# Final
# Supplemental Radiological Assessment
# Installation Restoration Sites 1 and 2
# Long Beach Naval Complex
# Long Beach, California

*Prepared for:*
*U. S. Department of the Navy*
*BRAC Program Management Office West*
*San Diego, California*

*Naval Facilities Engineering Command Southwest*
*Contract Number N62473-06-C-2005*
*DCN: CABR-2005-0000-0002*
*Prepared by:*

CABRERA SERVICES
RADIOLOGICAL • ENGINEERING • REMEDIATION

3355 Myrtle Avenue, Suite 210, North Highlands, CA 95660

Cabrera Project No. 06-6101.00
May 2014

This Page Left Intentionally Blank

# Table of Contents

**EXECUTIVE SUMMARY** ..... **ES-1**
**1.0 INTRODUCTION AND SITE BACKGROUND** ..... **1**
1.1 SITE LOCATIONS AND DESCRIPTIONS ..... 1
1.2 SITE HISTORIES ..... 2
1.3 PRIOR HISTORICAL USE ..... 4
1.4 RADIONUCLIDES OF CONCERN AND RADIATION CHARACTERISTICS ..... 7
1.5 RADIOLOGICAL CONCEPTUAL SITE MODEL ..... 9
1.6 REPORT OBJECTIVE ..... 9
**2.0 RADIOLOGICAL INVESTIGATION** ..... **11**
2.1 DATA QUALITY OBJECTIVES ..... 11
2.2 STEP 1 - STATE THE PROBLEM ..... 12
2.3 STEP 2 - IDENTIFY THE DECISION ..... 13
*2.3.1 Principal Study Question* ..... *13*
2.4 STEP 3 - IDENTIFY INPUTS TO THE DECISION ..... 13
*2.4.1 RCOPC* ..... *13*
*2.4.2 Potentially Affected Media* ..... *13*
*2.4.3 Investigation Levels (ILs)* ..... *13*
*2.4.4 Measurement Inputs* ..... *15*
2.5 STEP 4 - DEFINE THE STUDY BOUNDARIES ..... 16
*2.5.1 Define the Target Population* ..... *16*
*2.5.2 Constraints on Data Collection* ..... *17*
*2.5.3 Scale of Decision Making* ..... *17*
2.6 STEP 5 - DEVELOP A DECISION RULE ..... 17
2.7 STEP 6 – SPECIFY LIMITS ON DECISION ERRORS ..... 18
2.8 STEP 7 - OPTIMIZE THE DESIGN FOR OBTAINING DATA ..... 18
**3.0 SURVEY/SAMPLING DESIGN** ..... **19**
3.1 SITE CLASSIFICATION AND SURVEY UNIT SIZE ..... 19
*3.1.1 Impacted Areas* ..... *19*
*3.1.2 Non-Impacted Areas* ..... *20*
*3.1.3 Survey Units* ..... *20*
*3.1.4 Survey and Sampling* ..... *20*
3.2 MOBILIZATION ..... 21
3.3 GROSS GAMMA WALKOVER SURVEYS ..... 22
3.4 SURFACE SOIL SAMPLE COLLECTION ..... 23
3.5 SUBSURFACE SOIL SAMPLE COLLECTION ..... 24
3.6 IN SITU GAMMA SPECTROSCOPY ..... 24
3.7 ONSITE GAMMA SPECTROSCOPY LABORATORY ..... 25
3.8 OFFSITE ANALYTICAL LABORATORY ..... 25

# Table of Contents (Continued)

**4.0 SURVEY INSTRUMENTATION ..... 27**
4.1 INSTRUMENT SELECTION ..... 27
*4.1.1 Scanning Measurements - Gamma Walkover Survey ..... 27*
*4.1.2 Scanning Measurements - Surface Activity ..... 27*
*4.1.3 Fixed Measurements - Borehole Logging ..... 28*
*4.1.4 Fixed Measurements - In Situ Gamma Spectroscopy ..... 28*
*4.1.5 Onsite Sample Analysis - Gamma Spectroscopy ..... 28*
*4.1.6 Onsite Sample Analysis - Smears ..... 29*
*4.1.7 Offsite Sample Analysis - Gamma Spectroscopy ..... 29*
*4.1.8 Offsite Sample Analysis - Alpha Spectrometry ..... 29*
*4.1.9 Offsite Sample Analysis - Liquid Scintillation ..... 29*
*4.1.10 Offsite Sample Analysis - Gas-Flow Proportional Counting ..... 30*
4.2 INSTRUMENT CALIBRATION AND QUALITY ASSURANCE PROCEDURES ..... 30
*4.2.1 Hand-held Instruments ..... 30*
*4.2.2 In Situ Gamma Spectrometer ..... 30*
*4.2.3 Onsite Gamma Spectrometer ..... 31*
*4.2.4 Smear Counter ..... 31*
*4.2.5 Laboratory Analytical Instruments ..... 31*
4.3 INSTRUMENT OPERATIONAL CHECKS ..... 31
*4.3.1 Hand-held Instruments ..... 32*
*4.3.2 Gamma Spectrometer ..... 32*
*4.3.3 Smear Counter ..... 32*
*4.3.4 Laboratory Analytical Instruments ..... 33*
**5.0 EFFICIENCY AND DETECTION SENSITIVITY ..... 35**
5.1 INSTRUMENT AND SURFACE EFFICIENCY ..... 35
5.2 STATIC MINIMUM DETECTABLE CONCENTRATION ..... 35
5.3 GROSS GAMMA WALKOVER SURVEY MINIMUM DETECTABLE CONCENTRATION ..... 36
**6.0 SURVEY DATA INTERPRETATION ..... 37**
6.1 GAMMA WALKOVER SURVEY RESULTS ..... 37
*6.1.1 Gull Park GWS Results ..... 37*
*6.1.2 Sea Launch Facility GWS Results ..... 38*
*6.1.3 Former Athletic Fields GWS Results ..... 39*
6.2 IN SITU GAMMA SPECTROSCOPY RESULTS ..... 39
*6.2.1 Gull Park ..... 41*
*6.2.2 Sea Launch Facility ..... 41*
*6.2.3 Former Athletic Fields ..... 41*
6.3 SURFACE SOIL SAMPLE RESULTS ..... 42
*6.3.1 Onsite Laboratory Results Summary ..... 42*
*6.3.2 Offsite Laboratory Results Summary ..... 43*
*6.3.3 Gull Park Surface Soil Results ..... 44*
*6.3.4 Sea Launch Facility Surface Soil Results ..... 48*
*6.3.5 Former Athletic Fields Surface Soil Results ..... 50*
*6.3.6 Radium-226 In-growth Factor ..... 50*

# Table of Contents (Continued)

6.4 IDENTIFICATION AND REMOVAL OF RADIOACTIVE ITEMS ..... 51
6.5 SURVEY UNIT DATA SUMMARIES ..... 52
*6.5.1 Summary Statistics ..... 53*
*6.5.2 Graphical Data Review ..... 53*
*6.5.3 Radionuclides of Concern ..... 54*
6.6 BOREHOLE LOGGING ..... 54
6.7 SUBSURFACE SOIL SAMPLE RESULTS ..... 54
6.8 GROUNDWATER SAMPLE RESULTS ..... 56
**7.0 RADIATION EXPOSURE ANALYSIS ..... 59**
7.1 RADIATION EXPOSURE SCENARIO ..... 59
7.2 DOSE MODELING ..... 60
7.3 SURVEY UNIT DOSE ESTIMATES ..... 61
7.4 SURVEY UNIT RISK CALCULATIONS ..... 61
**8.0 CONCLUSIONS ..... 65**
8.1 NATURE AND EXTENT OF RADIOACTIVITY ..... 65
*8.1.1 Groundwater Sampling Results ..... 66*
*8.1.2 Subsurface Soil Sampling Results ..... 66*
*8.1.3 Human Health Dose and Risk ..... 66*
**9.0 REFERENCES ..... 67**

## List of Figures

Figure 1.0-1 Site Location Map

Figure 1.1-1 Areas of Potential Concern

Figure 1.2-1 Geophysical Anomaly Areas

Figure 3.1-1 Site Classification

Figure 3.1-2 Survey Design

Figure 3.1-3 Groundwater Well Sample Locations

Figure 6.1-1 Gull Park GWS Results

Figure 6.1-2 Former Athletic Field and Sea Launch GWS Results

Figure 6.2-1 Gull Park Sample Locations in SU 11 through 18

Figure 6.2-2 Gull Park Sample Locations in SU 19 through 25

Figure 6.2-3 Gull Park Sample Locations in SU 33

Figure 6.2-4 Sea Launch Facility Sample Locations in SU 1, SU 29 and SU 30

Figure 6.2-5 Sea Launch Facility Sample Locations in SU 2 through 10

Figure 6.2-6 Sea Launch Facility Sample Locations in SU 31 and SU 32

Figure 6.2-7 Former Athletic Field Sampling Locations in SU 26 through SU 28

Figure 6.4-1 Locations of Articles (Point Sources) Found in Survey Units

# List of Tables

Table 1.3-1 Previous Investigations ..... **4**
Table 1.4-1 Radiological Constituents of Potential Concern (RCOPCs) ..... **8**
Table 1.4-2 Properties of RCOPCs and Their Radioactive Progeny ..... **8**
Table 1.4-2 Properties of RCOPCs and Their Radioactive Progeny (Continued) ..... **9**
Table 2.4-1 ILs for Surface Soil and Groundwater ..... **14**
Table 2.6-1 Decision Rules ..... **17**
Table 3.1-1 Survey Unit Sizing ..... **20**
Table 6.1-1 Additional Biased Sampling (1) Locations from GWS in Gull Park ..... **38**
Table 6.1-2 Additional Biased Sampling(1) Locations from GWS in Sea Launch ..... **39**
Table 6.1-3 Additional Biased Sampling Locations from GWS in Former Athletic Fields ..... **39**
Table 6.2-1 In Situ Gamma Spectroscopy Results ..... **40**
Table 6.3-1 Summary of Onsite Gamma Spectroscopy Results ..... **42**
Table 6.3-2 Offsite Analytical Results ..... **43**
Table 6.3-3 Soil Analytical Results (pCi/g) for Locations with Radiological Contaminants of Concern (RCOC) Above ILs- Gull Park (SU11 through 25, and SU33) ..... **45**
Table 6.3-4 Soil Analytical Results (pCi/g) for Locations with Radiological Contaminants of Concern (RCOC) Above ILs- Sea Launch (SU1 through 10, and SU29 through 32) .. **49**
Table 6.3-5 Statistics for the 226Ra In-growth Factor ..... **50**
Table 6.4-1 Radioactive Articles (Point Sources) Removed During Soil Sampling ..... **51**
Table 6.7-1 Subsurface Soil Sampling Results ..... **55**
Table 7.1-1 Site-Specific Exposure Parameters ..... **59**
Table 7.1-1 Site-Specific Exposure Parameters (Continued) ..... **60**
Table 7.2-1 Dose Modeling Results ..... **60**
Table 7.3-1 Survey Unit Total Dose Estimates ..... **62**
Table 7.4-1 Survey Unit Risk Calculations ..... **63**

# List of Appendices

Appendix A: Instrumentation Inventory
Appendix B: Instrument Calibration Documentation
Appendix C: Quality Control and Quality Assurance Analysis
Appendix D: Dose Modeling Report

## List of Appendices (Continued)

Appendix E: Electronic Data Files (Disk 1 through 5)

Disk 1: a) Borehole Log Sheets

b) Offsite, Onsite, ISOCS, and Subsurface Raw Data

c) Photographs and Photo Log

d) QC Charts

e) Sample Logs

f) Smear Results

g) Standard Operating Procedures (SOPs)

Disk 2, Survey Unit Exploratory Data Analysis (EDAs) Data Files

Disk 3, Electronic Data Delivery (EDD) Files Part 1

Disk 4, EDD Files Part 2

Disk 5, EDD Files Part 3

Appendix F: Response to Regulatory Review Comments Draft Supplemental Radiological Assessment of Installation Restoration Sites 1 and 2 Long Beach Naval Complex June 2009

## Acronyms and Abbreviations

| | |
|---|---|
| Ac | Actinium (e.g., $^{228}$Ac) |
| Am | Americium (e.g., $^{241}$Am) |
| ALARA | As Low As Reasonably Achievable |
| ANSI | American National Standards Institute |
| AOPC | Area of Potential Concern |
| Ba | Barium (e.g., $^{137m}$Ba) |
| bgs | below ground surface |
| Bi | Bismuth (e.g., $^{214}$Bi) |
| BRAC | Base Realignment and Closure |
| C | Carbon (e.g., $^{14}$C) |
| Cabrera | Cabrera Services, Inc. |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act |
| CFD | Cumulative Frequency Distribution |
| COPC | Chemical of Potential Concern |
| cpm | count(s) per minute |
| Cs | Cesium (e.g., $^{137}$Cs) |
| CSM | Conceptual Site Model |
| DOE | United States Department of Energy |
| Digital | Digital International Systems |
| DQO | data quality objective |
| DTSC | Department of Toxic Substances Control |
| EDA | Exploratory Data Analysis |
| EDD | Electronic Data Deliverable |
| EPA | U.S. Environmental Protection Agency |
| GM | Geiger-Mueller |
| GPS | global positioning system |
| GWS | Gamma Walkover Survey |
| H | Hydrogen (e.g., $^{3}$H [Tritium]) |
| H&S | Health and Safety |
| HHRA | Human Health and Risk Assessment |
| HPGe | High-Purity Germanium |

**Acronyms and Abbreviations (Continued)**

| | |
|---|---|
| HRA | Historical Radiological Assessment |
| ICRP | International Commission on Radiological Protection |
| ID | identification |
| IL | Investigation Level |
| IR | Installation Restoration |
| ISOCS™ | In Situ Object Counting System |
| K | Potassium (e.g., $^{40}K$) |
| keV | Kiloelectron volt(s) |
| LBNC | Long Beach Naval Complex |
| LBNSY | Former Long Beach Naval Shipyard |
| LLRW | Low Level Radioactive Waste |
| $m^2$ | square meter |
| MARSSIM | Multi-Agency Radiation Survey and Site Investigation Manual |
| MDC | minimum detectable concentration |
| MeV | megaelectron volt(s) |
| µR/hr | microRoëntgen per hour |
| mrem/yr | millirem per year |
| mR/hr | milliRoëntgen per hour |
| NAD | North American Datum |
| NaI | Sodium Iodide |
| NAVFAC | Naval Facility |
| NAVSEA | Naval Sea Systems Command |
| NAVSEADET | Naval Sea Systems Command Detachment |
| NAVSTA | Former Long Beach Naval Station |
| NELAP | National Environmental Laboratory Accreditation Program |
| NIST | National Institute of Standards and Technology |
| NRC | United States Nuclear Regulatory Commission |
| PARCC | Precision, Accuracy, Representativeness, Completeness, and Comparability |
| Pb | Lead (e.g., $^{214}Pb$) |
| pCi/g | picoCurie per gram |
| pCi/L | picoCurie per liter |

**Acronyms and Abbreviations (Continued)**

| | |
|---|---|
| PID | photoionization detector |
| Pm | Promethium (e.g., $^{147}$Pm) |
| POLB | Port of Long Beach |
| PRG | Preliminary Remediation Goal |
| Pu | Plutonium (e.g., $^{239}$Pu) |
| QA | Quality Assurance |
| QC | Quality Control |
| Ra | Radium (e.g., $^{226}$Ra) |
| RASO | Radiological Affairs Support Office |
| RCOC | Radionuclide of Concern |
| RCOPC | Radionuclide Contaminant of Potential Concern |
| RESRAD | Residual Radioactivity |
| R/hr | Roëntgen per hour |
| RI | Remedial Investigation |
| Rn | Radon (e.g., $^{222}$Rn) |
| ROD | Record of Decision |
| SAP | Sampling and Analysis Plan |
| Sr | Strontium (e.g., $^{90}$Sr) |
| SU | Survey Unit |
| SWDIV | Southwest Division |
| TEDE | Total Effective Dose Equivalent |
| Th | Thorium (e.g., $^{232}$Th) |
| TWDR | Total Weighted Detector Response |
| U | Uranium (e.g., $^{236}$U) |
| VOC | Volatile Organic Compound |

**Executive Summary**

This Report presents an overview of the Radiological Assessment for Installation Restoration (IR) Sites 1 and 2 located on the eastern tip of the Navy Mole that extends out into Long Beach Harbor at the Long Beach Naval Complex (LBNC) in Long Beach, California. The purpose of this Radiological Assessment was to evaluate potential risks to receptors at the ground surface from residual radioactivity in the shallow subsurface soil at IR Sites 1 and 2. Based on the results from this Radiological Assessment; there are no unacceptable risks to industrial workers at IR Sites 1 and 2.

