffer zones were assigned as Class 3. This assignment was reasonable based on the usage of the former buildings and the extent of radiological D&D. The investigation revealed survey units 15 and 18 should have been assigned as Class 2. Section 4.2.1 describes the identification of two outlier data points for ^{137}Cs that were found in these two Class 3 survey units. Each of the outliers was present at a small fraction of the $DCGL_{Cs,mod}$.

The survey data for survey units 15 and 18 was reviewed for consistency with Class 2 requirements. Since survey unit 15 was already scanned at 100% coverage with 15 randomly spaced samples, the only possible change to the survey design would have been to use a systematic grid, or to collect more samples. A retrospective power analysis (see Table 4.6) showed that only 14 samples were required so the number of samples was appropriate. Furthermore, the spacing of the samples (see Figure 3.4) already placed them approximately equal distances from each other, which is consistent with the systematic grid design recommended in MARSSIM guidance. For these reasons, survey unit 15 was reclassified as Class 2 without redesign of the survey.

Approximately 20% of the total area in survey unit 18 was scanned. In addition, 15 surface soil samples were collected using a random-start triangular grid pattern, along with one biased sample based on the GWS results. A retrospective power analysis (see Table 4.6) showed that only 14 samples were required. Survey unit 18 could have been scanned at a larger percentage; however, the activity of the outlier (1.2 pCi/g) was below the scan MDC of 3.7 pCi/g so additional scanning would not have identified this sampling location. The presence of rock outcroppings restricted access to other portions of survey unit 18, so 100% of the accessible areas were scanned for gamma activity. For these reasons, survey unit 18 was also reclassified as Class 2 without redesign of the survey.

Based on these findings, it was concluded that no changes to the sample design, or additional sampling efforts, would have been beneficial to improving the estimate of the average activity of ^{137}Cs within survey units 15 or 18.

Another consideration based on finding the ^{137}Cs outliers described above is whether the classification process used to design the survey was incorrect, and should all of the Class 3 survey units been classified as Class 2. For each of the remaining Class 3 survey units, 100% of the area was surveyed, and a retrospective power analysis (see Table 4.6) showed the minimum required number of samples was collected and the samples were distributed fairly regularly over the survey area. Since these survey units already received the equivalent of a Class 2 survey, no additional investigation would have been included as part of the survey design.

3.2 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. Subsurface soil samples were collected in two survey units 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).

3.2.1 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 10 centimeters above the ground and moved in parallel lines about 0.5 meters apart at a speed of roughly 0.5 meters per second. The measurements were position correlated using the GPS. Data were automatically logged with the measurement coordinates using a Trimble TDC1 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).

3.2.2 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. Tritium samples at site 4030 were collected in four-ounce jars and shipped off-site for analysis by liquid scintillation.

Subsurface soil samples were excavated using direct-push sampling by a GeoProbe® sampling rig. Each successive extraction contained subsurface soil encapsulated by a four foot by two inch clear acetate sleeve. The sleeve was sectioned into one foot intervals and held until the target depth was attained. The desired samples were then placed into one-gallon plastic bags and labeled as described above.

3.2.3 Exposure Rate Measurements

Exposure rate measurements were performed at biased sample locations using a Ludlum® Model 19 MicroR meter, which was 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 3.2. These values range from 15 – 17 microRoentgens per hour (μR/hr). Daily QC readings in a low background area averaged 8 μR/hr. 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 3.2 – Exposure Rate Measurements Summary

Site	***Biased Sample Number***	***Date/Time of Reading***	***Reading (μR/hr)***
4023	10SSS01600	12/07/06 14:25	16
4023	11SSS01600	12/07/06 14:30	16
4363	12SSS01600	12/07/06 08:55	16
4363	13SSS01600	12/07/06 08:45	15
4028	14SSS01600	12/07/06 14:05	16
4028	15SSS01600	12/07/06 14:10	16
4030	16SSS01600	12/08/06 11:10	16
4030	17SSS01600	12/08/06 15:50	16
4583	18SSS01600	12/07/06 12:20	17

3.2.4 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 and ^{3}H analysis by liquid scintillation. Duplicates, laboratory control samples, and blanks were performed as part of the off-site laboratory QC activities (see Section 5.2 and Appendix C).

3.3 Initial Survey Data Collection

The survey was designed to provide sufficient data to support a release decision for a MARSSIM Class 2 or 3 survey unit, or to determine if additional data were required prior to making a release decision for the 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 a random-start systematic grid (Class 2 units) or random grid (Class 3 units) 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 at sites 4023 and 4028.

3.3.1 Gross Gamma Walkover Survey

The gross gamma walkover survey was designed to cover at least 50% of the accessible areas in each Class 2 survey unit, and at least 10% of each Class 3 survey unit. Due to the small coverage area and high degree of accessibility, the actual coverage was 100% in all units except 4583, which remained at 10 – 20%. This survey unit had limited accessibility due to the natural brush coverage and rock outcroppings. Inaccessible areas such as boulders, rock piles, rock outcroppings, and areas with heavy brush within 4583 were not surveyed and appear as gaps in the survey coverage. Figure 1.6 illustrates obstructions such as brush and rock outcroppings which the surveyors encountered at site 4583.

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.

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.

3.3.2 Surface Soil Samples

The survey design required a minimum of 15 surface soil sample locations in each survey unit. The sample locations, shown in Figures 3.1 through 3.5 for the respective survey units, were selected based on a random-start systematic (triangular) grid (Class 2 survey units), or random locations (Class 3 survey units). The minimum number of samples collected from each survey unit was based on the modified (or surrogate ratio) DCGL 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 2 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 135 surface soil samples were collected from either random-start systematic or random locations. Nine biased samples were collected based on the results of the GWS, one sample at each of the nine survey units.

A deviation from the original survey design occurred by assigning samples in survey unit 4583 (Class 3) to a random-start, triangular grid instead of a random grid. This change was considered conservative since it met the requirements for a Class 2 survey unit. No data were rejected based upon this deviation from the FSP (CABRERA, 2006b)

3.3.3 Subsurface Soil Samples

Two subsurface soil samples were collected, whereas three were planned. One was collected at site 4023 (survey unit 11), and was intended to be representative of the soils beneath a former sump pit. A target depth of 12 feet bgs was not attained due to seven refusals of the GeoProbe® occurring at depths of ranging from three to six feet bgs. These refusals were located in an approximate twenty foot radius from the original location, and were caused by a bedrock layer. One of the excavations to a depth of four feet bgs was selected as the most probable location of the former sump pit. The soil between depths of three and four feet bgs was removed for analysis (11SUS01703, sample location from survey unit 11 at a depth of 3 feet bgs). Subsurface sampling efforts were then discontinued at survey unit 11.

Two samples were planned at site 4028 that were intended to be representative of the soils beneath a former reactor pit and uranium furnace that were expected to be at a depth of 20 feet bgs. The planned locations were on a steep grade that was inaccessible by the GeoProbe® vehicle. One sample location was moved from survey unit 14 to an adjacent area in survey unit 15 that was on level ground. Direct-push efforts began, and encountered refusal at 16.5 feet bgs. The soil between depths of 15 and 16 feet were removed for analysis (15SUS01815, sample location 18 from survey unit 15 at a depth of 15 feet bgs). Subsurface sampling efforts were then discontinued at survey unit 15.

Given the nature of the subsurface barriers, available equipment, scheduling constraints, budget, and historical data (Rocketdyne, 1991, ETEC, 1994), the final locations and depths of samples 11SUS01703 and 15SUS01815 were approved by the Boeing PM as acceptable to satisfy the purpose of the subsurface sampling.

3.4 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.

3.4.1 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 exploratory data analysis (i.e., cumulative frequency distributions, 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 3.6 is an example of a plotted data file from survey unit 4023. 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. All survey units within this investigation 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.

Contour maps of the overall survey area and each individual survey unit were 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 are represented in Figures 3.7 through 3.11. The four color divisions represent various ranges of z-score values (see Section 3.4.1) 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 in survey units 10, 11, 12, 13, 14, 15, 17 and 18. Where no contours greater than 3.0 were identified in a survey unit, a minimum of one biased sample location was selected at the point of the highest gross gamma count rate (survey unit 16). GPS data were used to locate each biased sample location (northing and easting point) in the field. A total of 9 samples were collected from biased sample locations.

3.5 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 sum-of-fractions results were below the DCGL.

3.5.1 Off-site Laboratory Analysis

The off-site laboratory performed gamma spectroscopy, alpha spectrometry (isotopic uranium and plutonium), liquid scintillation counting (^{3}H, ^{241}Pu), and gas flow proportional counting (^{90}Sr) of the surface soil samples. None of the 146 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.

3.5.2 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.

3.6 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 3.3.

Table 3.3 – 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.	Eight biased sample locations selected for sampling from areas with z-score greater than 3.0 (survey units 10, 11, 12, 13, 14, 15, 17 and 18).

Parameter of Interest	***Criteria***	***Action Taken***
	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 16).
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.
	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 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 137Cs results exceeded the $DCGL_{Cs,mod}$, therefore, no further action was taken.

4.0 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, ^{241}Pu, and ^{3}H.

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, but for health and safety purposes (see Section 3.2.3). 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 3.4. The off-site laboratory performed gamma spectroscopy and alpha spectrometry analyses of the soil samples. Radionuclide-specific analyses for ^{90}Sr, ^{3}H and ^{241}Pu were also performed by the off-site laboratory to identify and measure these beta-emitting radionuclides of concern.

4.1 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.

4.2 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, cumulative frequency distributions, 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, 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, ^{3}H, ^{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 4.1 – 4.18. 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 4.1 below for both random-start systematic, random, and biased samples. Results are reported as pCi/g dry weight.

Table 4.1 – 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	146	0	-0.0039	0.048	0.12	-0.10	0.16
Cesium-134	901.1 MOD	146	0	0.00012	0.022	0.066	-0.050	0.069
Cesium-137	901.1 MOD	146	0	0.014	0.10	1.2	-0.050	0.089
Cobalt-60	901.1 MOD	146	0	0.0014	0.026	0.095	-0.084	0.090
Europium-152	901.1 MOD	146	0	-0.012	0.049	0.12	-0.13	0.13
Europium-154	901.1 MOD	146	0	0.0095	0.16	0.40	-0.53	0.093
Manganese-54	901.1 MOD	146	0	0.0066	0.022	0.082	-0.050	0.084
Plutonium-238	A-01-R MOD[2]	146	0	0.0018	0.015	0.080	-0.028	0.049
Plutonium-239/40	A-01-R MOD	146	0	0.0011	0.010	0.044	-0.033	0.034
Plutonium-241	STL-RC-0245[3]	146	0	0.36	1.2	4.4	-2.2	3.3
Strontium-90	905 MOD[4]	146	0	0.072	0.16	0.5	-0.65	0.48
Thorium-228, 232[6]	901.1 MOD	146	0	1.2	0.18	1.7	0.0	0.32
Tritium	906.0 MOD[5]	32	0	0.18	0.33	1.2	-0.15	0.55
Uranium-234	A-01-R MOD	146	0	0.87	0.21	2.3	0.56	0.055
Uranium-235/236	A-01-R MOD	146	0	0.038	0.022	0.11	-0.0090	0.043
Uranium-238	A-01-R MOD	146	0	0.89	0.20	2.1	0.56	0.044

[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.

4.2.1 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 with two outliers (see Figures 4.1 and 4.2). The average and maximum are 0.014 and 1.2 pCi/g, respectively.

Cesium-137 was detected above the MDC (0.1 pCi/g) in 3 samples. The highest result was 1.2 pCi/g in sample 18SSS00700 (surface soil sample from location 007 in survey unit 18). This outlier may have been elevated due to its location. The location of 18SSS00700 was along the northern perimeter of the rock outcropping shown in Figure 1.6, in a likely collection point for surface runoff (see Figures 1.7 and 3.11). Collection and evaporation of surface runoff from nearby areas may have provided a natural concentration mechanism.

Samples 15SSS00800 and 15SSS01400 (surface soil samples from locations 008 and 014 in survey unit 15) were also above the MDC, with results of 0.13 and 0.29 pCi/g, respectively, although only 15SSS01400 was considered to be an outlier.

Survey unit 15 (Site 4030) and survey unit 18 (Site 4583) were both assigned as Class 3 survey units in the FSP (CABRERA, 2006b). Since these Class 3 survey units contained unexpected outliers, they were reclassified as Class 2 (see Section 3.1).

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 shown in Appendix A.

4.2.2 Alpha Spectrometry Results

Surface soil samples were analyzed by alpha spectrometry for uranium and plutonium isotopes. All of the samples reported ^{234}U and ^{238}U above the MDC. One sample of $^{235/236}$U was reported above the MDC, but was not considered an outlier based on the CFD (see Figure 4.7) and histogram (see Figure 4.8). This result was not investigated further.

Three samples containing ^{238}U were considered to be outliers, although they were well below their respective DCGLs (see Figures 4.3 – 4.8). Each of these three samples also contained outliers for ^{234}U. These samples were 10SSS00400, 14SSS00600, and 15SSS01600 (Sites 4023 Class 2, 4028 Class 2 and 4028 Class 3, respectively). Concentration data (pCi/g) for these points are shown in Figures 4.3 and 4.5. 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 (17SSS00600), and two for ^{238}Pu (12SSS00300, 17SSS01500) (see Figures 4.9 – 4.12). One sample result exceeded (0.044 pCi/g) the average MDC (0.034 pCi/g) for the $^{239/240}$Pu analytical method. No sample results exceeded the average MDC (0.049 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.