This Radiological Assessment focused on investigating shallow soil to a depth of 1 foot below ground surface (bgs) to estimate potential radiological exposure to industrial worker receptors at the ground surface. Gamma scans, in-situ gamma spectroscopy, and surface soil samples were used to investigate shallow surface soils and to identify and remove any radiological discrete point sources (point sources). Radiological measurements included a combination of onsite scanning and fixed measurements along with the collection and analyzation of soil samples. The radiological survey design divided the Site (IR Sites 1 and 2) into 33 survey units (SUs). Each SU was evaluated for potential radiological impacts to human health and the environment. A Human Health Risk Assessment (HHRA) was conducted for each SU using the radionuclide contaminants of concern (RCOCs) for each SU to estimate potential doses and risks to industrial workers at the surface of IR Sites 1 and 2.

The only radionuclides detected in soil above the investigation levels (ILs) during this Radiological Assessment were Radium-226 ($^{226}$Ra) and Strontium-90 ($^{90}$Sr), which were observed in 17 of the 33 SUs. A total of 22 point sources were identified and subsequently removed from the shallow soil. Four point sources were identified and removed from SUs 04, 05, 29, and 31 in the Sea Launch Area while 18 point sources were identified and removed from SUs 11, 12, 13, 14, 15, 27, 28, 32, and 33 in the Gull Park Area. On the basis of the results from radiological surveys, sampling and dose modeling, $^{226}$Ra was the only radionuclide of concern and primary risk driver identified at the Site. No other radionuclides were identified as risk drivers.

The onsite laboratory employed for in-situ gamma spectroscopy used Bismuth-214 ($^{214}$Bi) as a surrogate isotope for evaluating $^{226}$Ra, in accordance with the agency concurred work plan, *Final Work Plan Supplemental Radiological Assessment of Installation Restoration (IR) Sites 1 &2, Long Beach Naval Complex, Long Beach, California* (Cabrera 2008). Eighty-two of the 800 soil samples analyzed by the onsite laboratory were also sent to an offsite laboratory for $^{226}$Ra analysis using the $^{214}$Bi in-growth method. These offsite laboratory data were then used to verify correlation of the onsite and offsite laboratory data sets and to allow for correcting (adjusting) the $^{214}$Bi gamma spectroscopy results obtained onsite to account for the difference between these two methods; these corrected results were used in the HHRA and are reported in the text and tables as $^{214}$Bi($^{226}$Ra).

The HHRA was accomplished by evaluating the total effective doses equivalent (TEDE) and the total [excess] lifetime cancer risk under an industrial worker scenario using the United States Department of Energy (DOE) Residual Radioactivity (RESRAD) exposure pathway model Version 6.4. Although not part of the original work plan, the Navy chose to perform an additional evaluation of the TEDE and human health risks using the onsite $^{226}$Ra data utilizing the 186 Kiloelectonvolt (keV) gamma peak as a comparison to the corrected $^{214}$Bi ($^{226}$Ra) data; this evaluation had similar results as the onsite $^{214}$Bi gamma adjusted using the offsite laboratory data duplicate samples.

The TEDE is the sum of the deep-dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures). The total TEDE is the sum of the TEDEs for $^{226}$Ra and $^{90}$Sr, the two RCOC at IR Sites 1 and 2. Under an industrial worker scenario using $^{214}$Bi ($^{226}$Ra) and $^{226}$Ra peak data, the total TEDEs were found to be less than 5 millirems per year (mrem/yr) in 32 of the 33 SUs. Maximum potential doses under an industrial worker scenario were estimated at 12.6 mrem/yr in SU 31 at the Sea Launch Facility, using $^{214}$Bi ($^{226}$Ra) data, and 6.05 mrem/yr in SU 11 using $^{226}$Ra peak data. The total [excess] lifetime cancer risk under an industrial worker scenario was estimated to be $10^{-6}$ in 32 of the 33 SUs using $^{214}$Bi ($^{226}$Ra) data and $10^{-6}$ in all 33 SUs using $^{226}$Ra peak data. The maximum total lifetime cancer risk under an industrial worker scenario was estimated to be $10^{-5}$ in SU 31 at the Sea Launch Facility, using the $^{214}$Bi ($^{226}$Ra) data. The total risk summed the excess lifetime cancer risk for both $^{226}$Ra and $^{90}$Sr. The excess cancer risk represents the increased number of cancer cases occurring from the contaminant over those caused by background conditions. The 32 of 33 SUs in the $10^{-6}$ risk range with only one survey unit (SU 31) in the $10^{-5}$ risk range indicates an acceptable and low cancer risk for the IR Sites 1 and 2 investigation areas under an industrial worker scenario.

Subsurface soils below 1 foot bgs were outside the scope of this Radiological Assessment, but were sampled for characterization purposes. Thirty-seven subsurface soil samples were collected from each of the 33 soil boring locations (1 borehole per SU) with an additional four judgmental samples collected based on field screening decisions at four of 33 SUs. The soil borehole was first logged for total gamma with depth and sampled in accordance with the work plan (Cabrera, 2008). Three subsurface soil samples exceeded the IL for $^{226}$Ra at depths ranging from two to 3 feet bgs; no soil samples exceeded the IL for $^{90}$Sr.

Results from groundwater sampling indicated that RCOCs were not detected in groundwater at concentrations exceeding project ILs. Based on the results obtained during previous removal actions and investigations and this Radiological Assessment, conditions at the surface of the Site are protective of industrial workers.

## 1.0 Introduction and Site Background

This Report presents an overview of the Radiological Assessment conducted for Installation Restoration (IR) Sites 1 and 2 at the Long Beach Naval Complex (LBNC) in Long Beach, California. The purpose of this Radiological Assessment was to evaluate potential risks to human receptors from potential exposure to residual radiation in shallow soil, or more specifically, the surface and top 1 foot at IR Sites 1 and 2.

IR Sites 1 and 2 are located on the eastern tip of the Navy Mole which extends from the shoreline out into Long Beach Harbor at the LBNC (Figure 1.0-1). This Report describes the data quality objectives (DQOs), survey design, data collection methodology, survey and sampling results, and data evaluation techniques which were followed in accordance with the *Sampling and Analysis Plan* (*SAP*) found in Attachment A of the agency concurred work plan, *Final Work Plan Supplemental Radiological Assessment of Installation Restoration (IR) Sites 1 &2, Long Beach Naval Complex, Long Beach, California* (Cabrera 2008).

### 1.1 Site Locations and Descriptions

The former Long Beach Naval Station (NAVSTA) and former Long Beach Naval Shipyard (LBNSY) together form the LBNC which is located on Terminal Island at the western boundary of the city of Long Beach, approximately 24 miles south of downtown Los Angeles in Los Angeles County, California. The LBNC is relatively flat, with less than 35 feet of total relief. Elevations vary from less than 15 feet above mean sea level at the northern end of the LBNC to more than 20 feet above mean sea level (Battelle, 2000).

IR Site 1 (Mole Solid Waste Operations) and IR Site 2 (Chemical Material and Waste Storage Area) are located on the eastern tip of the Navy Mole that extends out into Long Beach Harbor within the boundaries of the NAVSTA. The Navy Mole was constructed using hydraulic fill material between 1940 and 1944 (Bechtel, 1994a). The Navy Mole is approximately 2 miles long and approximately 500 feet wide, and forms a breakwater between the San Pedro Bay and the West Basin of Long Beach Middle Harbor. The Navy Mole, with the exception of the Defense Fuel Supply and Pier 12 located central portion of the Mole, has been in a lease in furtherance of conveyance to the Port of Long Beach (POLB) since 1998.

IR Sites 1 and 2 and other significant features of the Site, specifically the Sea Launch Facility and Gull Park, are shown in the aerial photograph in Figure 1.0-1. The IR Sites 1 and 2 boundaries and areas of potential concerns (AOPCs) identified in the previous remedial investigations (RI) (Bechtel, 1996) are identified in Figure 1.1-1 and described in the following Sections. The total area of IR Sites 1 and 2 is approximately 33 acres. IR Sites 1 and 2 are approximately 2,600 feet and 3,200 feet long, respectively, and extend the 500-foot width of the Navy Mole. IR Site 1 covers the area on the Navy Mole extending approximately from Pier 15 on the western Site boundary to the east end of the Navy Mole. IR Site 1 is located totally within the boundaries of IR Site 2, which covers the same general area, but extends from the former Building 815 on the western Site boundary to the east end of the Navy Mole.

Both Sites once contained many Navy buildings and recreational areas, which have been demolished or converted to other uses. The eastern end of IR Sites 1 and 2 is known as Gull Park. The POLB operates a migratory bird site in Gull Park for a colony of black-crowned night herons, protected under the Migratory Bird Treaty Act. Approximately 50 trees were relocated to Gull Park from other areas at the LBNC to provide nesting areas for migratory birds**.**

The central portion of IR Sites 1 and 2 is occupied by the Sea Launch Facility, which is a satellite-launching venture that uses the POLB site as a home base for its seaworthy launch platform and command ship. Access to IR Sites 1 and 2 is limited by the security provided by the POLB. Additional security is provided in some areas via chain-link fences.

## 1.2 Site Histories

Property for the NAVSTA and LBNSY was acquired from the cities of Long Beach and Los Angeles between 1940 and 1942. In 1946, NAVSTA was chartered to provide welfare, recreation, and social facilities. Activities at NAVSTA included berthing of tugboats, barges, and other similar vessels. Activities at LBNSY ranged from routine ship maintenance to extensive battle damage repairs and ship conversions. After closure of LBNSY in 1997, NAVSTA became the designated caretaker. Southwest Division Naval Facilities (SWDIV NAVFAC) assumed the responsibility and security of the LBNC until the property is disposed of, leased, or transferred (Battelle, 1999). Environmental activities at the Sites are being conducted to prepare the property for transfer in accordance with Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Under current agreements, the property will be transferred to the Local Redevelopment Authority after environmental activities are complete.

Beginning in the mid-1940s and continuing until the mid-1960s, solid waste operations occurred within the boundaries of IR Sites 1 and 2. Solid wastes managed or accumulated included empty wooden and cardboard boxes, construction and demolition debris, rags, and other shipyard trash, construction debris and other solid waste were buried on occasion at these sites. A map from 1950 was used to identify a 200- by 700-foot burn pit area. The types and quantities of wastes disposed of during the solid waste operations were not reported and are therefore unknown.

General radioactive materials were common in shipboard equipment and in equipment used in the shipyard and became an integral part of shipyard operations over time. Typical examples of equipment that included radioactivity at LBNC are sealed radiation detection instrument calibration and reference sources; sealed sources used in industrial radiography; and equipment such as gauges, dials, and bridge and deck markers containing radium or strontium. Examples of other activities potentially resulting in disposal of radioactive materials include grinding of thoriated tungsten welding rods and decontaminating ships that participated in Operation Crossroads, which was a two-detonation (one air and one underwater) nuclear test conducted in July and August 1946 at the Bikini Atoll.

There were five AOPCs identified within IR Sites 1 and 2 (Figure 1.1-1) in the *Remedial Investigation Work Plan* (Bechtel, 1994b). Site 1 and Site 2 do overlap but have different dimensions vertically and are considered different AOPCs based on site history, and contaminants of potential concern (COPCs). AOPCs 1, 3, and 4 are related to IR Site 1, as they were determined to be impacted by surface and subsurface solid waste disposal activities. AOPCs 2 and 5 are related to IR Site 2, as they were determined to be impacted by the disposal or leakage of hazardous or contaminated liquids into surface and subsurface soils.

- **AOPC 1.** Surface soils (0 to 1 foot below ground surface [bgs]) in Gull Park are considered to be within the same potential area of surface spills, dust suppression activities, shallow earthworks, and trench-and-fill activities, which may include cans, drums, or other debris. By 1962, this area was reportedly used as a pipe laydown area. By 1964, ball fields were established within the area; it is assumed that all waste disposal activities had ceased by this time (Bechtel, 1996).

- **AOPC 2.** Surface soils (0 to 1 foot bgs) in the Western Ball field immediately west of the Sea Launch Facility. This area was reportedly used for disposal of ship bilge water that may have contained organic and/or inorganic compounds and petroleum products. By 1964, the ball field was established and disposal of bilge water is assumed to have ceased (Bechtel, 1996).
- **AOPC 3.** Subsurface soils (deeper than 1 foot bgs) are considered to be within the same potential area of contamination related to the burning of wastes in the burn pit area from the early 1940s to the 1970s (Bechtel, 1996). This AOPC also includes groundwater at IR Sites 1 and 2.
- **AOPC 4.** Subsurface soils (deeper than 1 foot bgs) in Gull Park are considered to be within an area of similar earthwork and trench-and-fill activities, which may include cans, drums, and/or other debris (Bechtel, 1996).
- **AOPC 5.** Consists of all subsurface soils that are not part of the other four AOPCs. The primary potential contaminant source at AOPC 5 was leakage from drums of liquid wastes and raw chemicals from the LBNSY Public Works Department, production shops, and ships. Drums were stored in this area from the mid-1960s to the 1980s. In addition, a dark-colored (potentially stained) area was identified in a 1952 aerial photo that appears to have resulted from the flow of water or other liquid (Bechtel, 1996).

During the early IR Sites 1 and 2 remedial site investigations, electromagnetic induction, magnetometer, and ground-penetrating radar surveys were conducted which can be found as Appendix K (Geophysical Reports) of the *Final Remedial Investigation (RI) Report, Installation Restoration Program for Sites 1 through 6A, Naval Station Long Beach, Long Beach, California* (Bechtel, 1996). Based on the results of the surveys three areas of geophysical anomalies, Areas I, II, and III (Figure 1.2-1), were identified. The southern portion of the anomalies corresponds to the burn pit area (Areas I and II). A portion of the Sea Launch Facility is located in Area 1. A geophysical anomaly identified in the northeast part of IR Sites 1 and 2 (Area III) suggested the presence of cut-and-fill operations.

The *RI Report* (Bechtel, 1996), identified and evaluated COPCs in the soil and groundwater within the AOPCs at IR Sites 1 and 2. No radiological contaminants of potential concern (RCOPCs) were identified at that time. Subsequent to the *RI Report* (Bechtel, 1996), a *Record of Decision (ROD)* was completed for IR Sites 1 and 2, which identified excavation as the selected remedy for Area III (Battelle, 2000). This remedy was selected, in part, due to the possibility that the volatile organic compound (VOC) groundwater plume beneath Area III could migrate to the ocean. Area III was excavated down to groundwater (approximately 10 feet below land surface) and backfilled. The excavation began in October 2000 and was completed in February 2001. At the onset of excavation activities, routine health and safety (H&S) screening identified radioactivity exceeding background levels at the site. This discovery initiated a radiological survey that was conducted from November 2000 through May 2001, concurrent with and subsequent to excavation activities. During excavation, soil and debris was screened for radiological material, radiological material was collected in drums, the soil was segregated into seven stockpiles and debris was placed into 26 roll-off bins.

Radiation surveys were performed on the stockpiled soil in 12 to 18 inch lifts prior to reuse or offsite disposal. It was also determined that prior to disposal of the roll-off bins, the bins should be emptied onsite and screened for point sources. Radiological material identified during the radiation surveys of the seven soil stockpiles the radiological material identified during the screening of the debris from the bins was determined to meet the low level radiological waste (LLRW) criteria and was consolidated into six B25 containers. The six B25 boxes (capacity of 3.3 cubic yards each) containing LLRW were manifested and disposed offsite as LLRW. The clean soil was used for the excavation as backfill. The remaining CERCLA contaminated soil was manifested and disposed appropriately at offsite permitted landfills. The final excavation was backfilled with material consisting of 60 percent imported fill and 40 percent clean backfill from stockpiles generated from excavation activities (Battelle, 2006).

### 1.3 Prior Historical Use

Previous radiological investigations conducted at LBNC are summarized in Table 1.3-1.

**Table 1.3-1 Previous Investigations**

| Year, Contractor | Reference | Scope of Investigation | Key Findings |
|---|---|---|---|
| 1997, LBNSY | Historical Radiological Assessment (HRA) at LBNC | Basewide Radiological Investigations at LBNC | Preliminary investigations did not indicate the history or presence of radiological contamination. The presence of radiological contamination was not found at IR Sites 1 and 2. |
| 1998, Digital | HRA at LBNC | Decommissioning Radiological Survey and Remediation at LBNC | The presence of radiological contamination was not found at IR Sites 1 and 2. |
| Nov 2000 through May 2001, Battelle | Radiation Data Summary Report for IR Sites 1 and 2 at Naval Station Long Beach | Gamma Walkover Survey, Exposure Rate Measurements, Collection of soil samples, and limited in situ Gamma spectroscopy. | Strontium-90 and alpha-emitting radium ($^{224}$Ra, $^{226}$Ra, and/or $^{228}$Ra) were identified as being present at concentrations exceeding background reference concentrations. |

Two Historical Radiological Assessments (HRAs) conducted by LBNSY and Digital International Systems (Digital) in 1997 and 1998, respectively, did not indicate a history or presence of radioactive contamination at IR Sites 1 and 2. A radiation survey was conducted from November 2000 through May 2001, as part of site remediation efforts identified in the *ROD* (Battelle, 2000). Results from this survey presented in the *Radiation Data Summary Report for IR Sites 1 and 2 at Naval Station Long Beac*h (Battelle, 2001), identified Strontium-90 ($^{90}$Sr) and alpha-emitting radium ($^{224}$Ra, $^{226}$Ra, and/or $^{228}$Ra) as being present at concentrations exceeding background reference concentrations. Prior to this survey, radiological contamination had not been found at IR Sites 1 and 2.

In 1983, an *Initial Assessment Study* (NEESA, 1983) was conducted to identify and evaluate potential threats to human health and/or the environment caused by past hazardous materials storage, handling, or disposal practices at LBNC. IR Sites 1 and 2 were identified as potentially contaminated sites based on information from available records, aerial photographs, surface and aerial surveys, and personnel interviews. Since the boundaries of IR Site 1 are completely encompassed by IR Site 2, the two sites are considered as one site. In 1994, the *Risk Assessment Work Plan Remedial Investigation/Feasibility Study, Sites 1, 2, 3, 4, 5, 6A and 7, Naval Station Long Beach California* (Bechtel, 1994b) identified the five AOPCs within IR Sites 1 and 2.

The *RI Report* identified and evaluated COPCs in soil and groundwater within the AOPCs at IR Sites 1 and 2 (Bechtel, 1996). Soil and groundwater samples were not analyzed for radiological contaminants at that time. During the RI, buried debris and other construction material were noted within AOPCs 1, 3, and 4 at IR Site 1. Analytical data indicated that 1,1-dichloroethene; benzene; trichloroethene; and vinyl chloride were present in groundwater within AOPCs 1 and 4 at concentrations exceeding respective criteria listed in the *Water Quality Control Plan, Ocean Waters of California, California Ocean Plan* criteria (SWRCB, 2005). Therefore, the groundwater beneath AOPC 4 at IR Sites 1 and 2 was recommended for further action, since it had the potential to release chemical constituents to the surrounding marine environment (Battelle, 2004).

According to the 1997 *HRA* (LBNSY, 1997), no known activities involving licensed radioactive materials occurred at IR Sites 1 and 2. Based on the discovery of radioactive material during site remediation work (Battelle, 2001) and the potential sources of radiological contamination that have been identified, the single suspected significant mechanism of release of radioactive material to the environment is inadvertent disposal as part of the solid waste operations that occurred at IR Site 1 and that may have also impacted IR Site 2.

Since radiological controls were limited especially in the early years, it is possible that radioluminescent materials and other non-permitted radioactive material were disposed of in the same manner as other (i.e., non-radioactive) solid waste. The most likely indicator of such disposal would be the presence of radium used in radioluminescent items; the presence of radium and strontium in luminescent items was confirmed during previous remedial activities at AOPCs 1 and 4. During the 1970s, LBNSY participated in the Navy's program to eliminate radium from ships' instrumentation. In 1963, the Navy began a series of programs to remove all non-mission essential equipment containing radioluminescent (e.g., radium) material, and replace all such mission-essential equipment with equipment containing non-radioluminescent or lower energy radioluminescent substitutes where possible. From the mid-1970s, the disposal procedure at LBNSY was to transport this material off-site for disposal. There are no specific disposal records prior to the mid-1970s (LBNSY, 1997).

Operation Crossroads reports do not identify the instruments used to monitor decontamination operations and segregate radioactive debris (LBNSY, 1997). Depending on the sensitivity of the instruments used, decontamination wastes containing low-level radioactive material, such as sandblast grit, could have escaped detection, particularly those wastes emitting radiations other than readily detectable high-energy gamma-rays. Those wastes could have been disposed of as other (i.e., non-radioactive) solid waste.

IR Site 2 was identified as being potentially contaminated based on the storage of drums filled with raw chemicals and wastes from the LBNSY Public Works Department, production shops, and ships within its boundaries from mid-1960s until 1980. In the 1950s, $^{90}Sr$ began replacing $^{226}Ra$ and by the 1960s, radium deck markers were no longer in production. The years during which the waste and drum storage occurred make it unlikely radioactive materials were stored there, particularly due to the increasing Navy efforts over this time period to identify, control, and segregate non-licensed radioactive material, specifically radioluminescent materials. Therefore, liquid release is not considered a suspected mechanism of release of radioactive material at the Sites. Liquid wastes from the Operation Crossroad ship decontamination activities were generated prior to this time period.

There were no reported airborne releases of radioactive materials at LBNSY that could have transported measurable radioactivity to the soil. LBNSY did not perform permitted work that required filtered and/or monitored exhaust ventilation. Therefore, airborne release is not considered a suspected mechanism of release of radioactive material to the environment.

Radiological data were collected as part of the 2000-2001 radiation survey and related remedial actions conducted concurrently with the excavation of Area III (see Figure 1.2-1). These radiological data are reported in the *Radiation Data Summary Report for Installation Restoration Sites 1 and 2, Long Beach Naval Complex, Long Beach California* (Battelle, 2001).

The 2000-2001 radiation survey included excavation within Area III and the eastern three-fourths of Area II. The surveyed area was divided into grids. Gross gamma count rate readings, localized and general ambient exposure rate measurements, and soil samples were collected and analyzed. Limited in situ gamma spectroscopy was also performed which identified $^{226}Ra$, including its progeny, and naturally occurring Potassium-40 ($^{40}K$).

Gross gamma count rate readings were collected from Areas II and III using a 2- by 2-inch Sodium Iodide (NaI) scintillation detector by passing the detector 4 to 6 inches above the surface of the soil. Readings were collected from the surface of the soil in Area II. In Area III, readings were collected prior to excavation and during backfilling with clean on-site fill in 18-inch layers, referred to as "lifts." Soil was excavated to groundwater at approximately 10 feet bgs. Pre-remediation readings were reported up to 420,000 counts per minute (cpm), which was 42 times higher than the average background count rate of approximately 10,000 cpm (Battelle, 2001).

Contaminated soil and point source debris were removed, and localized exposure rates of excavated material were measured. Approximately 20 cubic yards (six B-25 boxes) of radiologically impacted soil and 368 radioactive point sources were removed from the survey area (Battelle, 2001). Seventy of the point sources included intact manufactured items (e.g., deck markers), 77 were debris (rusted soil encrusted partial items) and the remaining 221 included soil and soil-like material (e.g., sand, rocks, pebbles and clumps of dirt). Localized soil contamination and point source debris exposure rates were measured using a thin-window pancake Geiger-Müeller (GM) detector or an ion chamber survey meter. Readings of up to 20 milliRoëntgen per hour (mR/hr) were recorded at a distance from the source of 4 inches, which was approximately 5,700 times higher than the average background exposure rate of 3.5 microRoëntgen per hour ([µR/hr], Battelle, 2001).

Following soil remediation and point source removal, ambient exposure rate readings were collected from approximately 80 percent of the survey area grids. Readings were collected using a high-sensitivity pressurized ion chamber survey meter by holding the detector approximately 39 inches (1 meter) above the soil surface, allowing the instrument to stabilize, and then reading the meter. Post-remediation exposure rates in 21.5 percent of the survey area contained exposure rate measurements of 3.5 µR/hr (Battelle, 2001).

In addition to the field surveys laboratory soil samples were collected in the survey area (outside of the CERCLA excavation) from seven random locations and two biased locations with elevated gross gamma count rates. The samples were sent to an off-site laboratory and analyzed for total radium alpha, which included $^{224}$Ra, $^{226}$Ra, and $^{228}$Ra; and for $^{90}$Sr, (Battelle, 2001). The seven random samples collected from depths of 1-2 feet blow land surface ranged from 0.88 - 2.99 picoCuries per gram (pCi/g) for $^{226}$Ra with an average$^{226}$Ra value of 1.64 pCi/g. Stronium-90 ranged from 0.27-4.03 pCi/g for $^{90}$Sr average of 1.18 pCi/g. The highest reading was observed in the bias sample collected at location 13T with $^{226}$Ra reported at 55 pCi/g and 4.0 pCi/g of $^{90}$Sr (Battelle, 2001).

## 1.4 Radionuclides of Concern and Radiation Characteristics

Radioactivity exceeding background levels was discovered at IR Sites 1 and 2 in October 2000 while conducting remedial excavation activities (Battelle, 2001). At that time, the radionuclides known to be present at concentrations exceeding expected background concentrations were $^{90}$Sr and $^{226}$Ra (Cabrera, 2008).

Other radionuclides anticipated to be present were based on non-permitted activities involving radioactive materials. The potential sources of contamination identified and their associated radiological constituents were:

- Grinding of thoriated tungsten welding rods: Thorium-232 ($^{232}$Th).
- Handling of radioluminescent material: Hydrogen-3 ($^{3}$H [Tritium]), Carbon-14 ($^{14}$C) and Promethium-147 ($^{147}$Pm).
- Decontamination of ships participating in Operation Crossroads: $^{90}$Sr, Cesium-137 ($^{137}$Cs), Plutonium-239 ($^{239}$Pu), Plutonium-240 ($^{240}$Pu), Plutonium-241 ($^{241}$Pu), and Americium-241 ($^{241}$Am).

Other radionuclides from these and other less likely potential sources of contamination may be considered to be present. However, if present, they would be expected to be limited to small quantities in discrete localized areas. From a dose or risk perspective, their potential presence was not anticipated to be significant.

The RCOPCs were identified based on information in the *Risk Assessment and RI/FS Work Plan Report* (Bechtel, 1994b) regarding historical activities conducted at LBNC and on the results of previous investigations. Radium-226 and $^{90}$Sr were identified as RCOPCs based on historical information, including the results of previous investigations. The RCOPCs are listed in Table 1.4-1.

**Table 1.4-1 Radiological Constituents of Potential Concern (RCOPCs)**

| Transuranic | Fission | Natural | Activation |
|---|---|---|---|
| $^{241}$Am | $^{137}$Cs | $^{226}$Ra | $^{3}$H |
| $^{238}$Pu | $^{90}$Sr | $^{14}$C | |
| $^{239}$Pu | | | |
| $^{240}$Pu | | | |

Although not every RCOPC was expected to be present at every site, the same basic survey design for detecting RCOPCs was applied at every site. Most of the RCOPCs were measured directly using either gamma spectroscopy or alpha spectrometry, as specified in the *SAP* (Cabrera, 2008). Table 1.4-2 lists the radiological properties of the RCOPCs.

**Table 1.4-2 Properties of RCOPCs and Their Radioactive Progeny**

| RCOPC[a] | Radioactive Progeny[a] | Half-Life | Decay Mode | Radiation Energy (MeV)[b] | | |
|---|---|---|---|---|---|---|
| | | | | Alpha | Beta[c] | Gamma |
| $^{3}$H | --- | 12.35 y | beta | --- | 0.00568 | --- |
| $^{14}$C | --- | 5,730 y | beta | --- | 0.0495 | --- |
| $^{90}$Sr | --- | 29.12 y | beta | --- | 0.196 | --- |
| | $^{90}$Y | 64.0 h | beta | --- | 0.935 | <0.0001 |
| $^{137}$Cs | --- | 30 y | beta | --- | 0.187 | --- |
| | $^{137m}$Ba | 2.55 min | IT[d] | --- | 0.0651 | 0.596[e] |
| $^{226}$Ra | --- | 1,600 y | alpha | 4.86 | 0.00359 | 0.00673 |
| | $^{222}$Rn | 3.824 days | alpha | 5.59 | <0.0001 | 0.00040 |
| | $^{218}$Po | 3.05 min | alpha | 6.11 | <0.0001 | <0.0001 |
| | $^{214}$Pb | 26.8 min | beta | - | 0.291 | 0.248 |
| | $^{214}$Bi | 19.9 min | beta | - | 0.648 | 1.46 |
| | $^{214}$Po | <0.001 sec | alpha | 7.83 | <0.0001 | <0.0001 |
| | $^{210}$Pb | 22.3 y | beta | - | 0.038 | 0.00481 |
| | $^{210}$Bi | 5.012 days | beta | - | 0.389 | - |
| | $^{210}$Po | 138.4 days | alpha | 5.4 | <0.0001 | <0.0001 |
| $^{239}$Pu | --- | 24,065 y | alpha | 5.23 | 0.00665 | 0.00079 |
| | $^{235}$U[f] | 7.0E+8 y | alpha | 4.47 | 0.048 | 0.154 |
| $^{240}$Pu | --- | 6,537 y | alpha | 5.24 | 0.0106 | 0.00173 |
| | $^{236}$U[f] | 2.3E+7 y | alpha | 4.58 | 0.0114 | 0.00157 |
| $^{241}$Pu | --- | 14.4 y | beta | --- | 0.00523 | <0.0001 |
| $^{241}$Am[g] | $^{241}$Am[f] | 432.2 y | alpha | 5.57 | 0.0519 | 0.0324 |

**Table 1.4-2 Properties of RCOPCs and Their Radioactive Progeny (Continued)**

| RCOPC[a] | Radioactive Progeny(a) | Half-Life | Decay Mode | Radiation Energy (MeV)[b] | | |
|---|---|---|---|---|---|---|
| | | | | Alpha | Beta[c] | Gamma |
| Notes:<br>(a) Data Source: International Commission on Radiological Protection (ICRP) Publication 38, Radionuclide Transformations (ICRP, 1983).<br>(b) Sum of radiation energies in megaelectron volts (MeV) per disintegration.<br>(c) Sum of average beta radiation energies per disintegration.<br>(d) Decays by isomeric transition (gamma ray emission).<br>(e) Gamma emission from Barium-137 ($^{137m}$Ba) progeny (2.55 min half-life).<br>(f) Radioactive progeny is not of interest due to long half-life of parent radionuclide.<br>(g) Present as both a RCOPC and as the radioactive progeny of $^{241}$Pu. | | | | | | |

## 1.5 Radiological Conceptual Site Model

The radiological conceptual site model (CSM) for IR Sites 1 and 2 describes current site conditions related to radionuclide distributions, release mechanisms, exposure pathways, migration routes, and potential dose receptors. The CSM was developed based on radiological data previously collected at the Sites, historical records, aerial photographs, and maps. The radiological CSM described in the *SAP*, Appendix A, of the *Supplemental Radiological Assessment of Installation Restoration Sites 1 and 2, Long Beach Naval Complex* (Cabrera 2008) forms the basis for the DQOs and the sampling and analytical design described in Worksheets #10 and 11 in the *SAP* (Cabrera, 2008).

## 1.6 Report Objective

The main objective of the Radiological Assessment was to collect sufficient data to evaluate the potential radiological dose and risk to receptors, industrial workers, on the surface at IR Sites 1 and 2. This Report provides an evaluation of data collected during this investigation; it is focused on identifying RCOCs, defining the nature and extent of contamination at the Sites, and estimating the dose and risk for RCOCs under an industrial worker exposure scenario.

The number of samples that were needed from Sites 1 and 2 to obtain sufficient statistical confidence that the conclusions drawn from the sample population would be sound was determined using the method described in Section 5.5.2 of the *Multi-Agency Radiation Survey and Site Investigation Manual* ([MARSSIM, , 2002). Table 5.5 in MARSSIM (MARSSIM, 2002) indicates that 14 samples would be a statistically sufficient number of samples required to support decisions based on the relative shift and acceptable decision error rates using the Sign Test. To allow for lost and/or unusable data and/or other uncertainties in sample collection, the minimum number of samples was set at 16 (Cabrera, 2008).