4.2.3 Results of Radionuclide-Specific Analyses for ^{90}Sr, ^{3}H and ^{241}Pu

Surface soil samples were analyzed by gas proportional beta analysis for ^{90}Sr and liquid scintillation analysis for ^{241}Pu and ^{3}H. No samples reported ^{241}Pu above the MDC, however, three were identified as potential outliers (12SSS00500, 4.4 pCi/g; 16SSS01200, 4.0 pCi/g; 17SSS00200 4.0 pCi/g, see Figures 4.13 and 4.14). 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.

None of the samples reported ^{90}Sr concentrations above the MDC. The average concentration of ^{90}Sr was 0.072 ± 0.16 pCi/g. The ^{90}Sr data are also consistent with a normally distributed background population with no outliers (see Figures 4.17 and 4.18).

The results for ^{3}H show the distribution is skewed towards a maximum value of 1.2 pCi/g (see Figures 4.15 and 4.16). The maximum value was less than 1% of the DCGL (228 pCi/g), and only slightly above the average MDC (0.55 pCi/g). These results were not investigated further.

4.2.4 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 4.2. Thus, no uranium contamination was identified.

4.3 Off-site Laboratory MDCs - Target vs. Achieved

Target MDC values, given in Table 4.2, 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 35 analyses reported MDCs greater than the target MDC. Twenty-nine of these were for ^{137}Cs (target MDC 0.1 pCi/g, range 0.11 – 0.13 pCi/g), five for ^{238}Pu (target MDC 0.1 pCi/g, range 0.11 – 0.16 pCi/g), and one for ^{234}U (target MDC 0.1 pCi/g, 0.11 pCi/g).

Table 4.2 – Target vs. Achieved Off-site Laboratory MDCs

Constituent	*Analysis Method*	*No. Samples > 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	146	0.16	0.23	0.1
Cesium-134	901.1 MOD	0	0.3	146	0.069	0.11	0.1
Cesium-137	901.1 MOD	3	0.1	146	0.089	0.13	0.1
Cobalt-60	901.1 MOD	0	0.2	146	0.090	0.14	0.1
Europium-152	901.1 MOD	0	1	146	0.13	0.19	0.1
Europium-154	901.1 MOD	0	1.3	146	0.093	0.13	0.1
Manganese-54	901.1 MOD	0	0.5	146	0.084	0.12	0.1
Plutonium-238	A-01-R MOD[2]	0	0.1	146	0.049	0.16	0.021
Plutonium-239/40	A-01-R MOD	0	0.1	146	0.034	0.088	0.017
Plutonium-241	STL-RC-0245[3]	0	20	146	3.3	13	1.8
Strontium-90	905 MOD[4]	0	1	146	0.48	1.0	0.25
Thorium-228, 232[6]	901.1 MOD	126	1	146	0.32	0.85	0.22
Tritium	906.0 MOD[5]	0	23	32	0.55	0.66	0.50
Uranium-234	A-01-R MOD	146	0.1	146	0.055	0.11	0.020
Uranium-235/236	A-01-R MOD	1	0.1	146	0.043	0.088	0.017
Uranium-238	A-01-R MOD	146	0.1	146	0.044	0.10	0.010

[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.

4.4 Data Evaluation by Survey Unit

None of the sample results exceeded their respective DCGLs for any radionuclide at any of the nine sites. One small area of elevated gross gamma activity was identified in survey unit 18 (Site 4583) by GWS; however, the biased soil sample taken at that location had results below DCGLs.

A total of 146 soil samples were collected from 75 random-start systematic locations, 60 random locations, and nine biased (based on GWS). The total of 146 also includes two biased subsurface samples. One biased subsurface sample location was planned, but not collected at survey unit 14 (see Section 3.3.3). The two other biased subsurface locations at 4023 (sump pit) and 4028 (reactor pit) were collected, but repeated refusals at a bedrock layer prevented attainment of the specified target depth. In addition, the topography at 4028 required movement of the sample to a location that was accessible to the GeoProbe® (see Section 3.3.3). The angle of the GeoProbe® was adjusted to collect core samples near the original location; therefore, the sample was considered representative of the planned location.

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, cumulative frequency distributions, 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 4.3.

Table 4.3 – Survey Unit Sampling and Summary Statistics for Selected Nuclides

Site	***4023***	***4023***	***4363***	***4363***	***4028***	***4028***	***4030***	***4030***	***4583***	***Total***
Class	2	3	2	3	2	3	2	3	3	
Survey Unit Number	10	11	12	13	14	15	16	17	18	
#Systematic Samples	15	0	15	0	15	0	15	0	15	75
#Random Samples	0	15	0	15	0	15	0	15	0	60
#Biased Surface Samples	1	1	1	1	1	1	1	1	1	9
#Biased Subsurf. Samples	0	1	0	0	0	1	0	0	0	2
Total	16	17	16	16	16	17	16	16	16	146
Parameter	***^{137}Cs, Random and Biased Samples (pCi/g)***									
Average	-0.0048	-0.0028	0.0064	0.0053	-0.0013	0.035	0.0023	0.00088	0.081	0.014
Standard Deviation	0.016	0.021	0.033	0.032	0.022	0.080	0.016	0.021	0.29	0.10
Maximum	0.02	0.05	0.06	0.078	0.043	0.29	0.039	0.043	1.16	1.16
Minimum	-0.043	-0.031	-0.048	-0.048	-0.033	-0.032	-0.022	-0.042	-0.05	-0.05
	^{90}Sr, Random and Biased Samples (pCi/g)									
Average	0.15	0.043	0.12	0.19	-0.094	0.034	0.018	0.091	0.10	0.072
Standard Deviation	0.13	0.18	0.10	0.12	0.18	0.14	0.15	0.086	0.15	0.16
Maximum	0.38	0.33	0.28	0.48	0.17	0.4	0.24	0.28	0.45	0.48
Minimum	-0.17	-0.35	-0.07	0.0	-0.65	-0.18	-0.26	-0.070	-0.18	-0.65
	^{3}H, Random and Biased Samples (pCi/g)									
Average							0.046	0.31		0.18
Standard Deviation							0.26	0.34		0.33
Maximum							0.82	1.23		1.23
Minimum							-0.15	0.0020		-0.15

4.4.1 Survey Units 10 and 11 (Site 4023)

Samples were collected from 15 random-start systematic sample locations in survey unit 10, and 15 random locations in survey unit 11. The GWS was performed over 100% of survey units 10 and 11, and the data were combined. Eighteen out of 5562 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 3.1 and 3.7). One subsurface sample was collected to investigate a former sump pit (sample 11SUS01703, see Section 3.3.3). None of the samples reported radionuclide concentrations above their respective DCGLs.

4.4.2 Survey Units 12 and 13 (Site 4363)

Samples were collected from 15 random-start systematic sample locations in survey unit 12, and 15 random locations in survey unit 13. The GWS was performed over 100% of survey units 12 and 13, and the data were combined. Twenty-two out of 8861 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 3.2 and 3.8). None of the samples reported radionuclide concentrations above their respective DCGLs.

4.4.3 Survey Units 14 and 15 (Site 4028)

Samples were collected from 15 random-start systematic sample locations in survey unit 14, and 15 random locations in survey unit 15. The GWS was performed over 100% of survey units 14 and 15, and the data were combined. Twelve out of 7492 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 3.3 and 3.9). One subsurface sample was collected to investigate a former reactor pit (sample 15SUS01815, see Section 3.3.3). None of the samples reported radionuclide concentrations above their respective DCGLs.

4.4.4 Survey Units 16 and 17 (Site 4030)

Samples were collected from 15 random-start systematic sample locations in survey unit 16, and 15 random locations in survey unit 17. The GWS was performed over 100% of survey units 16 and 17, and the data were combined. Sixteen out of 8025 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 3.4 and 3.10). None of the samples reported radionuclide concentrations above their respective DCGLs.

4.4.5 Survey Unit 18 (Site 4583)

Samples were collected from 15 random-start systematic sample locations in survey unit 18 (see Section 3.3.2). The GWS was performed over 20% of survey unit 18, and the data were combined. Twenty out of 3476 measurements exceeded a z-score of 3 (<1%). What appeared to be a small area of elevated activity south of the large rock outcropping was investigated with biased surface soil sample (see Figures 3.5 and 3.11). None of the samples, including the biased location, reported radionuclide concentrations above their respective DCGLs.

4.5 Statistical Test

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

4.5.1 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 Ra, Th, and U radionuclides (see following section).

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

4.5.2 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 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. 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 Ra, Th, and U radionuclides of concern. This was done 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 4.4. 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 4.4 – 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*
10	15	15	15	15	15	15	15	11	PASS
11	15	15	15	15	15	15	15	12	PASS
12	15	15	15	15	15	15	15	11	PASS
13	15	15	15	15	15	15	15	11	PASS
14	15	15	15	15	15	15	15	11	PASS
15	15	15	15	15	15	15	15	12	PASS
16	15	15	15	15	15	15	15	11	PASS
17	15	15	15	15	15	15	15	11	PASS
18	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. 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 all nine survey units.

The eleven 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.

4.5.3 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 4.5, are from the FSP (CABRERA, 2006b) and are based on the concentration of ^{137}Cs in the surface soil.

Table 4.5 – Retrospective Power Analysis Assumptions

Parameter	*Value*
^{137}Cs $DCGL_{Cs,mod}$	4.7 pCi/g
Assumed Standard Deviation (σ)	1.84 pCi/g

Lower Bound of Gray Region (LBGR)	0.92 pCi/g
False Positive Decision Error (α)	0.05
False Negative Decision Error (β)	0.05

The results, shown in Table 4.6, 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 4.6 – Retrospective Power Analysis by Survey Unit

Analysis Parameter	***Survey Unit***								
	10	***11***	***12***	***13***	***14***	***15***	***16***	***17***	***18***
Actual Std Dev (pCi/g), ^{137}Cs	0.016	0.022	0.035	0.032	0.020	0.084	0.017	0.022	0.30
Required Number	14	14	14	14	14	14	14	14	14
Number Collected	15	15	15	15	15	15	15	15	15
Result	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass

A retrospective power curve for survey unit 18 is shown in Figure 4.19. The curve shows the probability of rejecting the null hypothesis versus the concentration of radioactivity. In the case of survey unit 18, where the average concentration is far 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.

5.0 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.

5.1 Portable Instrumentation

Table 5.1 lists the types of portable instrumentation that were used during the course of this investigation.

Table 5.1 – 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

5.1.1 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.

5.1.2 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.

5.1.3 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 Area IV, Block 1 were identified with ^{137}Cs concentrations above 1.2 pCi/g, which is the maximum value measured by the off-site laboratory. This sample point (18SSS00700) was in survey unit 18 (Site 4583), and did not have associated GWS data. 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 as high as 0.072 pCi/g (sample location 15SSS01600 in survey unit 15). 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 Site 4614 (RMHF Holdup Pond, CABRERA, 2006c) 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.

5.2 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.

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[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.

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

Table 5.2 – Laboratory Quality Control

QC Check	*Minimum Frequency*	*Acceptance Criteria*
Off-site Laboratory (Gamma Spectroscopy, Alpha Spectrometry, Gas Proportional, Liquid Scintillation)		
Laboratory Control Sample (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

5.2.1 Off-site Laboratory Duplicate Analyses

The off-site laboratory performed duplicate sample counts in eight different samples of 146 measured (5.5%), meeting the required frequency of 5% or one per 20. The total number of results that were not qualified as U (<MDC) was 75. Two of these 75 results had RPD exceeding 35% (^{208}Tl, 11SSS00600, 41% and ^{238}U, 14SSS01100, 52%). Results for different nuclides within the same samples showed acceptable agreement between sample and duplicate. Therefore, the results were considered acceptable, and no results were rejected based on RPD results. The full table showing the 75 results are provided electronically in Appendix C.

5.2.2 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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6.0 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.

6.1 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 not identified during the course of this investigation.

6.2 Nature and Lateral Extent of Radioactive Contamination

Since radionuclide concentrations did not exceed the project action levels, lateral extent could not be delineated at any of the nine survey units.

6.3 Verification of Survey Design Assumptions

The survey was designed as a graded approach for thorough characterization with the intensity of a Class 2 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.

6.4 Areas Where Data Support Recommendation for Unrestricted Release

The data collected in all survey units (10, 11, 12, 13, 14, 15, 16, 17, and 18) are of sufficient quantity and quality to support a recommendation for unrestricted release.

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7.0 RECOMMENDATIONS

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

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8.0 REFERENCES

Boeing 1998. *Approved Sitewide Release Criteria for Remediation of Radiological Facilities at the SSFL*, Report No. N001SRR140131, December 1998.

CABRERA 2006a. *Final Status Survey Report: Characterization and Final Status Survey Radioactive Materials Handling Facility Perimeter,* Cabrera Services, Inc., March, 2006.

CABRERA 2006b. *Field Sampling Plan: Final Status Survey Post Historical Site Assessment Sites, Block 1*, Cabrera Services, Inc., November, 2006.

CABRERA 2006c. *Final Status Survey Report: Characterization and Final Status Survey Radioactive Materials Handling Facility Holdup Pond (Site 4614),* Cabrera Services, Inc., Pending.

DOE 1990. *Radiation Protection of the Public and the Environment,* DOE Order 5400.5, United States Department of Energy, February 1990.

EPA 2000a. *Multi Agency Radiation Survey and Site Investigation Manual (MARSSIM)*, 402-R-97-016, Revision 1, United States Environmental Protection Agency, August 2000.

EPA 2000b. *Guidance for the Data Quality Objectives Process*, EPA QA/G-4, EPA/600/R-96/055, United States Environmental Protection Agency, September 2000.

ETEC 1994. *Safety Review Report, Final Radiological Survey Report of Building 023*, 023-ZR-0001, 1994.

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

Rocketdyne 1991. *Final Decontamination and Radiological Survey of Building T028*, N704SRR99033, February, 1991.

Sapere 2005. *Historical Site Assessment of Area IV, Santa Susana Field Laboratory, Ventura County, California*, Sapere Consulting, Inc. and The Boeing Company, May 2005.

Attachment 1

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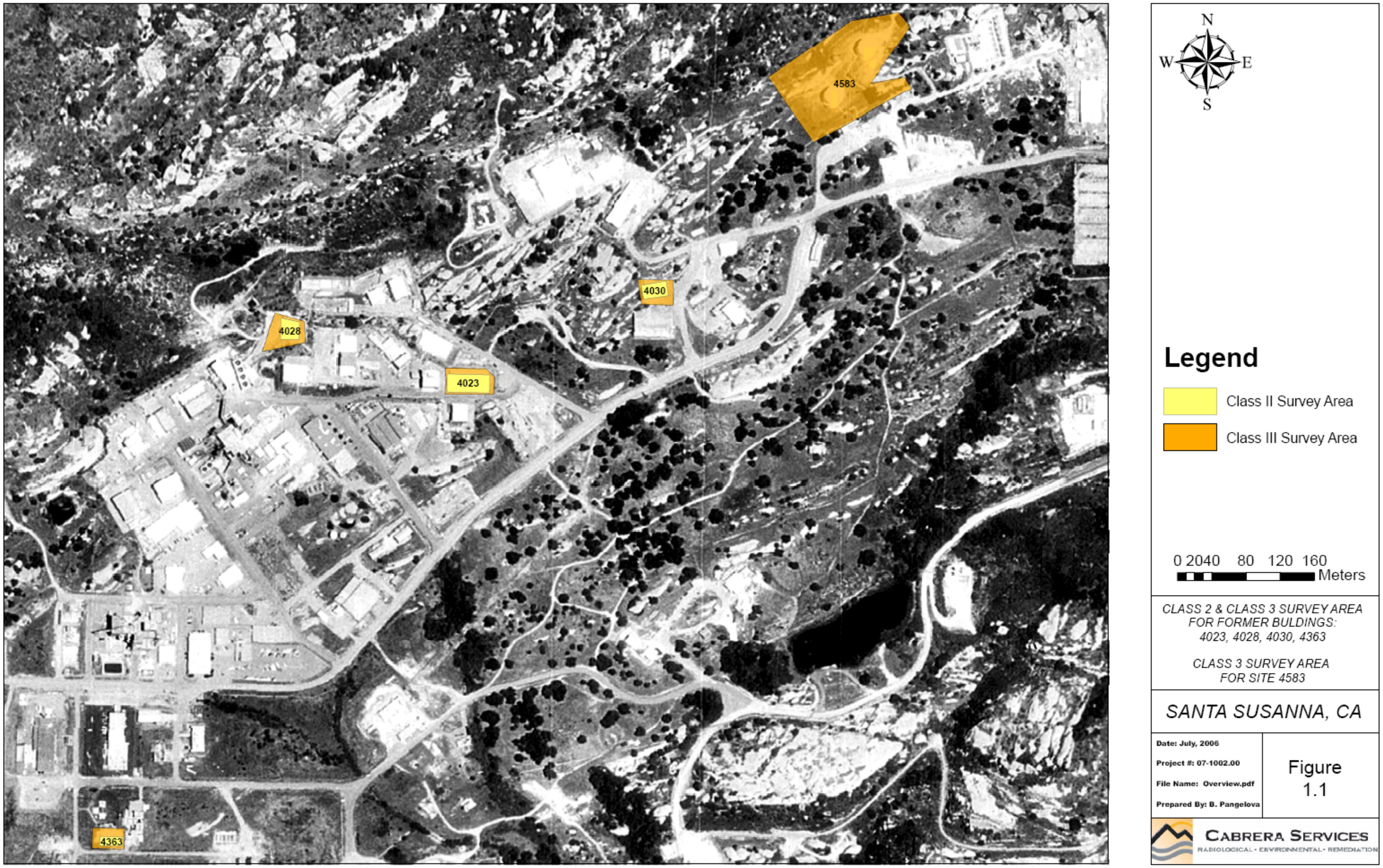

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Figure 1.3 Site 4363 (NE View)

Figure 1.4 Site 4028 (NE View)

Figure 1.5 Site 4030 (W View)

Figure 1.6 Site 4583 (NW View)