This Page Left Intentionally Blank

## 2.0 Radiological Investigation

This Section describes the radiological investigation conducted at LBNC IR Sites 1 and 2. The following Sections compare the actual field activities to those planned to demonstrate that the survey was implemented as designed.

### 2.1 Data Quality Objectives

Data Quality Objectives are qualitative and quantitative statements that were developed to define the purpose of the data collection effort, clarify what characteristics of the environment the data should represent, and specify the requirements that must be met for the quality of information to be obtained from the data. These DQOs were used to develop a data collection design that met all performance criteria and other design requirements and constraints (Cabrera, 2008).

The goals of the radiological investigation were to determine whether contamination was present, the nature (contaminant, form, and concentration) of the contamination, the extent (horizontal and vertical distribution) of contamination, and if there is an impact to human health for the industrial worker scenario. Therefore, the data collected had to be of sufficient quantity and quality to address these goals.

To achieve the DQOs, quality assurance (QA) measures were implemented throughout the project to ensure data met known and suitable quality criteria such as precision, accuracy, representativeness, completeness, and comparability (PARCC). The DQOs were established in the approved SAP (Cabrera, 2008) with concurrence from the regulatory agencies. The qualities of analytical data were also controlled through the performance of quality control (QC) measurements and the calibration of field and laboratory equipment. The overall quality of the QC data and evaluation is presented in detail in Appendix C.

This radiological investigation consisted of a combination of non-intrusive surface investigations combined with direct radiation measurements, intrusive sample collection, and both on-site and off-site laboratory analysis. Onsite radiological measurement techniques were selected based on the radiological characteristics of the RCOPCs, potentially impacted media, and reasonable implementation of the best available technology. The investigation measurement results were reviewed and compared to the project ILs.

Verification and validation of investigation measurement results were performed by the laboratory, by an independent reviewer, and Cabrera as part of the data quality assessment process. The results of the laboratory verification and validation process are documented in the case narrative provided with each set of sample analyses and include a variety of data flags that are only used by the laboratory. The raw data from the laboratory, including the case narratives, are provided in Appendix E. The results of the independent third party verification and validation process are provided in Appendix C. Sample results that do not meet the requirements for data quality are flagged with an "R" to signify these data have been rejected. Sample results that do not meet all of the data quality criteria but are still usable are flagged with a "J" to signify there is increased uncertainty associated with the use of these data. The data quality assessment included a review of the independent data verification and validation reports to get an understanding of the overall quality of the analytical results.

Under the direction of the Navy Base Realignment and Closure (BRAC) in consultation with Naval Sea Systems Command Detachment (NAVSEADET) Radiological Affairs Support Office (RASO), Cabrera was responsible for the development of the *Work Plan* and the *SAP* (Cabrera, 2008) for this radiological assessment at IR Sites 1 and 2.

All DQOs for data collected at LBNC IR Sites 1 and 2 were satisfied.

## 2.2 Step 1 - State the Problem

Radioactivity exceeding background levels was discovered at IR Sites 1 and 2 in October 2000. The presence of this residual radioactivity had not been previously suspected at these Sites. Radiation survey and remediation activities conducted from November 2000 through May 2001 were not sufficient to adequately determine the nature and extent of the residual radioactivity. Consequently, residual radioactivity could potentially be present at concentrations that are not protective of human health for the following reasons:

- The scope of the survey was too narrow. No radiological characterization and or scoping was conducted in Area I or in the western one-fourth of Area II (see Figure 1.2-1), which are located within the Sea Launch Facility. Elevated gross gamma count rate readings were identified and radioactively contaminated soil and debris were found throughout Areas II and III and up to the northern, southern, and western survey boundaries in Area II, suggesting contamination extended beyond the survey boundaries.
- Too few samples were collected. The radioactive contamination is composed of both distributed and discrete source contamination, which causes a high sampling uncertainty. Relatively few soil samples (nine) were collected to characterize a large-volume heterogeneous matrix. No groundwater samples were collected. There is little confidence that the contaminant populations are understood well enough to support decision-making.
- The analyses performed could not detect all of the RCOPCs. The sensitivity achieved by the in situ gamma spectroscopy performed was not documented. Therefore, its capability to detect low concentration gamma-emitters (other than gamma-emitting $^{226}$Ra progeny and naturally occurring $^{40}$K) is unknown. Laboratory analyses of soil samples were limited to $^{90}$Sr and $^{226}$Ra. Analyses for other radionuclides were not performed.
- Remediation activities were based on an unreliable correlation between surface radiation levels and soil concentrations. A correlation between gross gamma count rates and distributed and discrete point sources of radioactive contamination in the surface and shallow soil (i.e., the first 1 foot of soil) was not documented and, is therefore uncertain from a decision-making perspective. The physical nature of the radioactive contamination does not readily lend itself to indirect relational inference of its presence and concentration. The type of contamination ranges from soil and soil-like material (e.g., sandblast grit); to rusted, corroded, or soil-encrusted pieces of manufactured items; to identifiable intact manufactured items (e.g., deck markers).

This Radiological Assessment was conducted to determine whether radioactive contamination from RCOPCs associated with historical activities at IR Sites 1 and 2 is present in solid matrices. The potentially impacted matrices included surface soil, subsurface soil, and groundwater at IR Sites 1 and 2.

## 2.3 Step 2 - Identify the Decision

### *2.3.1 Principal Study Question*

The principal study question is: "Are the levels of residual radioactivity at IR Sites 1 and 2 protective of human health?" In order to answer this question using empirically collected radiological data, it is restated in terms of quantitative risk or dose: "Do the RCOPC concentrations at IR Sites 1 and 2 exceed ILs?" The ILs are risk- or dose-based upper concentration limits for specific RCOPCs in specific environmental media that are anticipated to be protective of human health. The goal of this step is to define the question that the survey will attempt to resolve, and identify alternative actions that may be taken based on the outcome of the surveys. The combination of these two elements is called the decision statement.

## 2.4 Step 3 - Identify Inputs to the Decision

Three inputs were used to answer the principal study question. They are: (1) the RCOPCs, (2) the matrices (i.e., media) in which the RCOPCs are found, which allow fate and transport predictions to be made, and (3) the concentrations of specific RCOPCs in specific media (i.e., ILs) at which human health may not be protected and a risk assessment should be performed. Measurement inputs will be both quantitative and qualitative.

### *2.4.1 RCOPC*

A list of nine RCOPCs was developed for IR Sites 1 and 2 based on historical use of radioactive materials at LBNC for IR Sites 1 and 2. Section 1.4 and Tables 1.4-1 and 1.4-2 provide more detailed information on the RCOPCs.

### *2.4.2 Potentially Affected Media*

Surface soil, which for this project was defined as soil to a depth of 1 foot bgs, and groundwater are potentially impacted media. The concrete and asphalt coverings were surveyed but not sampled. Impacted surface soil may be exposed or found beneath concrete and asphalt installed during construction activities subsequent to solid waste operations. Subsurface soils (below 1 foot) were outside the scope of the decision statement, but were sampled for characterization purposes. Soil and groundwater were the only media sampled.

### *2.4.3 Investigation Levels (ILs)*

Risk- or dose-based upper concentration limits for specific RCOPCs in specific environmental media that are anticipated to be protective of human health were developed based on the United States Environmental Protection Agency (EPA) and United Stated Nuclear Regulatory Commission (NRC) approaches to the protection of human health. These concentration limits, or investigation levels, generally represent an excess lifetime cancer risk of less than $10^{-6}$, but in no case more than $10^{-4}$, and a dose of 25 mrem/yr.

The EPA considers a $10^{-6}$ incremental risk of an individual developing cancer over a lifetime of exposure as protective of human health. The $10^{-6}$ risk serves as a point of departure for risk remediation, below which no action is taken (i.e., the risk is considered acceptable). The EPA guidance indicates that action is generally warranted when the excess lifetime cancer risk exceeds $10^{-4}$. Above the $10^{-4}$ risk, action is taken (i.e., the risk is considered unacceptable). When the risk is within the risk management range of $10^{-6}$ to $10^{-4}$, a decision about whether to take action (e.g., whether the risk is acceptable or unacceptable) is a site-specific determination.

The NRC considers a dose of 25 mrem/yr to an average member of the critical group as protective of human health, provided that residual radioactivity has been reduced to levels that are As Low As Reasonably Achievable (ALARA). No action is taken when the total effective dose equivalent (TEDE) is below 25 mrem/yr and ALARA (i.e., the dose is acceptable). Conversely, action is taken when it exceeds 25 mrem/yr or is not ALARA (i.e., the dose is unacceptable).

ILs for RCOPCs in surface soil and in groundwater were developed for the radiological assessment at IR Sites 1 and 2 as well as for assessment of the gamma walkover surveys (GWS). As a general rule, no further investigation was performed where RCOPC concentrations did not exceed the ILs. Likewise, further investigation was to be performed for areas where RCOPC concentrations exceeded the ILs. The surface soil and groundwater ILs are radionuclide-specific and were applied using the unity rule found in Section 4.3.3 of MARSSIM 2002. The fractions of the concentration of each RCOPC to its IL were summed, and a value greater than unity exceeded the IL.

### *2.4.3.1. ILs for Surface Soil and Groundwater*

ILs for RCOPCs in surface soil, given in pCi/g, and in groundwater, given in picoCuries per liter (pCi/L), were developed for the Radiological Assessment of IR Sites 1 and 2 in the *SAP* (Cabrera, 2008) (see Table 2.4-1). ILs have two purposes: (1) to screen out or remove from further investigation areas of the site, RCOPCs, and potentially impacted media from further investigation; and (2) to identify areas where there is need for further investigation.

**Table 2.4-1 ILs for Surface Soil and Groundwater**

| RCOPC | Surface Soil (pCi/g) | | Groundwater (pCi/L) | |
|---|---|---|---|---|
| $^{3}$H (organic) | 1.4E+00 | EPA Preliminary Remediation Goal (PRG) (default) | 1E+06 | *California Ocean Plan Criteria* |
| $^{14}$C | 1.2E+01 | Published NRC value | 3E+04 | *California Ocean Plan Criteria* |
| $^{90}$Sr | 1.7E+00 | Published NRC value | 5E+02 | *California Ocean Plan Criteria* |
| $^{137}$Cs | 1.9E-01 | EPA PRG (site-specific)[(b)] | 1E+03 | *California Ocean Plan Criteria* |
| $^{226}$Ra | 1.4E+00 | RESRAD Calculated[(b)(c)] | 6E+01 | *California Ocean Plan Criteria* |
| $^{239/240}$Pu[(a)] | 2.3E+00 | Published NRC value | 2E+01 | *California Ocean Plan Criteria* |
| $^{241}$Pu | 7.2E+01 | Published NRC value | 1E+03 | *California Ocean Plan Criteria* |
| $^{241}$Am | 2.1E+00 | Published NRC value | 2E+01 | *California Ocean Plan Criteria* |

Notes: (a) Radio-analytical results usually report both radionuclides together.
(b) Investigation level includes a background concentration component
(c) Using RESRAD version 6.3, site-specific modeling assumptions for site specific dose of 25mrem/yr

Potential ILs for surface soil were developed and evaluated for applicability to the radiological assessment at IR Sites 1 and 2. Radionuclide-specific risk-based ILs were developed using the *Soil Screening Guidance for Radionuclides: User's Guide* (EPA, 2000). Investigation levels were developed using both default and site-specific parameters. Radionuclide-specific dose-based ILs included default values corresponding to 25 mrem/yr published by the NRC in the

Federal Register (NRC, 1999) and site-specific values at 25 mrem/yr, calculated using U.S. Department of Energy (DOE) Residual Radioactivity (RESRAD) version 6.3. The ILs selected for the radiological assessment included U.S. EPA default values for $^{3}H$ and $^{137}Cs$ and NRC published values for all other radionuclides.

The ILs for groundwater are based on the assumption that the potential migration of residual radioactivity via groundwater to the nearby marine eco-system is insignificant if the RCOPC concentrations do not exceed the *California Ocean Plan* (SWRCB, 2005) at the point of compliance. The point of compliance is the interface along the north (bay) side of the Navy Mole and the receiving waters of Long Beach Harbor. Ultimate compliance is determined by direct measurements in the receiving waters. Table B of the *California Ocean Plan* (SWRCB, 2005) establishes water quality objectives for the protection of marine aquatic life. For radioactivity, the objective is not to exceed the limits specified in the *California Code of Regulations*, Title 17, Division 1, Chapter 5, Subchapter 4, Group 3, Article 3, Section 30253. The NRC uses the same limits for liquid effluent releases, which are published in 10 Code of Federal Regulations 20, Table 2 of Appendix B.

#### *2.4.3.2.ILs for Gamma Walkover Surveys*

Gamma radiation is associated with most of the RCOPCs for the radiological assessment as shown in Table 1.4-2 (i.e., $^{226}Ra$ and $^{137}Cs$). Elevated gross gamma activity (greater than three standard deviations) detected by the GWSs provided a qualitative indication of the potential presence of radioactive material.

The differences between each data point and the average of all data points in the site were calculated and divided by the standard deviation of all data points. This converted the measurements to multiples of the standard deviation above or below the average count rate of the site (i.e., z-scores). Calculation of z-score values is described in more detail in Section 3.3.

Locations with higher than expected gross gamma activity (z-score contours exceeding 3.0 or at the location of the highest count rate in cases where no z-score exceeded 3.0) were investigated using in situ gamma spectroscopy measurements and/or surface soil samples.

### *2.4.4 Measurement Inputs*

Instrument types and sample analysis methodologies are summarized below. The survey was designed as a graded approach using the following types of measurements and samples as inputs to the principal study questions.

- Gross GWS of all portions of the site that could be safely and accurately surveyed in this manner.
- In situ gamma spectroscopy measurements, using the In Situ Object Counting System (ISOCS™) which uses a high-purity germanium (HPGe) detector, at (a) randomly selected locations (systematic samples), (b) locations identified as elevated by the GWS (i.e. at locations where z-score > 3 or at the highest gamma reading if there were no locations where z-score > 3), and (c) additional locations adjacent to initial measurements that exceeded ILs (i.e., step-outs).
- Surface and subsurface soil samples at (a) randomly selected locations (systematic samples), (b) locations identified as elevated by the GWS (i.e. at locations where z-score > 3 or at the highest gamma reading if there were no locations where z-score >

3), and (c) additional locations adjacent to and beneath initial samples that exceeded ILs for surface soil (i.e., step-outs and step-downs).

- Gross Gamma Borehole Logging Surveys to determine the depth of some soil samples.
- Global Positioning System Data Collection for mapping and documenting measurement locations.
- Groundwater samples collected from existing wells around the perimeter of the impacted soil area.

The results of in situ gamma spectroscopy measurements of the surface media and surface soil and groundwater sample analyses were used as quantitative inputs to the principal study question: "Are the levels of residual radioactivity at IR Sites 1 and 2 protective of human health?" The z-scores calculated using GWS data were used as qualitative input. The results of gross gamma borehole logging and subsurface soil sample analyses were used for characterization purposes.

The following types of measurements were conducted as part of this radiological investigation but the results of these measurements were not utilized as inputs to the principal study question. The results of these measurements were used to perform H&S surveys and to ensure sampling equipment was adequately decontaminated between sampling. The results of these measurements are not included in this Report.

- Gross Beta-Gamma GM Scans (sampling equipment only).
- Smear Sampling and Analysis (sampling equipment and materials only).
- Gamma Dose Rates for each sample locations.
- Weekly radiological surveys for the trailers (office and laboratory trailer) and the sample preparation room.

## 2.5 Step 4 - Define the Study Boundaries

### *2.5.1 Define the Target Population*

The target population of interest is the RCOPCs and their radioactive progeny volumetrically contained in surface soil and groundwater. The spatial boundaries are surface soil (to a depth of 1 foot bgs) and groundwater at IR Site 1 and 2 which is subdivided into 33 survey units (SUs) as described in Section 3.1.3. Subsurface soil (greater than 1 foot bgs) is outside the scope of the study boundaries, but was sampled for characterization purposes.