Figure 1.7 Site 4583, Location of Sample 18SSS00700

Figure 3.1 Soil Sample Locations, Site 4023

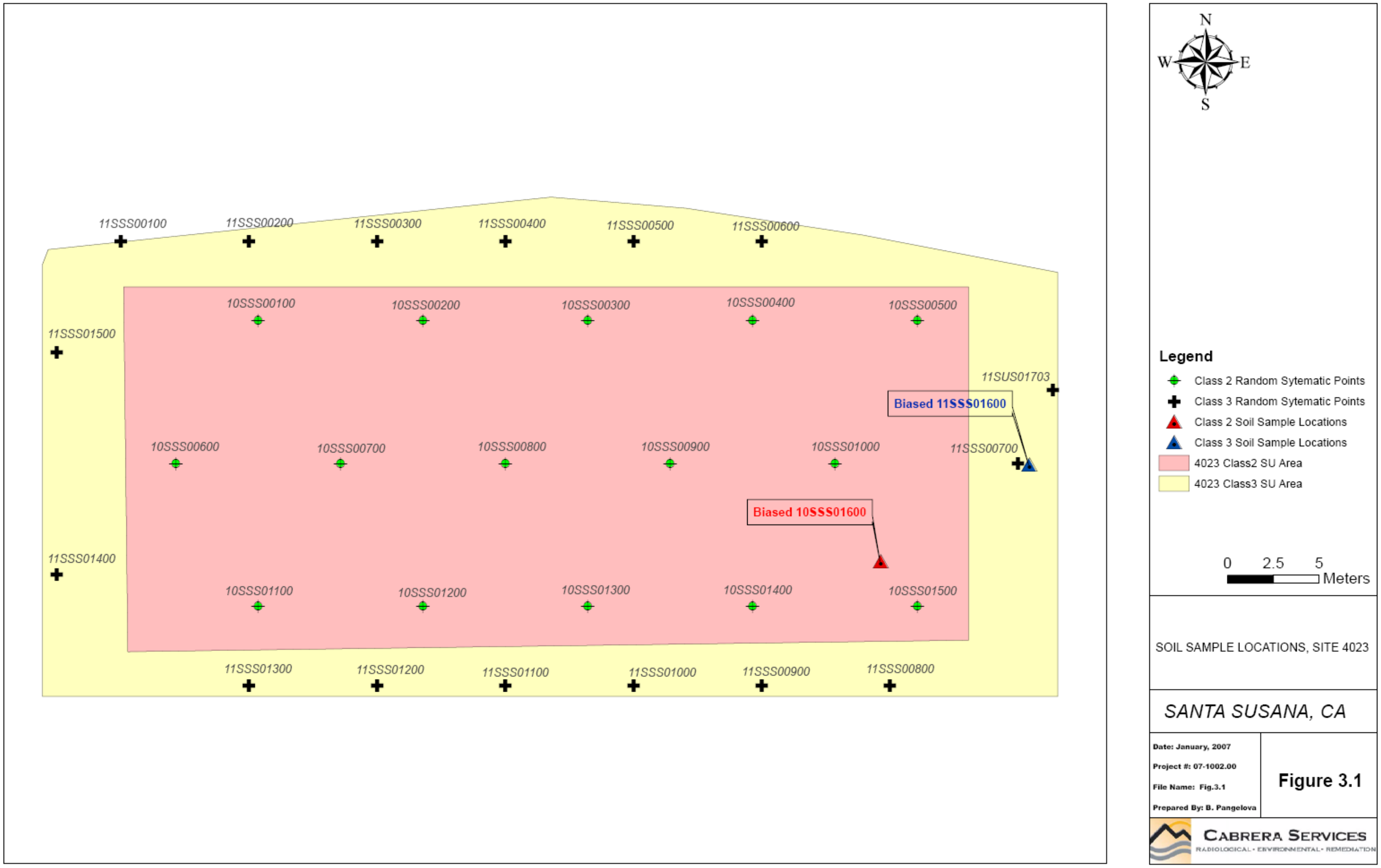


Figure 3.2 Soil Sample Locations, Site 4363

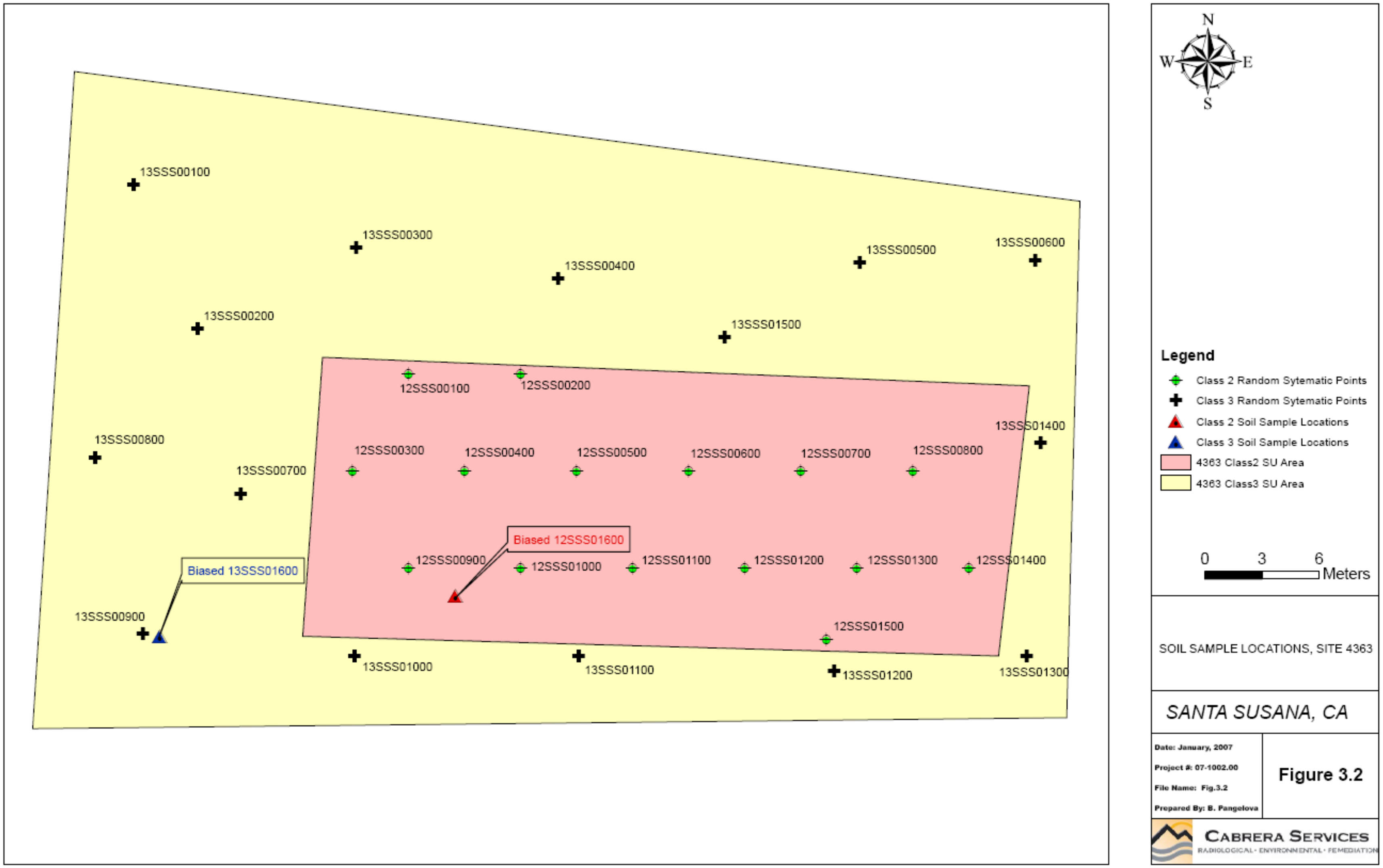


Figure 3.3 Soil Sample Locations, Site 4028

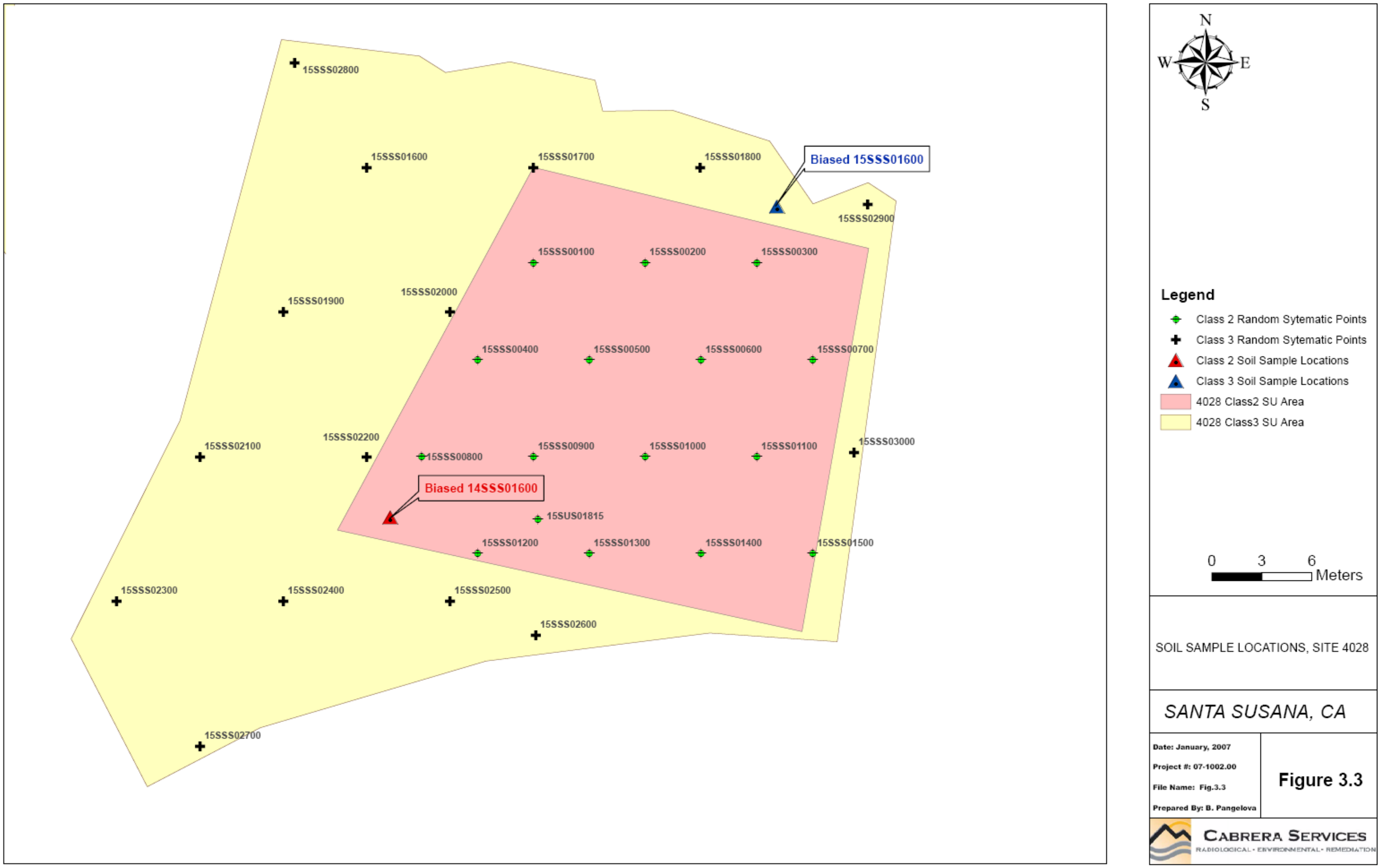


Figure 3.4 Soil Sample Locations, Site 4030

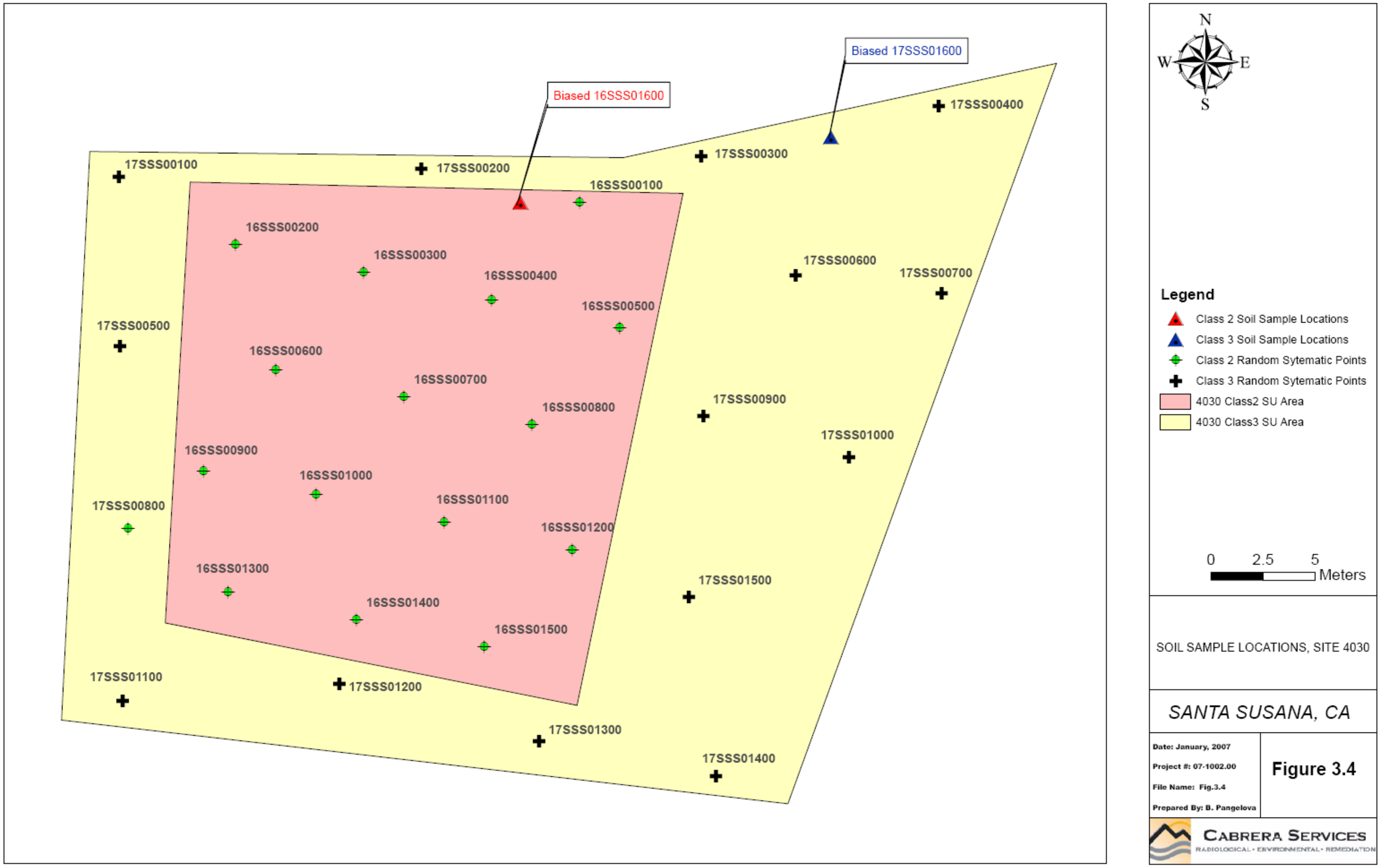


Figure 3.5 Soil Sample Locations, Site 4583