Surface soil samples were collected by hand, each from an area approximately 4 inches square by 12 inches thick (deep), sifted to remove vegetation and debris, and homogenized to obtain approximately 1,000 grams of sample for laboratory analysis. Subsurface soil samples were collected by direct-push technology from a 2-inch diameter cylinder over a length of approximately one foot, sifted to remove debris, and homogenized to obtain approximately 1,000 grams at the depth designated by the site-specific survey design. Debris separated from soil samples was screened for radioactivity using hand-held instruments to identify any sources of radiation. All sources of radiation identified during the investigation were removed to maintain exposures ALARA.

### *2.5.2 Constraints on Data Collection*

Several areas were constrained due to physical features blocking access to the surface to be measured (e.g., fences, heavy vegetation, trees, large pieces of stored equipment and materials), and structures which limited global positioning system (GPS) reception. These areas are described in Section 6.2. None of the constraints on data collection affected the ability to address the principal study questions.

### *2.5.3 Scale of Decision Making*

Decisions on whether to perform additional investigations were made for individual sample locations. Each measurement result was compared to the appropriate IL to determine if additional data were to be collected. Systematic sample locations were considered representative of general site conditions and biased or targeted sample locations were considered representative of the locations most likely to have contamination in excess of the ILs. The location-by-location evaluation of sample results against ILs is, therefore, considered adequate to draw conclusions about the need for additional investigation for the entire site.

## 2.6 Step 5 - Develop a Decision Rule

As a general decision rule, no further investigation was performed where RCOPC concentrations did not exceed the ILs. Conversely, further investigations were performed in areas where RCOPC concentrations exceeded the ILs. The decision statements presented in Section 2.3.1 resulted in the decision rules listed in Table 2.6-1.

**Table 2.6-1 Decision Rules**

| Parameter of Interest | IF | THEN |
|---|---|---|
| Surface Soil | | |
| Gamma Scan | Presence of elevated residual radioactivity suspected; i.e., z-score > 3.0 | Perform additional sampling in/around area of suspected elevated residual radioactivity:<br>In situ gamma spectroscopy measurement, or(if soil location) surface soil sample<br>(if non-soil location) soil sample from beneath concrete or asphalt covering |
| | Presence of elevated residual radioactivity not suspected; i.e., z-score < 3.0 | Perform no additional biased sampling. |
| In Situ Gamma Spectroscopy | RCOPC concentrations exceed the ILs | Step out no more than 10 meters (m) in at least four directions and perform additional sampling in/around area of suspected elevated residual radioactivity:<br>In situ gamma spectroscopy measurement, or<br>(if soil location) surface soil sample, or<br>(if non-soil location) soil sample from beneath concrete or asphalt covering. |
| | RCOPC concentrations do not exceed the ILs | Perform no additional biased sampling. |

**Table 2.6-1 Decision Rules (Continued)**

| Parameter of Interest | IF | THEN |
|---|---|---|
| Surface Soil Samples | RCOPC concentrations exceed the ILs | Step out no more than 10 m in at least four directions and perform additional sampling in/around area of suspected elevated residual radioactivity:<br>In situ gamma spectroscopy measurement, or<br>(if soil location) surface soil sample, or<br>(if non-soil location) soil sample from beneath concrete or asphalt covering. |
| | RCOPC concentrations do not exceed the ILs | Perform no additional biased sampling. |
| Groundwater | | |
| Groundwater Samples | RCOPC concentrations exceed the ILs | Collect one or more upgradient groundwater samples. |
| | RCOPC concentrations do not exceed the ILs | Collect no upgradient groundwater samples. |

## 2.7 Step 6 – Specify Limits on Decision Errors

Decision errors occur when an incorrect action is recommended based on the decision rules. The radiological investigation design starts with performing a minimum number of measurements to characterize each site. Based on the results of the initial measurements, decisions are made on whether additional data are required to completely define the nature and extent of radioactivity at the site. Therefore, at each step of the survey graded approach the consequences of making a decision error were biased towards collecting additional data.

The principal study question was to detect the potential presence of radioactive contamination at the Sites. Therefore, the decision error rates for calculating the minimum number of initial measurements were selected to be consistent with the minimum detectable concentrations (MDCs). For the null hypothesis that no detectable radioactivity is present, a Type I decision error would occur when it is decided there is radioactivity present when there is actually no detectable radioactivity. A Type II decision error would occur when it is decided there is no detectable radioactivity when radioactivity is present. The Type I and Type II decision error rates for calculating the minimum number of initial measurements and calculating MDCs for individual measurements were set at 0.05, or 5 percent.

## 2.8 Step 7 - Optimize the Design for Obtaining Data

The data collection process was designed to provide near real-time data during implementation of field activities. Data were evaluated against the ILs using Exploratory Data Analysis (EDA), an approach analyzing data sets to summarize their main characteristics, to refine the scope of step-out field activities, as needed, to optimize implementation of the survey design and ensure the DQOs were met. The data used in the EDA process are compiled by SU and provided in Appendix E. Please see the *SAP* (Cabrera, 2008) for more detailed information.

## 3.0 Survey/Sampling Design

The survey/sampling design integrates both probability-based (random and random-start/systematic) and judgmental (biased) methods to data collection, as described in Sections 4.0 and 5.0 of the MARSSIM (2002) to achieve the project DQOs.

The survey/sampling design had two objectives. The first objective was to collect sufficient data to determine whether the RCOPC concentrations exceeded respective ILs. The intensity of this effort is based on the number of SUs and their classification. The second objective was to define the extent of residual radioactivity where RCOPC concentrations exceeded the ILs. The second objective was achieved by additional targeted sampling in accordance with the decision rules in Section 2.6.

## 3.1 Site Classification and Survey Unit Size

The areas at IR Sites 1 and 2 do not all have the same potential for residual radioactivity and accordingly, do not all need the same level of sampling to determine whether the levels of residual radioactivity would be protective of human health. Different areas of the Sites were grouped into impacted and non-impacted areas, shown in Figure 3.1-1, and were based on the potential presence of residual radioactivity evaluated using the criteria given below. The site classifications were based on professional judgment, considering historical site operations and characterization data.

It was not the intent of this radiological assessment to clear SUs or as a Final Status Survey. SUs were however, remediated by removing small discrete point sources identified in the first foot of soil, and the data collected in this report is consistent with MARSSIMs principals and suitable for use in future characterizations and final status surveys of the SUs.

### *3.1.1 Impacted Areas*

An area that has reasonable potential for residual radioactivity from solid waste operations is designated as an impacted area. The IR Site 1 and the portion of IR Site 2 that corresponds with the boundaries of IR Site 1 (i.e., east of Pier 13, see Figure 3.1-1) were determined to be impacted areas since that is where solid waste operations occurred. The IR Sites 1 and 2 were divided into Class 1 and Class 2 areas.

- **Class 1 –** an impacted area where, prior to remediation, there are expected to be locations with RCOPCs at concentrations that exceed ILs.

Class 1 areas include AOPCs 1, 3, and 4 and Areas I, II, and III which were identified during the RI (see Figures 1.1-2 and 1.2-1). AOPCs 1 and 4 are areas where aerial photographs from the 1950s indicated that there were cut-and-fill operations. AOPC 3 was identified as a "Burn Pit Area" from aerial photographs and records reviews found in Appendix N of the *RI Report* (Battelle, 1996) whereas Areas I, II, and III are areas where electromagnetic and magnetometer survey data collected during the RI suggested the presence of cut-and-fill operations Appendix K of the *RI Report* (Battelle, 1996) .

- **Class 2 –** an area is an impacted area where, prior to remediation, there are expected to be locations with RCOPCs at concentrations that are detectable above background levels, but that do not exceed ILs.

Class 2 areas are the portions of IR Sites 1 and 2 outside of the AOPCs and Areas I, II, and III. The entire IR Site 1 was identified as having solid waste operations during the *Initial Assessment Study* (NEESA, 1983). However, during the RI, the areas most likely to have been used for solid waste operations were refined through identification of AOPCs and the geophysical surveys.

A third classification, Class 3, was not used due to the uncertainty in historical site operations. A Class 3 area is an impacted area where there are not expected to be locations with RCOPCs at concentrations that are detectable exceeding background levels.

### *3.1.2 Non-Impacted Areas*

An area that has no reasonable potential for residual radioactivity from solid waste operations is designated as a non-impacted area. The western portion of IR Site 2 that is outside of IR Site 1 has been determined to be a non-impacted area. For this investigation, the single suspected significant mechanism of release of radioactivity to the environment is the potential inadvertent disposal as part of the solid waste operations that occurred in IR Site 1. Because the western portion of IR Site 2 is an area outside of IR Site 1 and, therefore, outside the solid waste operations area, it is not probable that residual radioactivity would be found. Radiological surveying or sampling of this non-impacted area was not required or necessary based on the current CSM and work plan.

### *3.1.3 Survey Units*

Impacted portions of IR Sites 1 and 2, approximately 30 acres (121,000 square meters [$m^2$]), were divided into Class 1 and Class 2 areas as described above, and further divided into SUs based on MARSSIM (2002) guidance as described in Table 3.1-1 and as shown in Figure 3.1-2. Subsurface soil and groundwater were not divided into SUs.

**Table 3.1-1 Survey Unit Sizing**

| Class | MARSSIM Survey Unit Size ($m^2$) | Approximate Size of Impacted Area ($m^2$) | Number of Survey Units | Survey Units |
|---|---|---|---|---|
| 1 | 2,000 | 51,000 | 25 | SU 1 Through SU 25 |
| 2 | 10,000 | 70,000 | 8 | SU 26 Through SU 33 |

### *3.1.4 Survey and Sampling*

A GWS was performed over 100 percent of the accessible areas in each SU in Class 1 and Class 2 areas to locate radiation anomalies that might indicate areas with elevated residual radioactivity where further data collection would be warranted.

In situ gamma spectroscopy measurements were recorded and samples were collected at a predetermined number of locations for surface soil. The number of measurements was determined based on the survey objectives and the statistical tests using MARSSIM guidance (MARSSIM, 2002). Sample locations were selected using a random-start triangular grid for surface soil samples and ISOCS™ measurements. These predetermined measurements were referred to as "systematic measurements." Samples were analyzed by gamma spectroscopy at an onsite laboratory to expedite the selection of step-out sampling locations. The samples were also sent to a state-certified offsite laboratory for analysis by gamma and alpha spectrometry.

Onsite laboratory results and in situ gamma spectroscopy measurements were compared to the project ILs to identify areas requiring additional investigation.

Once areas requiring additional investigation were identified, a second stage of data collection activities was conducted to determine the extent of the areas where radionuclides exceeded ILs. Additional measurements were performed at "step-out" locations adjacent to soil sampling locations or in situ measurement locations that had exceeded project ILs. Step-outs were typically taken approximately 3 to 6 meters from the initial exceedances. This process was continued until all areas that had exceeded respective ILs were bounded horizontally and vertically by measurements that did not exceed the ILs.

The onsite gamma spectroscopy laboratory was used to reduce the time required to analyze samples and to provide close to real-time analytical results. QA/QC procedures for the onsite laboratory met the same requirements as other analytical laboratories (see Appendix C). All samples were sent to an offsite laboratory for liquid scintillation counting, gas-flow proportional counting, and alpha spectrometry measurements (Section 4.1). Approximately 12 percent of the samples were sent offsite for gamma spectroscopy. The decision for offsite laboratory analysis included the two samples with the highest RCOPC concentrations in each SU (with the exception of SU 19 which had only one offsite sample analyzed) for a total of 65 samples. In addition to the required two highest samples per SU, an additional 16 biased samples were collected from SUs 04, 06, 10, 11, 14, 15, 20, 29, and 31. Biased or "judgmental samples" were collected based on professional judgment while conducting field sampling activities and where used in accordance with the DQOs and to support decision-making.

One borehole was installed for subsurface sampling in each SU. Gamma logs were performed on each borehole by lowering a 1 inch by 1 inch cylindrical NaI detector into an open borehole to assist in selecting subsurface soil samples for additional analysis. Thirty-seven subsurface samples were collected for characterization purposes only; three of these samples were sent to an offsite laboratory for gamma spectroscopy based on professional judgment and those samples having elevated RCOPC concentrations. The rest of the subsurface samples were counted onsite for gamma spectroscopy. All subsurface samples were sent offsite for liquid scintillation counting, gas-flow proportional counting, and alpha spectrometry measurements (Section 4.1).

Groundwater samples were collected from six existing monitoring wells located closest to the Bay and ocean around the perimeter of IR Site 1 (see Figure 3.1-3 for sample locations). Samples were sent to an offsite lab for gamma spectroscopy, alpha spectrometry, liquid scintillation, and gas-flow proportional counting analysis.

## 3.2 Mobilization

Onsite laboratory setup, trailers setup, equipment, materials, and personnel were mobilized in accordance with the project schedule as described in the *Work Plan* (Cabrera, 2008). Personnel working onsite received require training and/or certification in radiation safety, site-specific construction safety, task-specific training, and regulatory permitting and notifications, based upon their assigned work. An onsite field office/laboratory was set up for conducting field activities and performing sample analyses and consisted of separate soil preparation, storage, and counting areas. The preparation area was equipped to handle soil drying and grinding operations, if required. A shielded HPGe system was set up in the counting area. A ventilation hood with high-efficiency particulate filtration was installed. The clearance of excess vegetation and site

grubbing, which involved removal of grasses, bushes, and small trees (less than 10 centimeters in diameter) down to less than 10 centimeters in height, was conducted.

### 3.3 Gross Gamma Walkover Surveys

Gross GWS data were collected using a Ludlum Model 2221r scaler/ratemeter with a Ludlum Model 44-9 3 inch by 3 inch 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 a global positioning system (GPS). Data were automatically logged with the measurement coordinates using a Trimble TSCe™ GPS. The GPS link tied survey data to spatial locations using state plane coordinates North American Datum (NAD) 1983, State Plane California Zone 5. The results from the GWS were reported as z-scores to account for differences in detector response and natural background in different surface media. This means that the highest z-score values are more likely to correspond to localized areas of elevated gamma radiation, and thus identifying more specifically areas of contamination potentially requiring additional investigation.

One hundred percent of the accessible areas in each of the SUs were surveyed. Areas that were not surveyed included those where access was physically restricted due to vehicles, equipment, buildings, trailers, and/or vegetation, etc.

At a minimum, gross GWS data were processed for each medium (i.e., asphalt or soil) in each SU as follows:

- The measurements were presented as posting plots contouring z-scores for visual review and evaluation of completeness for the GWS for each SU.
- Outliers were identified based on a graphical data review. Outliers include very high and very low results that are not part of the normal distribution incorporating the majority of the data.
- The average and standard deviation of the gamma count rate for each media in each SU was calculated based on the normal distribution incorporating the majority of data. Not including outliers provides an unbiased estimate of the average and minimizes the estimate of the standard deviation.
- The location of the maximum gamma count rate in each SU was determined.
- The differences between each data point and the average (all data points for each media in each SU, including outliers) were calculated and divided by the standard deviation (all data points for each media in each SU). This converted the measurements to multiples of the standard deviation above or below the average count rate for the SU (i.e., z-scores). The z-scores were plotted as color-coded filled contours for visual review and evaluation, where the color-coding was based on multiples of the SU and media specific standard deviation.
- Survey Unit Areas exhibiting a z-score exceeding 3.0 were identified for additional investigation as described in Section 6.0 text and figures of this Report. The data for each SU is provided in the SU EDAs found in Appendix E.

The average counts per minute were calculated using the following equation:

$$\mu = \frac{\sum X}{N}$$

where:

μ = average (cpm)

X = individual results (cpm)

N = number of results

The standard deviation was calculated using the following equation:

$$\sigma = \sqrt{\frac{\sum (X - \mu)^2}{(N - 1)}}$$

where:

σ = standard deviation (cpm)

Measurements exceeding 3 standard deviations above the mean measurement (z-score > 3) were identified for additional investigation while measurements with z-score < 3 required no further investigation.

### 3.4 Surface Soil Sample Collection

Surface soil samples were collected at a minimum of 16 systematic locations in each SU. The number of sample locations was calculated using the methodology described in Section 5.5.2 of MARSSIM (, 2002) and is based on the sampling design goals and constraints specified in the *SAP* (Cabrera, 2008). Surface soil samples were also collected at biased locations in accordance with the decision rules in the *SAP*.

Surface soils were each collected over an area of 100 square centimeters (4 square inches) to a depth of approximately 1 foot at each location. Visually identifiable non-soil components such as stones, twigs, and foreign objects were manually separated from the soil samples. 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 sampler.