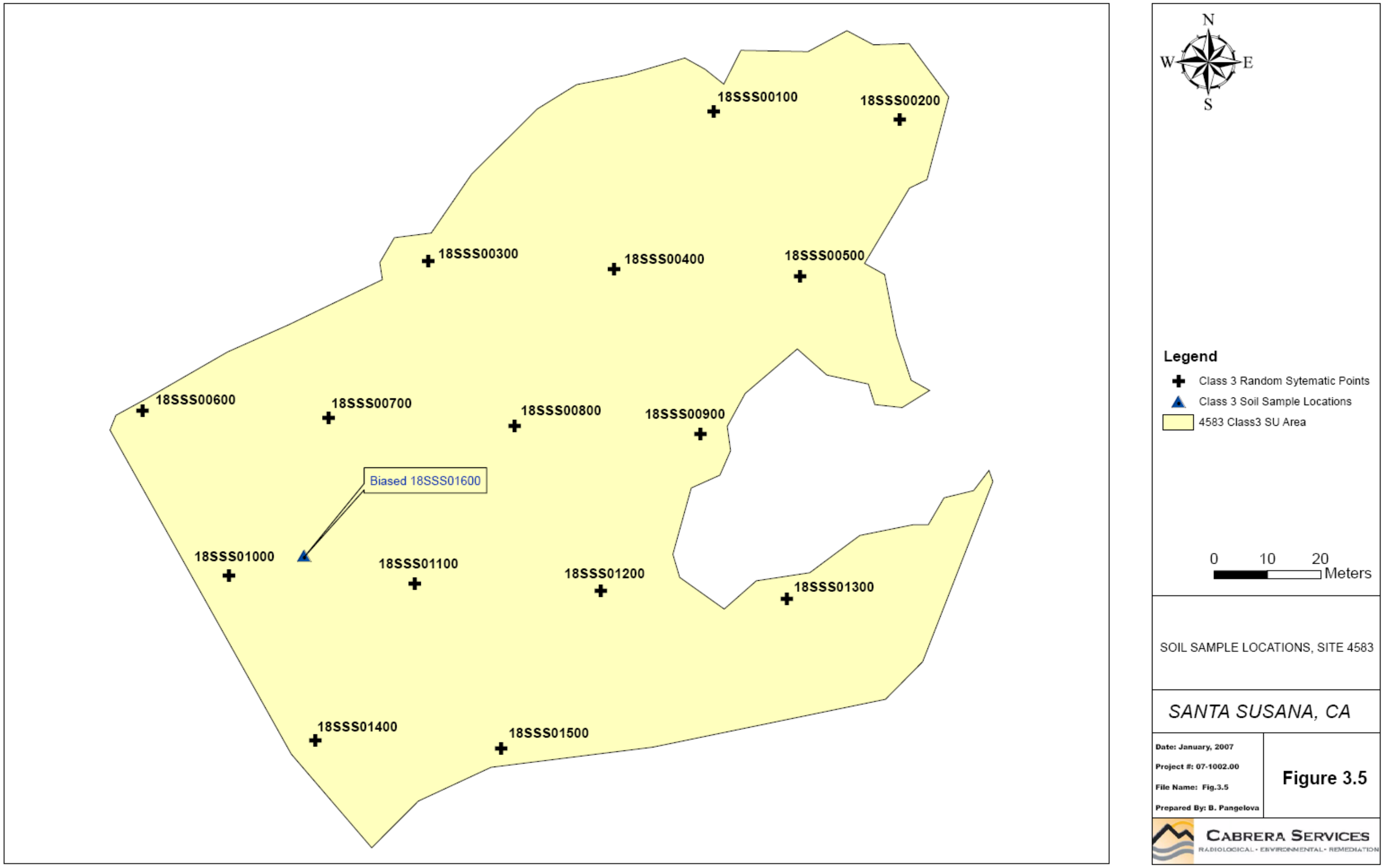


Figure 3.6 Example Cumulative Frequency Distribution For Survey Unit 4023

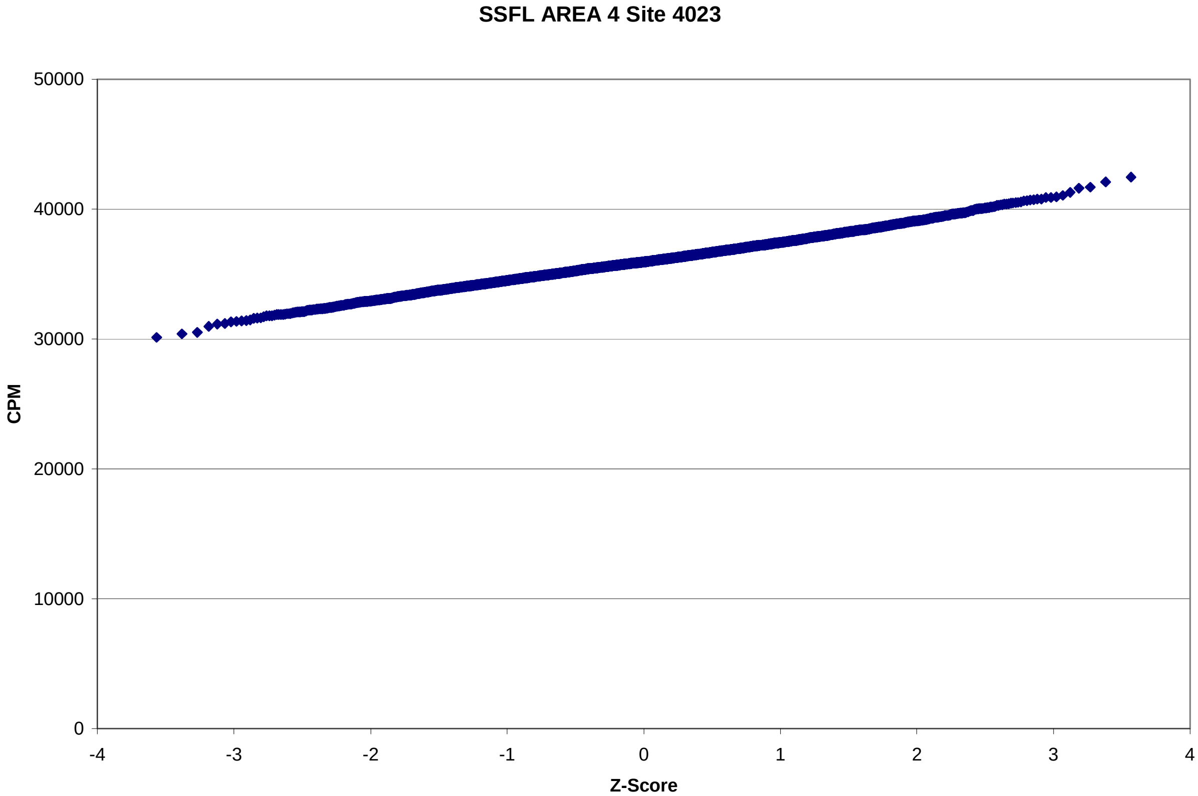
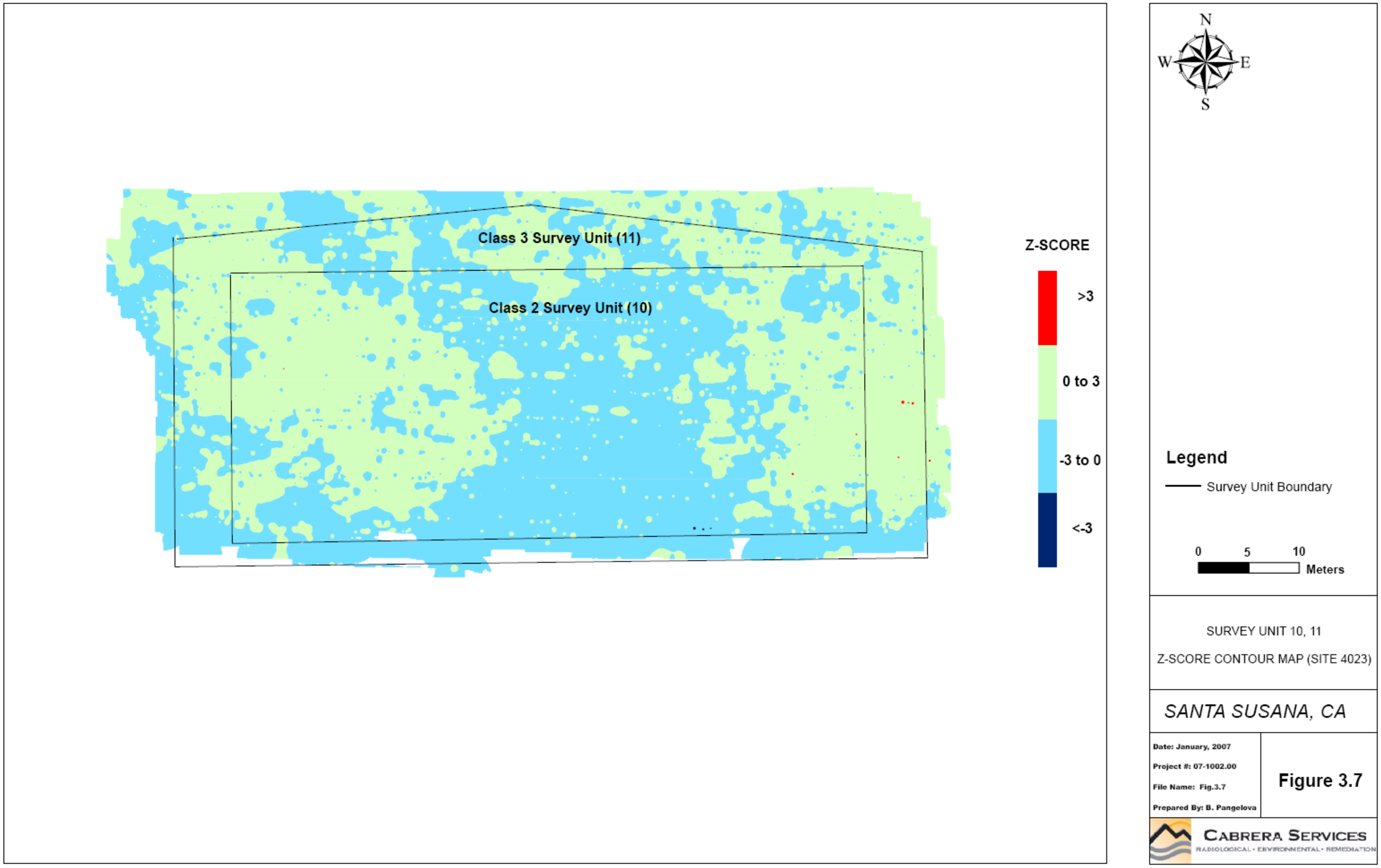


Figure 3.7 Survey Unit 10, 11 Z-Score Contour Map (Site 4023)



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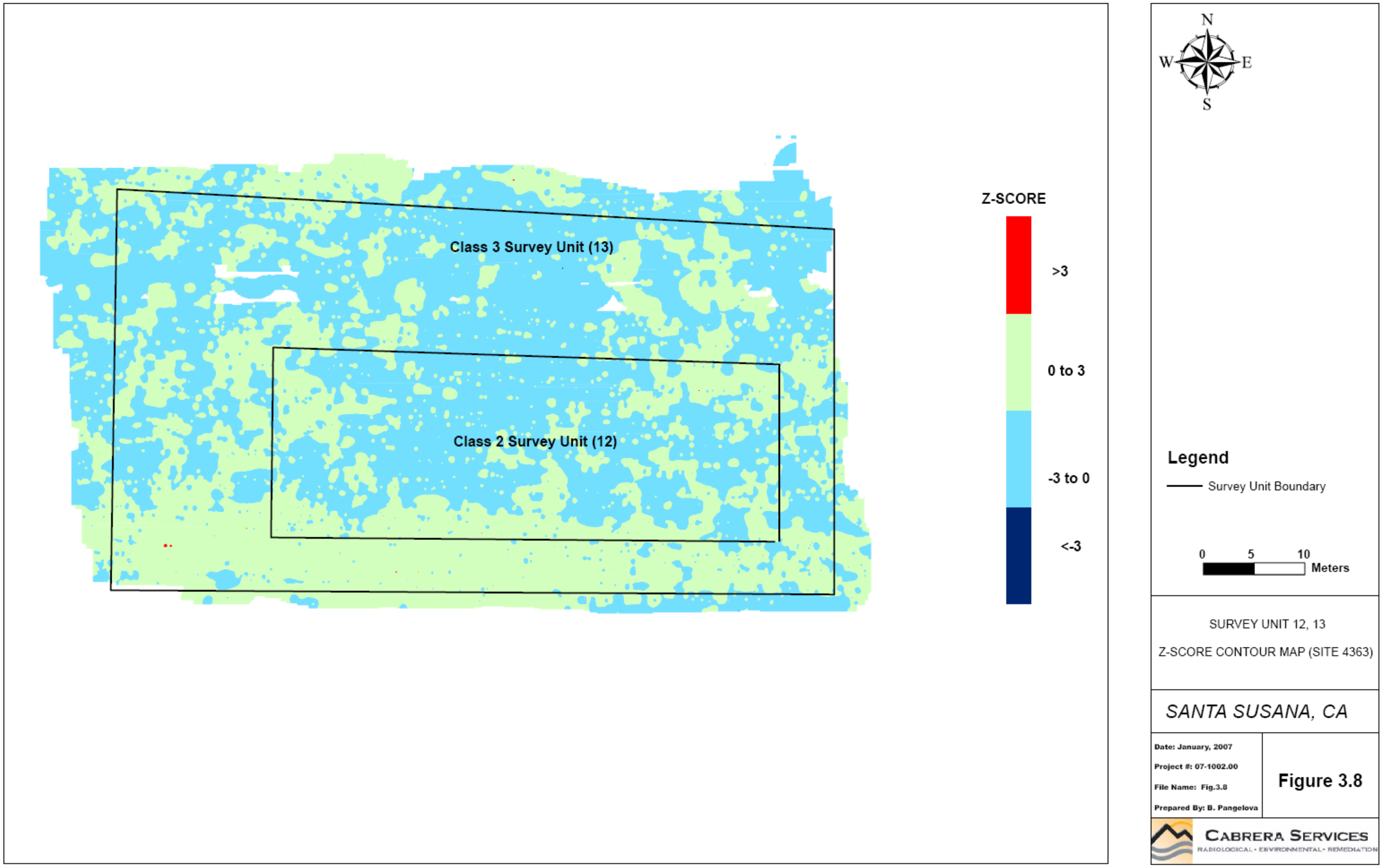

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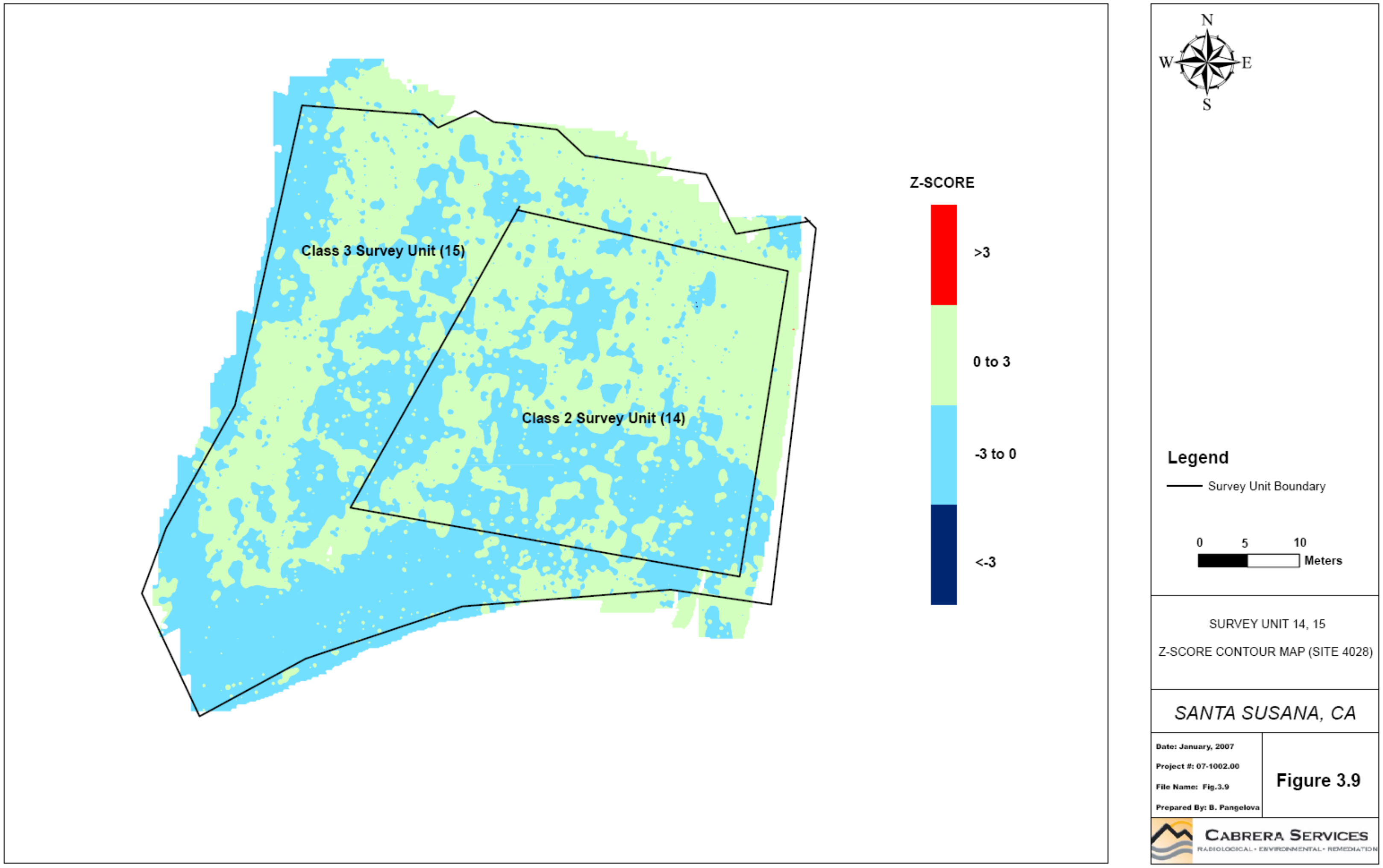

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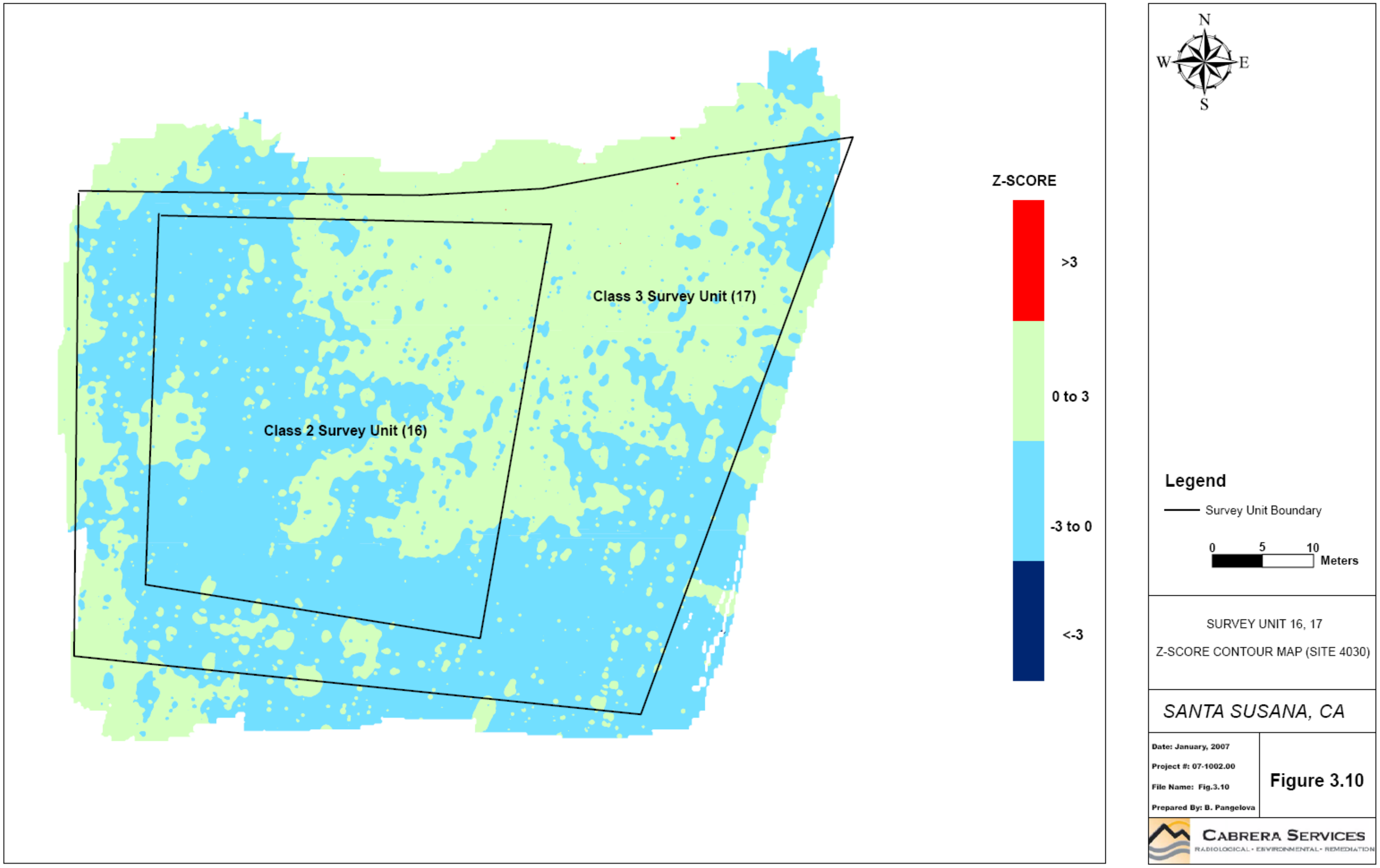


Figure 3.11 Survey Unit 18 Z-Score Contour Map (Site 4583)

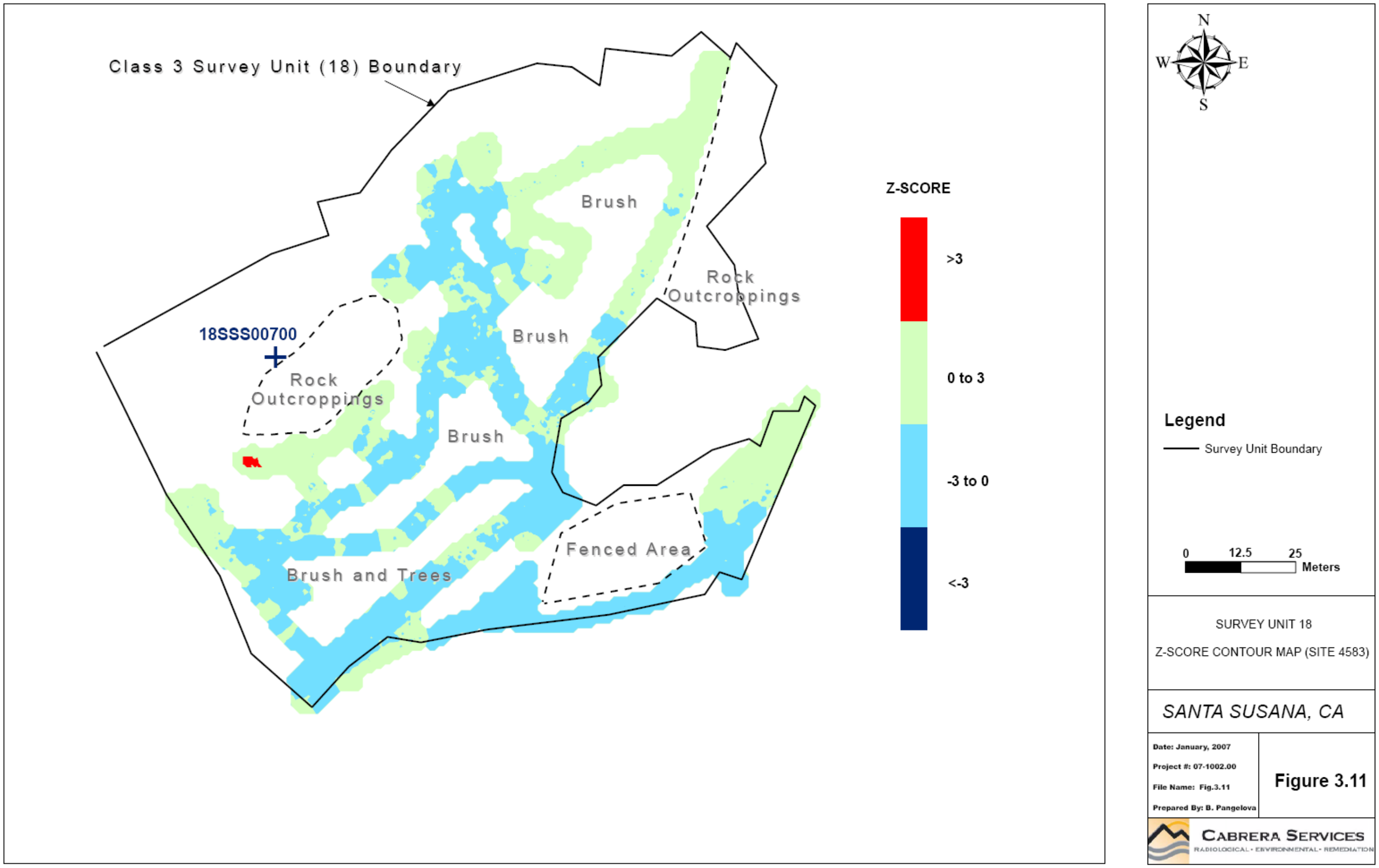


Figure 4.1 Cumulative Frequency Distribution, Area IV, ^{137}Cs

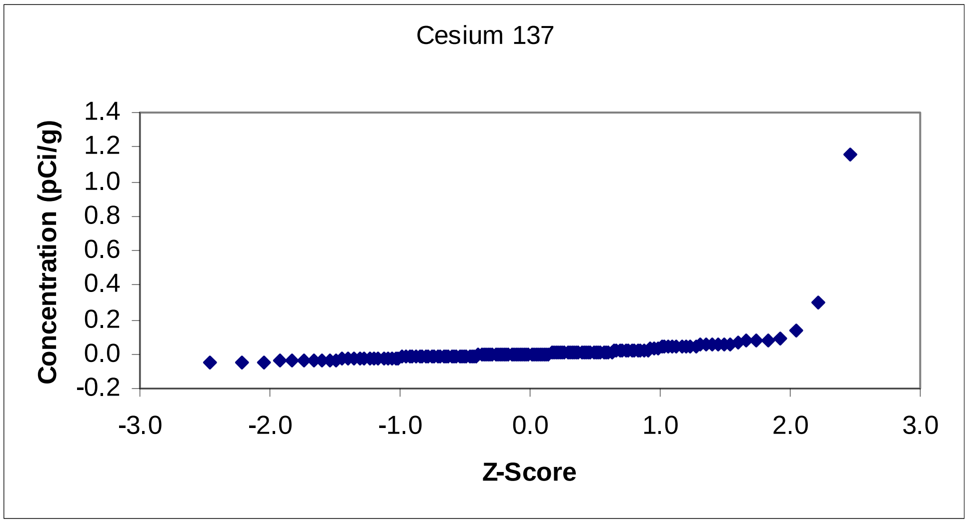


Figure 4.2 Frequency Plot, Area IV, ^{137}Cs

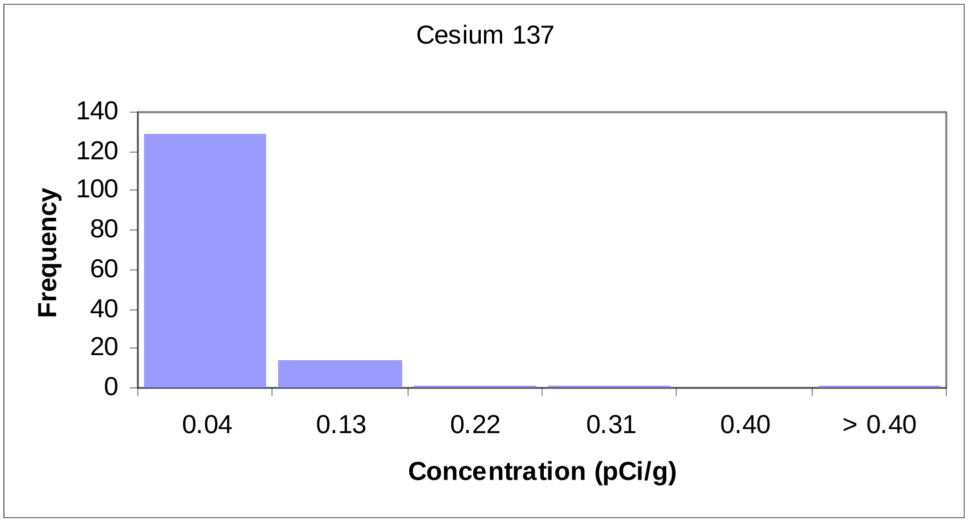


Figure 4.3 Cumulative Frequency Distribution, Area IV, ^{234}U

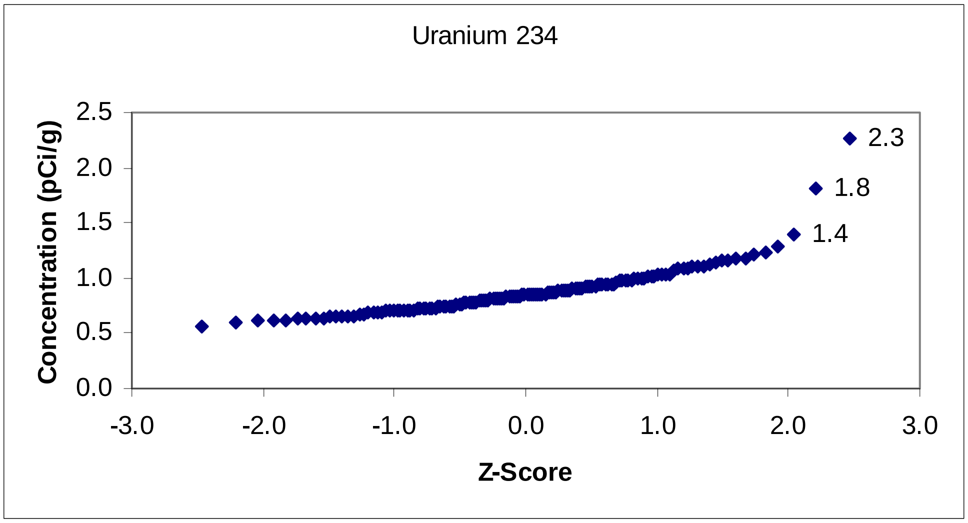
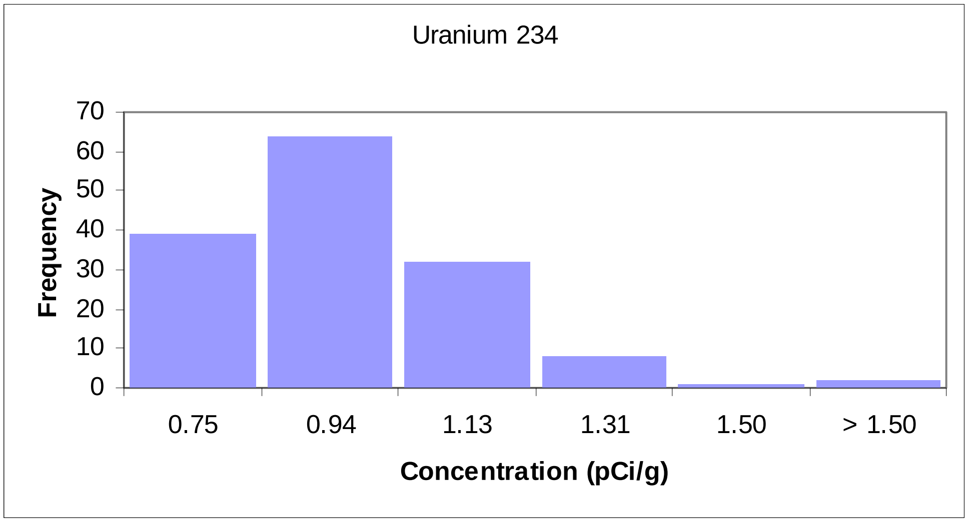