Surface soils were collected using jackhammers and hand augers. When collecting surface soil samples, clean tools (e.g., trowels) were used to remove soil samples. The sampling equipment was decontaminated prior to use at each sampling location. Smear samples were collected from the sampling equipment at each sampling location and counted on a Ludlum 2929 to ensure that no cross contamination occurred between sampling locations.

Holes in asphalt areas were temporarily backfilled with cold patch material consistent with the surrounding surface. At the completion of all field activities, all asphalt areas were restored and repaired using hot patch asphalt material.

### 3.5 Subsurface Soil Sample Collection

Subsurface soil samples were collected at systematic random locations and at targeted locations identified by the GWS results (z-score >3).

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 long by two-inch diameter clear acetate sleeve. The samples were extracted from the sleeve in one-foot intervals into one-gallon plastic bags and labeled.

Subsurface soil samples were prepared in the onsite gamma spectroscopy laboratory which was used to provide near real-time feedback for estimating the extent of radioactive contamination. A total of 37 subsurface soil samples (one or two per SU) were sent to the offsite laboratory for gamma spectroscopy, liquid scintillation, and alpha spectrometry analysis.

Borehole logging was conducted using a Ludlum Model 44-2 1-inch by 1-inch cylindrical NaI detector coupled with an integrated scaler. The NaI detector was lowered into the boreholes and a one-minute integrated count was performed at one foot depth intervals to the total depth of the boreholes which ranged between 8-12 feet below land surface based on water table. All borehole logging surveys were performed in conjunction with subsurface soil sampling.

Copies of the borehole logs are provided in Appendix E, Disk 1. The borehole logs also include photoionization detector (PID) readings and dose rate readings which provided H&S information concerning the potential presence of VOC or radiological contamination.

Boreholes were backfilled with bentonite chips. Holes in asphalt areas were temporarily backfilled with cold patch material consistent with the surrounding surface. At the completion of all sampling activities, all asphalt areas were restored and repaired using hot patch material.

The results of the subsurface soil samples are discussed in Section 6.0, and summary EDA data spreadsheets are provided for each SU in Appendix E.

### 3.6 In Situ Gamma Spectroscopy

In situ gamma spectroscopy measurements were performed at a minimum of 16 systematic sampling locations in each SU. In situ gamma spectroscopy measurements were also performed recorded at biased locations in accordance with the decision rules.

In situ gamma spectroscopy measures the average gamma activity over a circular disk 6 inches thick with a 10 foot radius. Laboratory gamma spectroscopy measures the average gamma activity in a soil sample approximately 12 inches thick and 4 inches square. These two different measurement techniques are comparable only if the average activity over the 4 inch square is equal to the average activity over the 10 foot radius. Where no areas of elevated radioactivity are present, the average activity over both areas is the same (i.e., everything is equal to background). Therefore, the only time that in situ gamma spectroscopy results were combined with laboratory results in the same data set was when the results were less than project ILs.

In situ gamma spectroscopy measurement data were used to qualitatively and quantitatively identify radionuclides present at measurement locations. In situ gamma spectroscopy measurements were performed using ISOCS™ from Canberra. The detector was positioned two feet above the surface to be measured and data were collected for 15 minutes. The gamma spectroscopy analysis library included the photon-emitting project RCOPCs. A copy of the gamma spectroscopy library file is provided in Appendix E.

The results of the in situ gamma spectroscopy measurements are discussed in Section 6.0 and summary EDA data spreadsheets are provided for each SU in Appendix E, Disk 2.

### 3.7 Onsite Gamma Spectroscopy Laboratory

An onsite gamma spectroscopy laboratory was used to provide near real-time feedback for estimating the extent of radioactive contamination. Surface and subsurface soil samples were dried, ground to a uniform particle size, and placed in a container with a known counting geometry for measurement by gamma spectroscopy. The results of the onsite gamma spectroscopy analyses were used to determine the concentrations of gamma emitting radionuclides and support decisions on collecting additional samples based on the decision rules listed in Table 2.6-1. Samples with radionuclide concentrations exceeding the ILs in Table 2.4.1 identify potential areas of elevated activity.

All analytical results were reported in units of pCi/g of dry soil. The results of the onsite gamma spectroscopy analyses of surface and subsurface soil samples are discussed in Section 6.7 and summary EDA data spreadsheets are provided for each SU in Appendix E, Disk2.

### 3.8 Offsite Analytical Laboratory

Collection and offsite analysis of samples was used to determine whether additional sampling was necessary to delineate areas of elevated activity and to support the final determination of the boundaries for areas of elevated activity within each SU. Following analysis in the onsite laboratory, a determination was made on whether to send the sample to an offsite laboratory for analysis by gamma spectroscopy. Samples with radionuclide concentrations exceeding the ILs in Table 2.4.1 were compared to identify potential areas of elevated activity in accordance with the decision rules in Table 2.6-1. Representative samples (two samples per SU) from each SU were sent to the offsite laboratory for gamma spectroscopy. All samples were sent offsite for liquid scintillation, gas flow proportional counting, and alpha spectrometry analysis. In addition, all other surface and subsurface soil samples with radionuclide concentrations below the ILs were sent to the offsite laboratory for liquid scintillation and alpha spectrometry analysis.

All soil analytical results were reported in units of pCi/g of dry soil. The results of the offsite gamma spectroscopy analyses, liquid scintillation, gas flow proportional counting, and alpha spectrometry analysis of surface and subsurface soil samples used for risk and dose calculations are discussed in Section 6.0 and summary EDA data spreadsheets are provided for each SU in Appendix E, Disk2.

ALS Laboratory Group, Environmental Division, Fort Collins, Colorado (formerly Paragon Analytics) was selected as the analytical laboratory performing the offsite radiochemical analyses. The laboratory is certified to perform analyses of radionuclides in drinking water, non-potable water, and hazardous waste under the National Environmental Laboratory Accreditation Program (NELAP) as certified by the State of California (certificate number 06251CA) and the State of Utah (ID# ATL2, EPA ID CO00078). The laboratory was also approved to perform radiochemical analyses following an assessment by the Naval Sea Systems Command (NAVSEA) Laboratory Quality and Accreditation Office (report SER 04XQ (LABS)/240).

This Page Left Intentionally Blank

## 4.0 Survey Instrumentation

This Section discusses the instrumentation used to perform radiological characterization measurements at the LBNC. Field instrumentation selection and measurement technique was selected based on the ability to meet the requirements of the survey design. Instrumentation was maintained and calibrated to manufacturers' specifications to ensure they have the required traceability, sensitivity, accuracy, and precision. Instruments were calibrated at a facility possessing appropriate NRC or Agreement State licenses for performing calibrations using National Institute of Standards and Technology (NIST) traceable sources. Instrument operational checks were performed daily to assure constancy in instrument response and to verify the detector was operating properly.

## 4.1 Instrument Selection

The combination of survey instrumentation and measurement techniques was selected based on the ability to meet the requirements of the survey design. Two measurement techniques were included in the survey design; scanning measurements where the detector is in constant motion and fixed measurements where the detector is stationary. Samples were collected and analyzed when scanning or fixed measurements alone would not meet the requirements of the survey design.

### *4.1.1 Scanning Measurements - Gamma Walkover Survey*

Scanning measurements were performed over all accessible ground surfaces to detect levels of radiation that could result in significant exposures to people at the site. External exposure was the major concern, so the scanning survey instruments were selected to detect photon-emitting RCOPCs. Sodium iodide detectors were selected to perform the scanning measurements because they detect photon radiation over a broad range of energies, and perform well over a wide range of environmental conditions. The Ludlum Model 44-20 3 inch by 3 inch NaI detector is a large, commercially available detector that maximizes detectability while maintaining availability of replacement detectors if required. The Ludlum Model 2221r ratemeter/scaler was used with the NaI detector to provide an interface between the NaI detector and the GPS unit. The Model 2221r includes specially modified electronics for performing scanning surveys as well as audio and visual outputs that allow the surveyor to monitor the survey results during data collection. GWS measurements were performed using Cabrera operating procedures (OP)-020 Rev. 0, OP-051 Rev.0, and OP-051A Rev. 2a, which are provided in Appendix E.

### *4.1.2 Scanning Measurements - Surface Activity*

Scanning measurements were performed to monitor for the potential presence of radiological contamination as part of the health and safety plan. Monitoring surveys were performed on sampling equipment, trash, samples, shipping containers, and work surfaces as required to evaluate the potential presence of contamination. Scanning measurements for monitoring surface radioactivity were performed with a GM detector. A Ludlum Model 44-9 GM pancake detector was selected for performing these measurements because this detector can detect alpha, beta, and photon radiation (primarily beta), is small and maneuverable for surveying equipment, and has successfully been used for these types of surveys. Scanning measurements for surface activity were performed using Cabrera OP-020 Rev. 0.

### *4.1.3 Fixed Measurements - Borehole Logging*

Borehole logging measurements were performed in each borehole to assist selecting subsurface soil samples for additional analysis. Photon-emitting radionuclides were used as an indicator for selecting soils for additional analysis, so NaI detectors were again selected for the measurements. The Ludlum Model 44-2 1 inch by 1 inch NaI detector was selected as the largest detector that would fit inside the installed open boreholes. The Ludlum Model 2221r ratemeter/scaler was selected because it served as a scaler to perform the fixed measurement but was also the same instrument used for the scanning measurements so the surveyors did not require additional training on a separate instrument. Borehole logging measurements were performed in accordance with Cabrera OP-020 Rev. 0 at 1 foot intervals to depth up to 12 feet belowground surface. The borehole gamma logs are provided in Appendix E, Disk 1.

### *4.1.4 Fixed Measurements - In Situ Gamma Spectroscopy*

In situ gamma spectroscopy measurements were performed for surface soils to provide near real-time indications of RCOPC concentrations exceeding project ILs. In situ gamma spectroscopy provides semi-quantitative results of radionuclide concentrations. The field of view of the detector determines the sample size, and the results are averaged over the entire field of view of the detector. This reduces the spatial variability compared to collecting relatively small samples for subsequent laboratory analysis. The distribution of radionuclides in soil determines the detector response and efficiency. Since this distribution is unknown and may be variable, the measurement variability associated with in situ measurements is usually higher than comparable laboratory measurements. The ISOCS™ with an HPGe detector was selected for performing the in situ gamma spectroscopy measurements because of the availability of the instruments, the familiarity of the technicians with the equipment, and comparability with the onsite laboratory counting systems which used the same data reduction software (i.e., Genie 2K).

In situ gamma spectroscopy results are comparable to laboratory gamma spectroscopy results under certain conditions. In situ gamma spectroscopy uses the same analytical method and the same type of detector. However, because the analysis was performed in situ, the sample being measured was not the same. The decision rule called for using in situ gamma spectroscopy in lieu of collecting surface samples in areas of paved surfaces. In situ gamma spectroscopy analysis was also performed at locations were point sources were recovered during site investigation and characterization activities. In the case were gross gamma activity level was reduced by more than a factor of 10 by collecting a sample or removing a point source the in situ sample collected after point source removal was used instead of the analytical laboratory result in the final SU data set because this number better reflects the activity in the soil remaining at the site.

### *4.1.5 Onsite Sample Analysis - Gamma Spectroscopy*

Onsite gamma spectroscopy was performed on all soil samples collected as part of the radiological characterization to provide estimates of photon-emitting RCOPC concentrations using Cabrera OP-029 Rev. 3 (see Appendix E). In accordance with the approved *SAP* (Cabrera 2008), $^{137}$Cs reporting was based on the gamma emissions of its progeny Barium-137m ($^{137}$mBa), and $^{226}$Ra, based on the gamma emissions of its progeny $^{214}$Bi and is reported as $^{214}$Bi($^{226}$Ra) for the insitu and onsite laboratory measurements as reflected in the Tables 6.2-1 through 6.3-3. While it is not a RCOPC, $^{232}$Th, based on the gamma emissions of its progeny Actinium-228 ($^{228}$Ac), was also be used as an indicator radionuclide due to its relative ease of detection.

An HPGe detector was selected to perform the onsite gamma spectroscopy analyses because this instrument detects a wide energy range of photons, has high resolution for identifying photons, is comparable to instruments used for offsite gamma spectroscopy and in situ gamma spectroscopy, and provides results in a relatively short period of time. The data reduction software used for onsite gamma spectroscopy (i.e., Genie 2K) was the same software used for in situ gamma spectroscopy.

### *4.1.6 Onsite Sample Analysis - Smears*

Smears were collected and analyzed onsite to evaluate potential contamination as part of the health and safety plan using Cabrera OP-021 Rev. 0 (see Appendix E). Smears were collected from sampling equipment as described in Section 3.4 as well as on working surfaces and floors in the onsite gamma spectroscopy laboratory and sample preparation areas. The Ludlum Model 2929 was selected as the instrument for counting smears. This detector includes an integrated detector for measuring alpha and beta radioactivity, a sample holder designed for counting smears, and an integrated dual scaler for simultaneously counting both alpha and beta activity.

### *4.1.7 Offsite Sample Analysis - Gamma Spectroscopy*

Offsite gamma spectroscopy was performed on 2 samples per SU using ALS Laboratory Group procedure 713R9 (EPA901.1). Radium-226 emits a photon with energy similar to a photon emitted by $^{235}U$. Both radionuclides are naturally present in soil, so there is interference. Radium-226 decays to $^{222}Rn$, which is a gas and may escape from the soil matrix before continuing to decay. Therefore, it is necessary to seal the soil sample in an airtight container and allow the $^{222}Rn$ to come into equilibrium with $^{226}Ra$, which takes approximately 3 weeks. After secular equilibrium is established, the $^{226}Ra$ decay products $^{214}Bi$ and $^{214}Pb$ can be measured to provide an accurate estimate of the $^{226}Ra$ concentration with no interference from $^{235}U$. Both $^{214}Bi$ and $^{226}Ra$ are reported separately by the offsite laboratory. An HPGe detector was selected to perform the offsite gamma spectroscopy analyses because this instrument detects a wide energy range of photons, has high resolution for identifying photons, and is comparable to instruments used for onsite gamma spectroscopy and in situ gamma spectroscopy.

### *4.1.8 Offsite Sample Analysis - Alpha Spectrometry*

Alpha particles have a high mass and high electrical charge relative to other types of radiation. This means that alpha particles are more likely to interact with other materials before they can be detected making them difficult to detect in the environment. Since alpha particles are difficult to detect in the environment, alpha emitting radionuclide concentrations were determined by collecting and analyzing soil samples in a laboratory. Alpha spectrometry was selected to measure alpha emitting RCOPCs because this method combines chemical purification and energy-specific measurements to identify and quantify concentrations of alpha-emitting radionuclides. Alpha spectrometry has been used to successfully quantify concentrations of alpha-emitting radionuclides for other projects. The ALS Laboratory Group procedure 714R11 (HASL 300) was used to analyze samples for isotopic plutonium by alpha spectrometry.

### *4.1.9 Offsite Sample Analysis - Liquid Scintillation*

Beta particles have a lower mass and lower electrical charge relative to alpha radiation, but low-energy beta particles are still difficult to detect in the environment. Tritium and $^{14}C$ are RCOPCs that emit low-energy beta particles. Liquid scintillation was selected as the measurement method for these RCOPCs because liquid scintillation incorporates the chemically separated sample

within the detector (the liquid scintillation cocktail) to maximize the counting efficiency. Liquid scintillation counting is also energy specific, but with low resolution. The ALS Laboratory Group procedure 704R7/8/9 was used to analyze for low-energy beta ($^{14}C$ and $^{3}H$) emitting radionuclides by liquid scintillation.

#### *4.1.10 Offsite Sample Analysis - Gas-Flow Proportional Counting*

High-energy beta particles are easier to detect than alpha particles or low-energy beta particles. However, the mass and electrical charge of beta particles still results in interactions with materials in the environment that make them difficult to detect reliably using direct measurements or scans except on hard, non-porous surfaces. Gas-flow proportional counting was selected as the measurement method for $^{90}Sr$ because this method historically provides the most reliable results. Because gas-flow proportional counters have very poor energy resolution, it is critical that the chemical separation remove all other radiation sources from the sample prior to counting. The ALS Laboratory Group procedure 724R10 was used to analyze samples for $^{90}Sr$ using a gas-flow proportional counter.

### 4.2 Instrument Calibration and Quality Assurance Procedures

This Section discusses the instrumentation used to perform radiological characterization measurements at the LBNC. Instrumentation were maintained and calibrated to manufacturers' specifications to ensure they have the required traceability, sensitivity, accuracy, and precision. Instruments were calibrated at a facility possessing appropriate NRC or Agreement State licenses for performing calibrations using NIST traceable sources. Instruments were checked daily in order to ensure that the calibration is current (i.e., not expired). Instruments were operationally checked daily (QC, or source checks) to ensure they respond in a consistent manner when exposed to known radiation sources and ambient background. Records of daily source checks were maintained and filed, along with any control charts or logs associated with each instrument. See Appendix B for instrument calibration certificates and Appendix E for the QC charts. The impact of instrument calibration on the overall quality of the survey results is discussed in Appendix C.

#### *4.2.1 Hand-held Instruments*

Calibration of hand-held survey instruments was performed prior to mobilization. The calibration included comparing the instrument response to reference standards, establishing the voltage plateau, and checking the operational status of the instrument in accordance with *Radiation Protection Instrumentation Test and Calibration, Portable Survey Instruments*, American National Standards Institute (ANSI) N323A. All calibrations were performed within one year of use for performing measurements. Comparison of instrument response to reference standards was always within 20 percent of the expected value. Copies of the instrument calibration certificates are provided in Appendix B.

#### *4.2.2 In Situ Gamma Spectrometer*

Calibration of the in situ gamma spectrometer uses a computer model based on the assumed distribution of radioactivity in the material being measured, the physical characteristics of the material being measured and the detector, and the physical geometry of the detector relative to the material being measured. The manufacturer of the ISOCS™ system determines the characteristics of the detector and the other variables are input by the user. A calibration check was performed at the beginning of the project to serve as the annual calibration of the ISOCS™ system. Efficiency was calculated for a reference standard using the ISOCS™ system, and then

the standard was counted and analyzed as a sample to demonstrate the result was within 10 percent of the expected value. The calibration certificate for the reference standard ($^{137}$Cs) is included in Appendix C.

#### *4.2.3 Onsite Laboratory Gamma Spectrometer*

Calibration of the onsite gamma spectroscopy system was performed using a mixed gamma reference standard in the same geometry as the soil samples. The mixed gamma reference standard provided known concentrations of radionuclides with a wide range of photon energies in a fixed geometry. Prior to measuring the soil samples, the reference standard was counted on the gamma spectroscopy system to develop an efficiency curve. This efficiency curve was used to evaluate the results of the soil sample analyses. The calibration certificate for the mixed gamma reference standard is included in Appendix C.

#### *4.2.4 Smear Counter*

Calibration of the smear counter was performed using electroplated reference standards of alpha and beta radioactivity. The alpha reference standard was used to calculate the efficiency for alpha particles, while the beta reference standard was used to calculate the efficiency for beta particles. In addition, the smear counter was calibrated prior to mobilization. The instrument calibration certificate and the calibration certificates for the alpha and beta reference standards are provided in Appendix B.

#### *4.2.5 Laboratory Analytical Instruments*

Laboratory analytical instruments were calibrated within one year of when measurements were performed for this radiological characterization. Calibrations were performed using reference standards appropriate for the RCOPCs being measured. The results of the calibrations and the reference standard calibration certificates are included in the electronic data deliverables provided by the laboratory and included electronically in Appendix B.

### 4.3 Instrument Operational Checks

Instrument operational checks were performed daily to assure constancy in instrument response and to verify the detector was operating properly. The response check was performed at a set location using a specified source-detector alignment that could be easily repeated. Corrective actions were taken for instruments exhibiting response outside the acceptance criteria and the instrument would not be used until corrected; however, no instruments exhibited unacceptable responses.

Instrument QC was documented and maintained in accordance with Cabrera procedures. Instrument response acceptance criteria were established for each instrument prior to initial use. Ten one-minute counts were collected using a source representative of the radiation types and energies of interest, and the mean of the source counts calculated. The source response acceptance criterion was ± 20 percent of the mean of the source counts. Ten one-minute counts were also collected with the source removed to determine expected instrument response to ambient background. The background response acceptance criterion was ± 20 percent of the mean of the background counts. Chi-square tests were performed for procedure to maintain QC compliance for Ludlum 2929 (smear counter) and Ludlum 2360 (direct measurement).

Daily response checks were monitored using a control chart. Background was monitored qualitatively to assess daily variations that may impact the instrument's MDC. Records of daily response checks were maintained, along with any control charts or logs associated with each

instrument. These records are included in Appendix D, included electronically. The impact of instrument calibration on the overall quality of the survey results is discussed in Appendix C.

By design, the GPS unit was self-calibrating, using data received from the satellite constellation to determine the precision and accuracy of its readings. No response checks of the GPS unit were required.

### *4.3.1 Hand-held Instruments*

Survey instrument operational checks were performed each time a detector was used. At the beginning of each day before a detector was used the instrument was inspected to ensure it was operating properly. The inspection included a battery check, verification of current calibration, check of the condition of the detector cord, cleanliness, and general condition of the instrument. Source response checks were performed before and after each use to ensure the instrument was responding properly to radiation, check the precision of the instrument to remain within 20% of the expected response, and to check for bias in the instrument response. Background response checks were performed before and after each use to ensure that the instrument was not contaminated and to check for bias in the instrument response. Results of the operational checks for each hand-held instrument are provided electronically in Appendix E.

### *4.3.2 Gamma Spectrometer*

Instrument operational checks were the same for all three gamma spectroscopy systems; in situ gamma spectroscopy, onsite gamma spectroscopy, and laboratory gamma spectroscopy. Each day prior to use operational checks were performed to check instrument response, energy calibration, and peak resolution. Results of the operational checks were monitored to identify trends in the results that could impact the quality of the results. The in situ gamma spectrometer identified minor issues with the stability of the energy calibration that are not unusual for a field system and did not impact the quality of the results, although some measurements required an internal energy calibration be performed to correctly identify all of the energy peaks in the spectrum.

Background operational checks were performed weekly for the onsite and laboratory gamma spectrometers to check for contamination and the stability of the system during longer count times. The results of the background measurements were monitored to identify trends in the background. No background measurements were performed for the in situ gamma spectrometer because of the short count times and the lack of background subtraction applied to individual measurements.

No problems were identified for the onsite or laboratory gamma spectroscopy systems. The results of the in situ and onsite gamma spectrometers operational checks are included in Appendix E. The results of the laboratory gamma spectrometer operational checks are included as part of the Electronic Data Deliverable (EDD) provided electronically in Appendix E.

### *4.3.3 Smear Counter*

Daily smear counter operational checks were performed prior to each use. Source response checks were performed to ensure the instrument was responding properly to radiation, check the precision of the instrument to remain within 2 standard deviations of the expected response, and to check for bias in the instrument response. Background response checks were performed to ensure the instrument was not contaminated and to check for bias in the instrument response. Results of the operational checks for the smear counter are provided electronically in Appendix E.

### *4.3.4 Laboratory Analytical Instruments*

Operational checks were performed on laboratory analytical instruments according to the operating procedures. Response checks were performed on all instruments to check precision and bias. Energy calibration and peak resolution checks were performed on all spectrometry systems to ensure proper identification of peaks. Voltage plateaus were checked on gas flow proportional counters to ensure stability of the system during measurements. Instrument backgrounds were checked to check for contamination and proper operation of the instruments. Results of the laboratory analytical instrument operational checks are included in the EDD files electronically in Appendix E.

This Page Left Intentionally Blank

## 5.0 Efficiency and Detection Sensitivity

Measurement efficiency and detection sensitivity are measurement quality objectives that were used to assist in the selection of measurement techniques used during the radiological assessment. This Section compares the values used for efficiency and detection sensitivity during planning with the results of the radiological assessment. This evaluation assists in the survey design and provides information that can be used to assist in planning similar types of surveys.

### 5.1 Instrument and Surface Efficiency

Instrument efficiency is the ratio of the net count rate of the instrument and the surface emission rate of a source for a specified geometry. Surface efficiency is the ratio of the number of radiations of a given type emerging from the front face of a source and the number of radiations of the same type created or released within the source. The total efficiency is the product of the instrument efficiency and the surface efficiency.

Gross GWS measurements as described in Section 3.3 and in situ gamma spectroscopy measurements were field measurements where instrument and surface efficiencies were estimated during survey planning. The total efficiency, or total weighted detector response (TWDR), for gross GWS measurements of $^{226}$Ra was calculated prior to use in the field and is described in detail in Attachment C to Worksheet #11 in the *SAP* (Cabrera, 2008). This value was calculated using the MicroShield computer program to generate a surface emission rate and the estimated detector response, or instrument efficiency, provided by the detector manufacturer using the methodology described in MARSSIM.

The total efficiency for the in situ gamma spectroscopy measurements was calculated using the ISOCS™ software and detector parameters provided by the detector manufacturer.

Total efficiency for laboratory measurements was determined empirically by measuring a standard with a NIST traceable surface emission rate or activity. The empirical efficiency determinations were made within one year of the sample measurements being performed.

### 5.2 Static Minimum Detectable Concentration

The MDCs for static measurements performed in the onsite and offsite laboratory were reported with each radionuclide-specific analysis. The reported MDCs were compared to the required MDCs listed in Worksheet #15 of the *SAP* (Cabrera, 2008). The average reported MDC was less than the required MDC for all analyses except those performed by liquid scintillation (i.e., $^{3}$H and $^{14}$C). The requirements were based on liquid scintillation measurements where an aliquot of the sample would be completely oxidized and the water vapor and carbon dioxide produced collected for liquid scintillation counting. ALS Laboratory Group did not have the equipment required to perform the complete oxidation of the sample for analysis of $^{3}$H and $^{14}$C and used a method that measured organically bound $^{3}$H and $^{14}$C with a higher MDC. It was decided that using a single laboratory for all analyses was preferable to collecting additional sample material, splitting the samples in the field, and providing replicate samples to multiple laboratories in order to meet the required MDC values. The MDC values for the selected analytical methods were less than 5 percent of the ILs for the Site RCOPCs (See Table 2.4-1).

### 5.3 Gross Gamma Walkover Survey Minimum Detectable Concentration

The gross GWS MDC as described in Section 3.3 was developed during planning for the radiological assessment in Attachment C to Worksheet #11 of the *SAP* (Cabrera, 2008).

The calculated scan MDC for $^{226}$Ra was 1.2 pCi/g. Approximately 9 percent of the systematic samples $^{226}$Ra concentrations exceeded 1.2 pCi/g in SU areas where no GWS elevated gamma activity was detected, with a maximum concentration of 2.09 pCi/g. This exceeds the estimated value of 5 percent based on the MDC calculation assumptions. The 95$^{th}$ percentile of the randomly collected data in areas where no elevated gamma radiation was detected was approximately 1.4 pCi/g, which corresponds to the actual scan MDC of the gross GWS. The major reason for the underestimate in the scan MDC calculation during planning resulted from the estimated background count rate of 13,700 cpm. The actual ambient background count rate for a large area of Gull Park was approximately 26,000 cpm, and 95 percent of the samples that exceeded the predicted scan MDC of 1.2 pCi/g were collected in Gull Park. Whenever practical, site-specific background data should be used to estimate the scan MDC. Since this was the initial radiological characterization of this site, no site-specific data were available during survey planning.

## 6.0 Survey Data Interpretation

This Section describes survey data and the results of the Radiological Assessment. Sections 6.1, 6.2, and 6.3 discuss results from the GWS, in situ gamma spectroscopy measurements, and soil sample analyses, respectively. Results are discussed by measurement location and by SU, and summarized for the entire site. This Section describes the construction of data sets for each SU to describe the radiological conditions at the surface in individual SUs. Information from the SU data summaries is used to support the risk analysis described in Section 7.0. Sections 6.7 and 6.8summarize the laboratory analytical results of the subsurface soil and groundwater investigations, respectively. Information on subsurface soil and groundwater is not used in the risk analysis but does provide additional information about radioactivity at the site.

## 6.1 Gamma Walkover Survey Results

The GWS were performed over 100 percent of the accessible surface areas to identify areas with elevated gamma radioactivity relative to the surrounding area. Results from the GWS were separated into data sets according to which NaI detector was used to perform the GWS. Each detector data set was further divided by surface media (i.e., soil, concrete, or asphalt). Averages and standard deviations were calculated for each data set, and the results were converted into z-scores as described in Section 3.3. GWS results reported as z-scores account for differences in detector response and natural background in different surface media. This means that the highest z-score values are more likely to correspond to localized areas of elevated gamma radiation appropriate for additional investigation. Contour plots of the GWS results were created to identify areas with elevated z-scores and are presented for the Site in Figures 6.1-1 and 6.1-2. A more detail presentation of the contour plots are provided in the SU EDAs provided in Appendix E (Disk 2).

### *6.1.1 Gull Park GWS Results*

Gull Park includes Class 1 SUs 11 through 25 and Class 2 SU 33. Figure 6.1-1 shows the contour plot of the Gull Park GWS results. The contour plot shows a large area of elevated gamma activity (Z-scores exceeding 3.0) in the north-eastern part of Gull Park that includes portions of SUs 18, 23, 24, 25, and 33; noted as a predominantly green (3.0-6.0 range z-scores) and orange (6.0-12.0 range z-scores) area; and covering a large portion of the west end of the Navy Mole. This area of elevated activity corresponds with the remediation performed in Area III in October 2000 (see Section 1.2 and Figure 1.2-1) which was excavated to a depth of approximately 10 feet below land surface. There are also several small, isolated areas of elevated gamma activity scattered throughout Gull Park (Figure 6.1-1). Areas of dense vegetation that were inaccessible for the GWS are noted as non-shaded areas on the contour plots of SUs 13, 15, 16, 21, 23 and 24 provided in the SU EDA Site Maps (Disk 2, Appendix E) .

The elevated results on the contour plot in Figure 6.1-1 were reviewed to identify locations for additional investigation. Additional soil samples were collected based on the following factors: the ILs discussed in Section 2.4.3 and the measurement inputs in Section 2.4.4, and areas where the contour plots showed the z-score exceeding 3.0. Table 6.1-1 lists the SUs and sample IDs for locations where additional investigations of GWS results were performed in Gull Park. Results from this additional biased sampling are discussed in Section 6.2.

**Table 6.1-1 Additional Biased Sampling [1] Locations from GWS in Gull Park**

| Survey Unit | Investigation Location ID[2] | GWS Results |
|---|---|---|
| SU 11 | 017, 018, 019, 020 | z-score above 3 |
| SU 12 | 017, 026 | z-score above 3 |
| SU 13 | 017 | z-score above 3 |
| SU 14 | 017, 018 | z-score above 3 |
| SU 15 | 017, 018 | z-score above 3 |
| SU 16 | 017 | z-score above 3 |
| SU 17 | 017, 018, 019, 020 | z-score above 3 |
| SU 18 | 017, 018 | z-score above 3 |
| SU 19 | 017 | z-score above 3 |
| SU 20 | 017, 018, 019, 020 | z-score above 3 |
| SU 21 | 017, 018, 019, 020, 021 | z-score above 3 |
| SU 22 | 017, 018 | z-score above 3 |
| SU 23 | ---[3] | |
| SU 24 | 017 | z-score above 3 |
| SU 25 | 017, 018, 019 | z-score above 3 |
| SU 33 | 017(4), 019, 020, 021 | z-score above 3 |

1) Additional biased samples, not included in this table, were collected based on elevated onsite gamma spectroscopy and not GWS results.
2) Biased locations are depicted for SU11-SU18 on Figure 6.2-1, Figure 6.2-2 for SU 19-25, and Figure 6.2-3 for SU 33.
3) No biased samples were collected in SU 23 because systematic samples fell within the z score above 3 areas and around that area to bound any elevated activity.
4) ISOC sample 018 obtained at location 017 name convention was changed from 33IA01864 to 33IA01764 to eliminate confusion.

### *6.1.2 Sea Launch Facility GWS Results*

The Sea Launch Facility includes 10 Class 1 SUs (1 through 10) and 4 Class 2 SUs (29 through 32). Figure 6.1-2 presents a contour plot of the Sea Launch GWS results. The contour plot shows an area of elevated gamma activity where SU 29 and SU 30 join. This area of elevated activity (z-scores between 3.0 and 12.0) is shown as a green and yellow area in the middle of Figure 6.1-2. There are also several small, isolated areas of elevated activity scattered throughout the Sea Launch facility. Structures and storage areas that were inaccessible for GWS are noted as non-shaded areas on the contour plots of SUs 1, 5, 10, 28, 29, 30, 31, and 32 provided in the SU EDA Site Maps (Disk 2, Appendix E).