Figure 4.4 Frequency Plot, Area IV, ^{234}U



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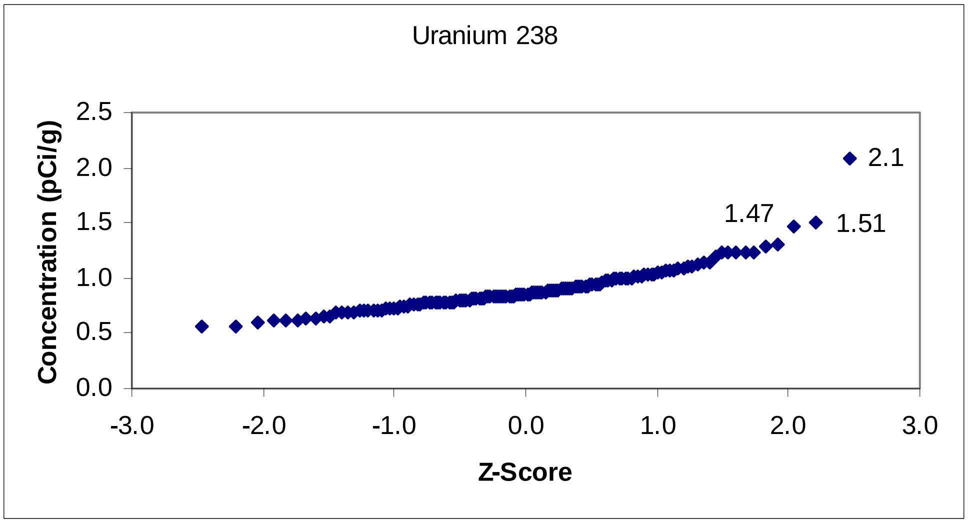

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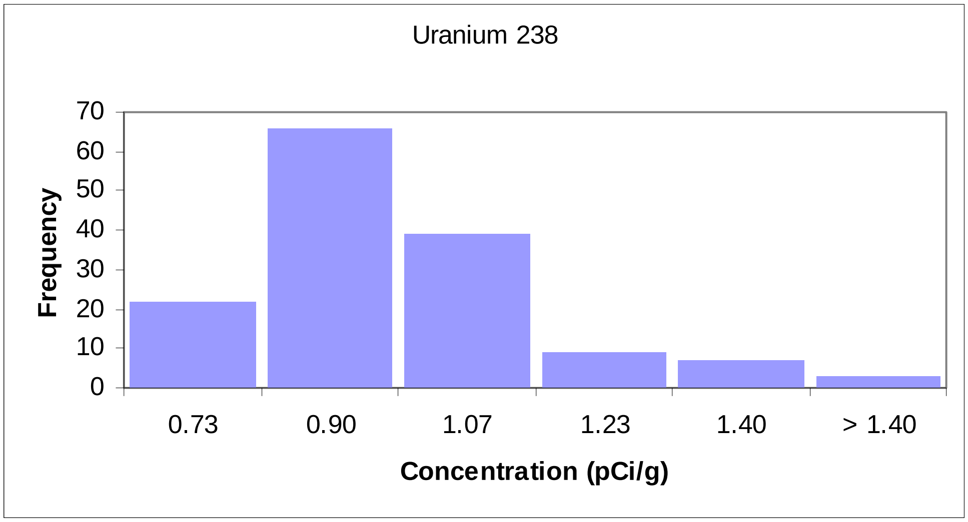
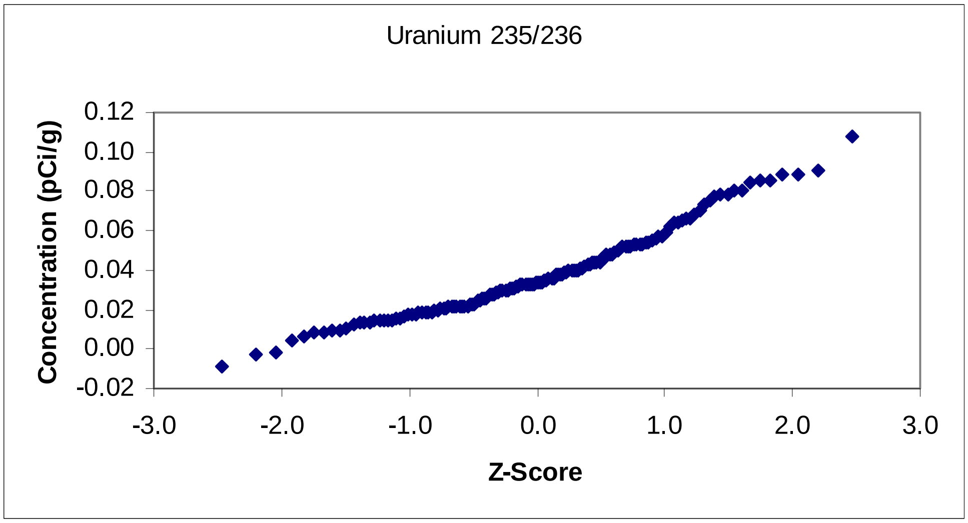


Figure 4.7 Cumulative Frequency Distribution, Area IV, ^{235}U



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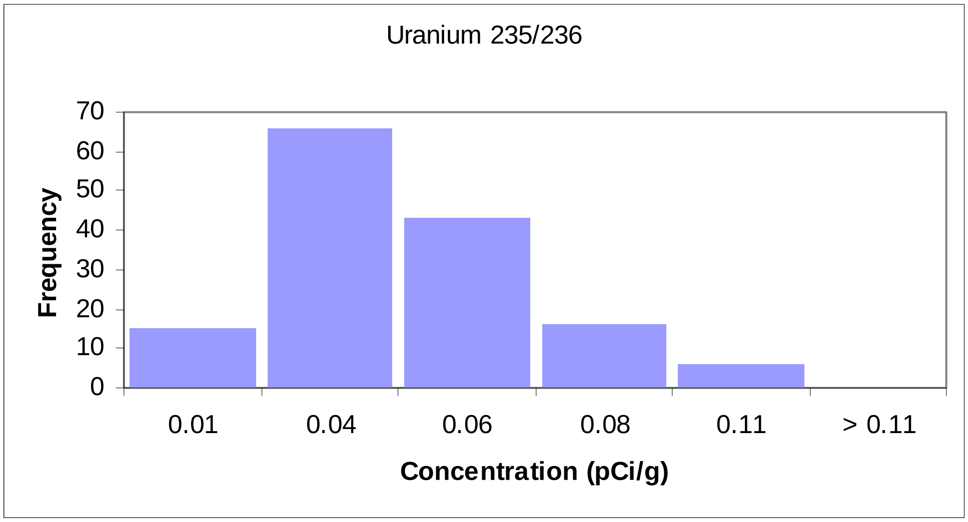

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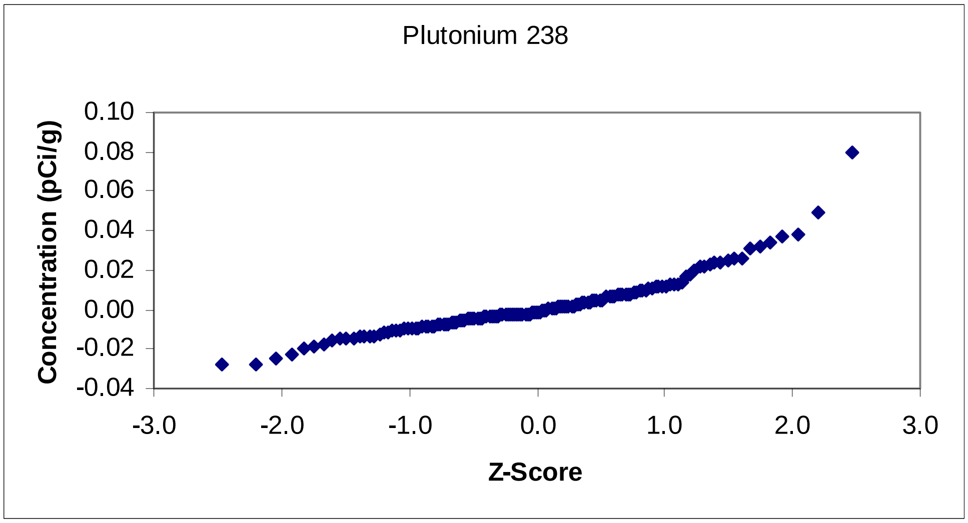

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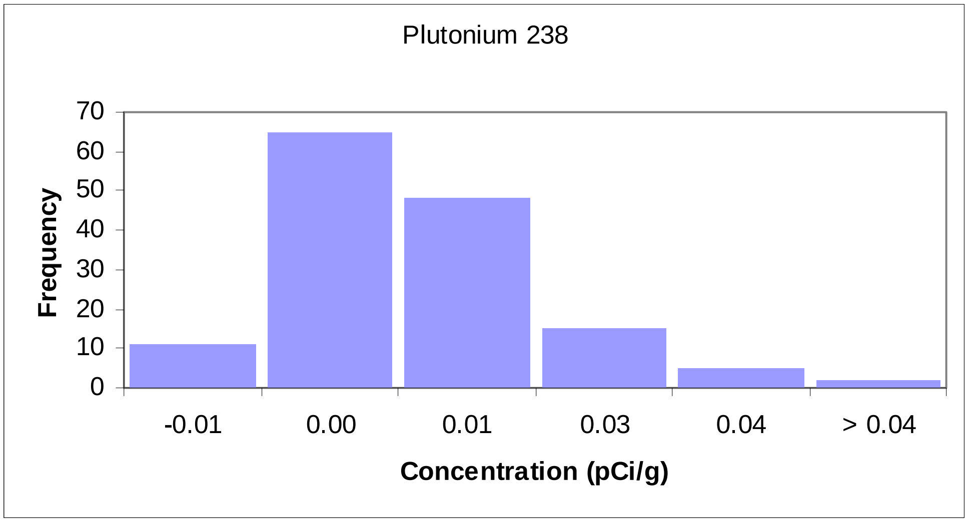

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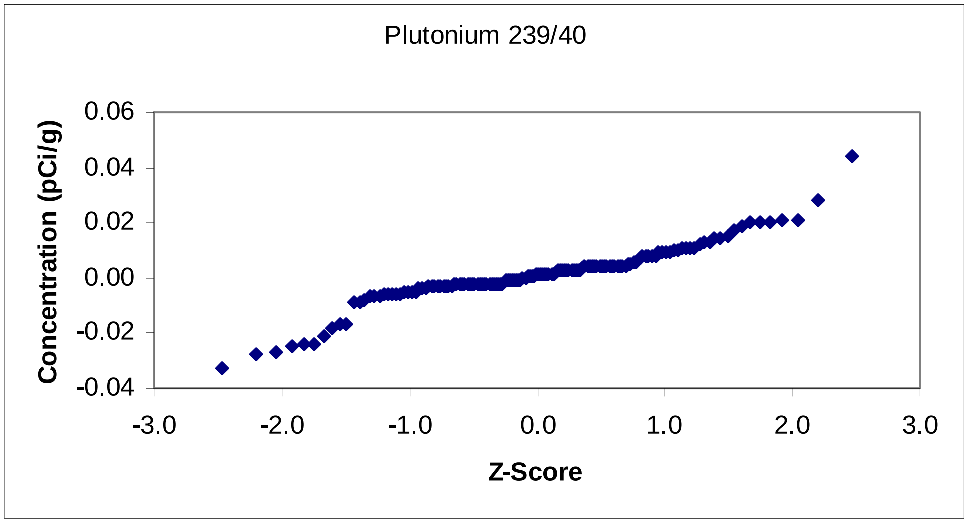

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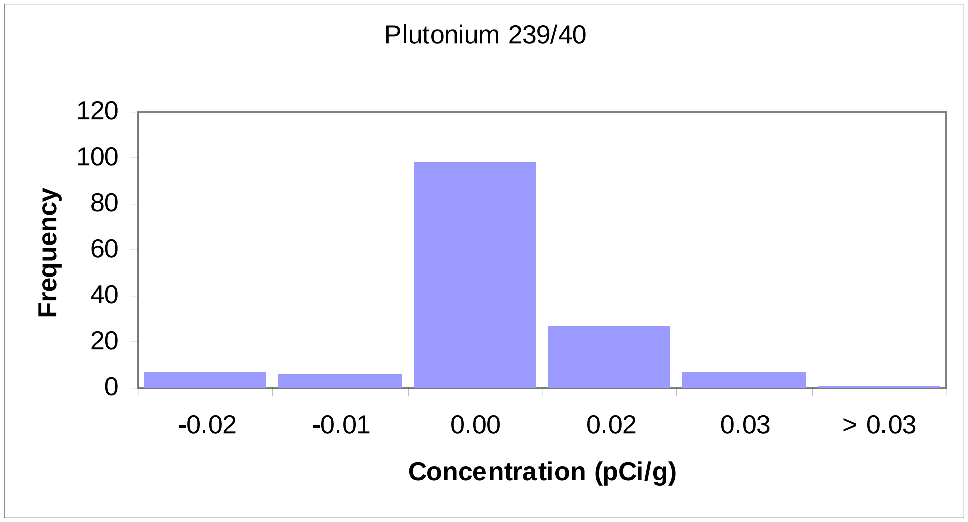

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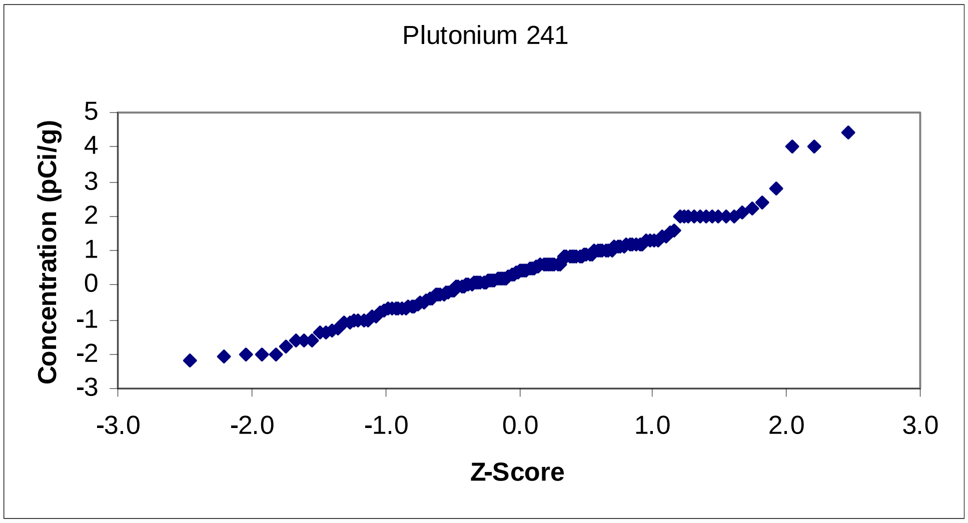

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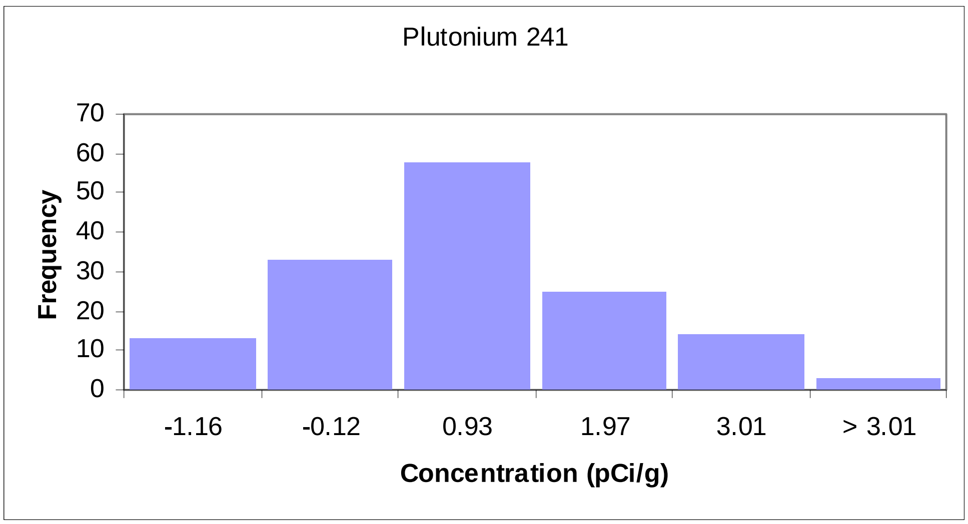

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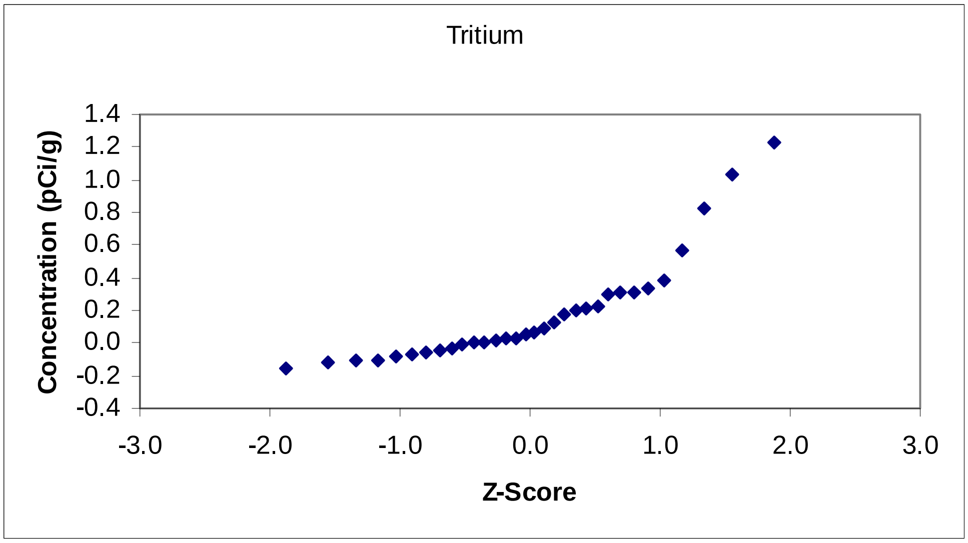

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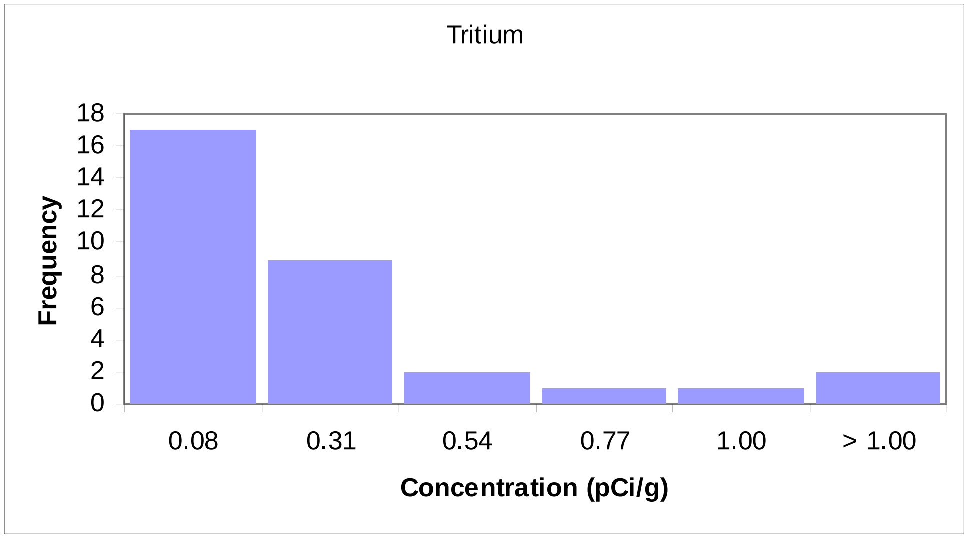

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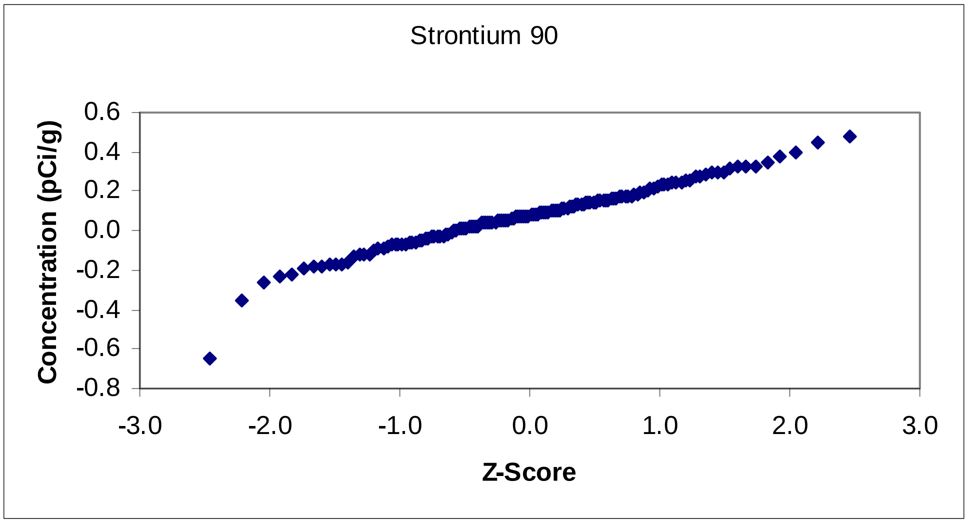

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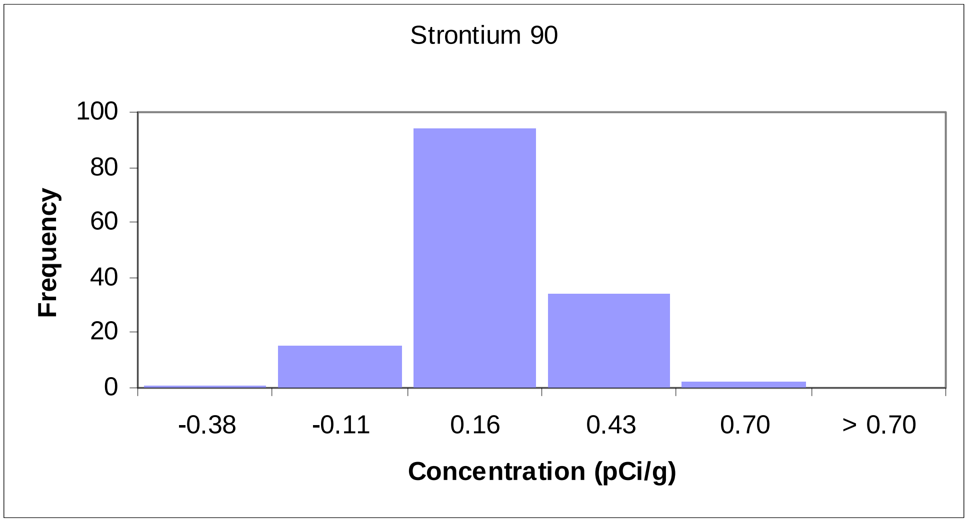

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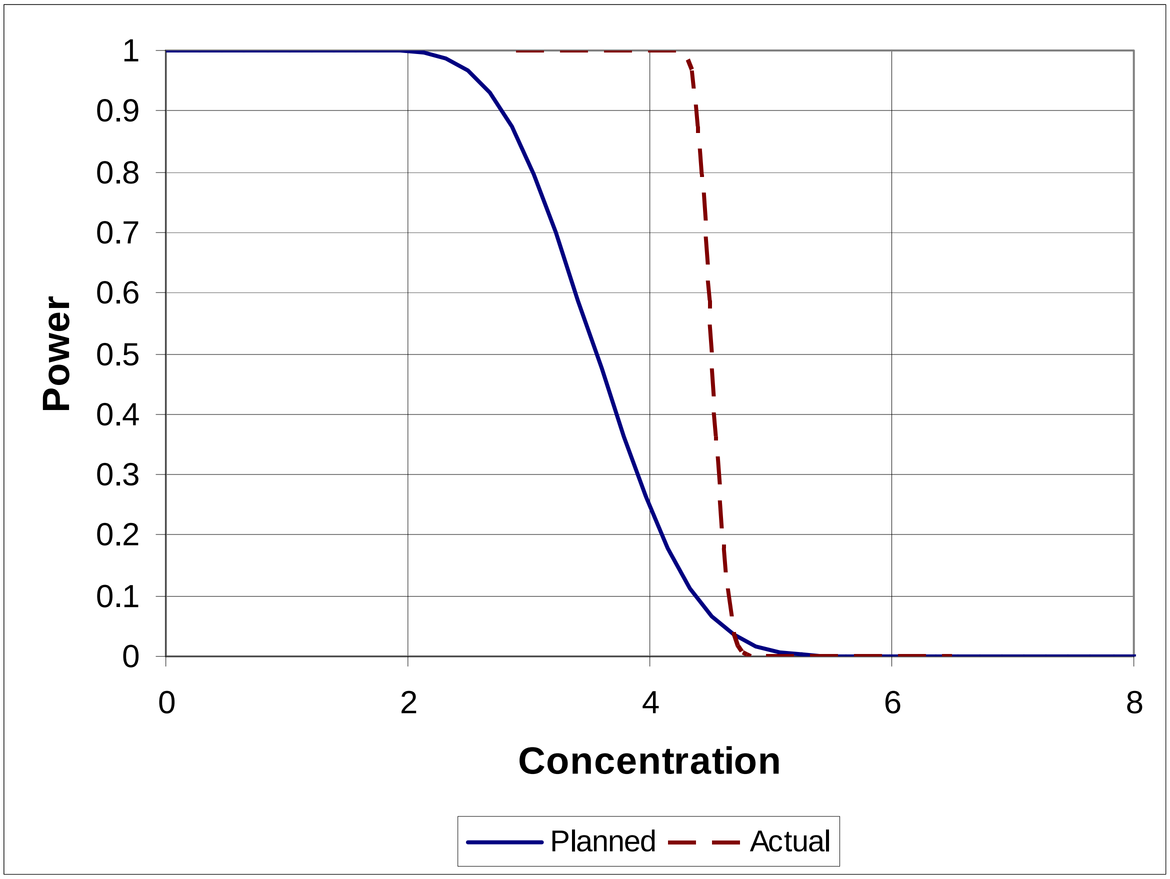

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