The results of the contour plot were reviewed to identify locations for additional investigation. Table 6.1-2 lists the SUs and sample ID for locations where additional investigations were conducted. Results from this additional biased sampling are discussed in Section 6.2.

**Table 6.1-2 Additional Biased Sampling(1) Locations from GWS in Sea Launch**

| Survey Unit | Investigation Location ID(2) | GWS Results |
|---|---|---|
| SU 1 | 017 | z-score above 3 |
| SU 2 | 017 | z-score above 3 |
| SU 3 | 017, 018 | z-score above 3 |
| SU 4 | 017, 018 | z-score above 3 |
| SU 5 | 017 | z-score above 3 |
| SU 6 | 017, 018 | z-score above 3 |
| SU 7 | 017 | z-score above 3 |
| SU 8 | ---(3) | z-score above 3 |
| SU 9 | 017, 018, 019 | z-score above 3 |
| SU 10 | 017 | z-score above 3 |
| SU 29 | 017, 018, 019, 020, 021 | z-score above 3 |
| SU 30 | 017, 018, 019, 020, 021, 022 | z-score above 3 |
| SU 31 | 017, 018 | z-score above 3 |
| SU 32 | 017, 018, 019, 020, 021 | z-score above 3 |

1) Additional biased samples, not included in this table, were collected based on elevated onsite gamma spectroscopy and not GWS results.
2) Biased locations are depicted for SU2-SU10 on Figure 6.2-5, Figure 6.2-6 for SU 1,29&30, and Figure 6.2-4 for SU 31&32.
3) Biased Sampling was not necessary very limited elevated GWS readings in the area of existing SU 8 systematic sample locations 003 and 014.

### *6.1.3 Former Athletic Fields GWS Results*

The Former Athletic Fields include three Class 2 SUs (26 through 28) including the paved area west of the Sea Launch Facility. Figure 6.1-2 shows the contour plot of the Former Athletic Fields GWS results. This area includes a public road, railroad spur, former ball fields, tennis courts, and basketball court. The contour plot shows relatively few small isolated areas of elevated activity scattered throughout this area. Almost all of this area was accessible for the GWS; inaccessible areas were noted as blank areas on the contour plot.

The results of the contour plot were reviewed to identify locations for additional investigation. Table 6.1-3 lists the SUs and sample IDs for locations where investigations of GWS results were performed in the Former Athletic Fields. The results of this additional biased sampling are discussed in Section 6.2.

**Table 6.1-3 Additional Biased Sampling Locations from GWS in Former Athletic Fields**

| Survey Unit | Investigation Location ID | GWS Results |
|---|---|---|
| SU 26 | 017, 018, 019, 020, 021 | z-score above 3 |
| SU 27 | 017, 018, 019, 020, 021, 022, 023, 024, 025, 026 | z-score above 3 |
| SU 28 | 017, 018 | z-score above 3 |

## 6.2 In Situ Gamma Spectroscopy Results

In situ gamma spectroscopy was used to provide near real-time estimates of photon-emitting radionuclides in surface soil at specified locations. The results of in situ gamma spectroscopy measurements of the surface media and surface soil were used as semi-quantitative inputs to the principal study question: "Are the levels of residual radioactivity in IR Sites 1 and 2 protective of

human health?" In situ gamma spectroscopy measurements were performed at systematic locations (locations 001 through 016 in each SU), GWS investigation locations with z- scores > 3 (see Section 6.1), and investigations to determine lateral extent around sample locations where ILs listed in Table 2.4-1 were exceeded in accordance with the decision rules in Table 2.6-1. In situ gamma spectroscopy measurements were also performed at locations where radioactive articles (point sources) were removed to determine whether the article was the sole source of elevated gamma activity which is discussed further in Section 6.4.

Table 6.2-1 summarizes the results of the in situ gamma spectroscopy measurements from all SUs in all areas of the site including systematic and bias sampling locations where point sources were encountered. Summary statistics are included for a limited number of RCOPCs in Table 6.2-1 to provide a basis for comparison with other measurement methods and provide an indication of the structure of the data. In accordance with the approved *Work Plan* and *SAP* $^{214}$Bi was assumed to be in equilibrium with $^{226}$Ra and is reported in the Table 6.2-1 as $^{214}$Bi ($^{226}$Ra) The difference between the mean (average) of 2.3 pCi/g and the median of 1.4 pCi/g for $^{214}$Bi ($^{226}$Ra) and the maximum measured value indicate there is a potential for elevated concentrations of $^{214}$Bi ($^{226}$Ra) at the site (see Table 6.2-1). The $^{137}$Cs results are consistent with ubiquitous distributions of manmade radionuclides in the environment and do not indicate the potential presence of contamination. These skewed results, which are a result of the maximum in situ reading of 9.8 pCi/g for $^{137}$Cs SU 31 (017), were associated with elevated concentrations of $^{226}$Ra decay products measured at SU 31(017), specifically the 664 kiloelectron volts (keV) photon from decay of $^{214}$Bi and not indicative of $^{137}$Cs contamination Surface and subsurface (12 feet below land surface) soil sample results for $^{137}$Cs at SU 31 (017) were 0.03 and 0.02 pCi/g, respectively. The differences in average and median results shows a potential positive bias for $^{228}$Ac ($^{232}$Th), $^{137}$Cs, and $^{40}$K compared to the onsite and offsite sample results. The $^{214}$Bi ($^{226}$Ra) results show a potential positive bias for the lower concentrations (compare median results) and a potential negative bias at higher concentrations (compare mean and maximum results). The complete set of in situ gamma data results and map of sample location and analyses performed if provided for each individual SU in the EDAs (See Appendix E, Disk 2).

**Table 6.2-1 In Situ Gamma Spectroscopy Results**

| Statistic | $^{228}$Ac ($^{232}$Th) (1) | $^{214}$Bi ($^{226}$Ra) (2) | $^{137}$Cs | $^{40}$K |
|---|---|---|---|---|
| **Investigation Level (pCi/g)** | | | | |
| Mean (pCi/g) | 1.5 | 2.3 | 0.056 | 30.8 |
| Median (pCi/g) | 1.4 | 1.4 | 0.044 | 31.0 |
| Standard Deviation (pCi/g) | 0.47 | 20.5 | 0.39 | 6.5 |
| Minimum (pCi/g) | 0.0030 | 0.6 | -0.13 | 12.6 |
| Maximum (pCi/g) | 3.7(3) | 523.8(4) | 9.8(4) | 55.8(3) |
| Number of Samples | 648 | 648 | 648 | 648 |

Notes:(1)- Thorium-232 ($^{232}$Th) based on the gamma emissions of its progeny Actinium-228 ($^{228}$Ac)
(2)- Radium-226 ($^{226}$Ra) based on the gamma emissions of its progeny Bismuth-214 ($^{214}$Bi) "not adjusted for ingrowth"
(3)-Maximum value observed at Survey Unit 33 Surface Location 015
(4)-Maximum value observed at Survey Unit 31 Surface Location 017

### *6.2.1 Gull Park*

A total of 332 in situ gamma spectroscopy measurements were performed in Gull Park with the ISCOCs (see Figures 6.2-1, 6.2-2 and 6.2-3). Surface soil samples were also collected at 319 of these locations for analysis in accordance with the Work Plan; results of these analyses are described in Section 6.3.1. The 12 locations where in situ gamma spectroscopy was performed did not have accompanying surface soil samples includes 7 locations in SU 11 (Figure 6.2.1) where asphalt restricted access for collecting surface soils locations (021, 022, 024, 025, 026, 027, and 028); 1 location in SU 12 location 026; 1 in SU 15 location 028; 2 locations in SU 16 (locations 018 and 020); and 1 location in SU 33 where concrete restricted access for collecting soil at location 021.

Three in situ gamma spectroscopy sampling locations results exceeded the IL for $^{137}$Cs at concentrations ranging from 0.19 pCi/g in SU 14 location 007 to 0.21 pCi/g in SU 22 location 003. None of the collected soil sample results exceeded the project IL for $^{137}$Cs.

A total of 22 in situ gamma spectroscopy results exceeded the IL for $^{228}$Ac ($^{232}$Th) at the following locations: SU 23 (006); SU 24 (007, 008, 010, 012); SU 25 (003, 004, 005, 007, 008, 009, 010, 011, 012, 017, 018, and 019); and SU 33 (009, 010, 012, 013, 015) with activities ranging from 2.83 through 3.66 pCi/g. None of the soil sample results exceeded the project IL for $^{228}$Ac ($^{232}$Th).

A total of 175 in situ gamma spectroscopy exceeded the IL for $^{214}$Bi ($^{226}$Ra) in SUs 11 through 25, and 33 with activities ranging from 0.74 through 4.97 pCi/g, with the highest and lowest activities observed at SU 15 (019) and SU 23 (014), respectively. Locations of in situ gamma spectroscopy measurements in SU 11 through 18 are shown in Figure 6.2-1, SU 19 through 25 in Figure 6.2-2, and SU 33 in Figure 6.2-3.

### *6.2.2 Sea Launch Facility*

A total of 253 in situ gamma spectroscopy measurements were performed at the Sea Launch Facility with the ISCOCs (see Figures 6.2-4, 6.2-5 and 6.2-6). Surface soil samples were also collected at 233 of the locations for onsite laboratory gamma spectroscopy (see Section 6.3.2). One in situ gamma spectroscopy result exceeded the IL for $^{137}$Cs with an activity of 9.82 pCi/g for sample location 017 in SU 31, which is also the location with the highest reported $^{214}$Bi ($^{226}$Ra) result. A total of 101 in situ gamma spectroscopy results exceeded the IL for $^{214}$Bi ($^{226}$Ra) in SUs 1 through 10, and SUs 29 through 32 with activities ranging from 1.40 through 523.8 pCi/g with the highest and lowest activities observed at SU 15 (019) and SU 23 (014), respectively. The $^{214}$Bi ($^{226}$Ra) observed at SU 23 (014) was two orders of magnitude higher that the next highest reading of 4.0 pCi/g at SU 04 (017). None of the in situ gamma spectroscopy results exceeded the ILs for $^{228}$Ac ($^{232}$Th). Locations of in situ gamma spectroscopy measurements in SUs 01, 29, and 30 are shown in Figure 6.2-4; SU 02 through 10 in Figure 6.2-5; and SU 31 and 32 in Figure 6.2-6.

### *6.2.3 Former Athletic Fields*

A total of 63 in situ gamma spectroscopy measurements were performed in the Former Athletic Field area. Surface soil samples were collected at all 59 of the locations (see Figure 6.2-7) analyzed with onsite gamma spectroscopy (see Section 6.3.3). One in situ gamma spectroscopy result, SU 27(009), exceeded the IL for $^{137}$Cs with an activity of 0.21 pCi/g. A total of 28 in situ gamma spectroscopy results exceeded the IL for $^{214}$Bi ($^{226}$Ra) in SU 26 and SU 27 with activities

ranging from 0.84 through 1.96 pCi/g with the highest and lowest activities observed at SU 27 (003) and SU 26 (016), respectively. None of the in situ gamma spectroscopy results exceeded the IL for $^{228}$Ac ($^{232}$Th). Locations of in situ gamma spectroscopy measurements in SUs 26, 27, and 28 are shown in Figure 6.2-7.

## 6.3 Surface Soil Sample Results

Surface soil samples were analyzed to provide estimates of RCOPC concentrations in surface soil that could result in radiological exposure to industrial workers at the LBNC. Surface soil samples were collected at systematic locations (locations 001 through 016 in each SU) and biased "judgmental" sampling locations from GWS investigation locations (see Section 6.1), and investigations to determine the lateral extent around sample locations where radionuclide concentrations exceeded ILs listed in Table 2.4-1.

Surface soil samples were analyzed in the onsite laboratory by gamma spectroscopy to provide estimates of radionuclide concentrations in surface soil. All 698 soil samples, with the exception of 12 samples (See Sections 6.3.1 and 6.3.2), were sent to an offsite analytical laboratory for analysis of plutonium isotopes by alpha spectrometry; $^{90}$Sr by gas flow proportional counting; and for tritium, $^{14}$C and $^{241}$Pu by liquid scintillation. Approximately two samples per SU were sent to an analytical laboratory for gamma spectroscopy (see Section 6.3.4). Samples exceeding ILs were investigated further to identify, delineate and characterize source area of contamination using the onsite laboratory and ISOCs. In the case where radioactive items and soil where remediated confirmation analysis for surface soil at the location was performed using the onsite laboratory or ISOCs the confirmation data was also used in the dose and risk model as indicated in the Appendix E modeling data set for each SU.

### *6.3.1 Onsite Laboratory Results Summary*

Table 6.3-1 summarizes the results of the onsite gamma spectroscopy measurements from all SUs in all areas of the site and includes 661 surface soil samples and 37 subsurface samples. Summary statistics are provided as a basis for comparison with other measurement methods and provide an indication of the structure of the data.

**Table 6.3-1 Summary of Onsite Gamma Spectroscopy Results**

| Statistic | $^{228}$Ac ($^{232}$Th)(1) | $^{214}$Bi ($^{226}$Ra)(2) | $^{137}$Cs | $^{40}$K |
|---|---|---|---|---|
| Investigation Level (pCi/g) | NA(3) | 1.4 | 1.9 | NA |
| Mean (pCi/g) | 0.89 | 3.7 | 0.034 | 16 |
| Median (pCi/g) | 0.85 | 0.68 | 0.025 | 16 |
| Standard Deviation (pCi/g) | 0.35 | 53 | 0.21 | 3.4 |
| Minimum (pCi/g) | -5.2 | 0.25 | -0.23 | 3.6 |
| Maximum (pCi/g) | 2.1(4) | 1346(5) | 5.5(6) | 31(4) |
| Number of Samples | 698 | 698 | 698 | 698 |

The maximum reported value of $^{214}$Bi ($^{226}$Ra) was 1,346 pCi/g identified at the Gull Park SU 11 (018) (see Table 6.3-3) with the next highest value being 361 pCi/g $^{214}$Bi ($^{226}$Ra) found at the Sea Launch Facility SU 31 (017) (see Table 6.3-4). The maximum detected $^{137}$Cs concentration of 5.5 pCi/g was also identified at SU 31 (017) with the next highest concentration of 0.35 pCi/g being identified at Sea Launch Facility SU 29 (018).

The difference between the mean (average) and the median for $^{214}$Bi ($^{226}$Ra), and the maximum measured value indicate there is a potential for elevated concentrations of $^{214}$Bi ($^{226}$Ra) at the site. The $^{137}$Cs results are consistent with ubiquitous distributions of manmade radionuclides in the environment and do not indicate the potential presence of contamination.

The difference between the average results for each of the radionuclides of potential concern indicates a potential bias compared to the results of the in situ gamma spectroscopy results (see Table 6.2-1), although the average and median values are consistent with the offsite sample results (see Table 6.3-2).

The complete set of in situ gamma data results and map of sample location and analyses performed if provided for each individual SU in the EDAs (See Appendix E).

### *6.3.2 Offsite Laboratory Results Summary*

Table 6.3-2 summarizes the results of the offsite gamma spectroscopy measurements from all SUs in all areas of the site. Summary statistics are provided as a basis for comparison with other measurement methods and provide an indication of the structure of the data. In Table 6.3-2, the $^{214}$Bi and $^{226}$Ra activities in soil samples were measured by the offsite laboratory after the appropriate in-growth period in accordance with the approved SAP (Cabrera 2008) and Sections 4.1.5 and 4.1.7 of this report. The $^{214}$Bi results, in secular equilibrium with $^{226}$Ra, and the 186 keV direct measurements of $^{226}$Ra were used to quantitate $^{226}$Ra activities in soil. The complete set of data results and map of sample locations and analyses performed if provided for each individual SU in the EDAs (See Appendix E).

**Table 6.3-2 Offsite Analytical Results**

| Statistic | $^{228}$Ac ($^{232}$Th)(1) | $^{214}$Bi ($^{226}$Ra)(2) | $^{226}$Ra(3) | $^{14}$C | $^{137}$Cs | $^{3}$H | $^{40}$K | $^{239/240}$Pu | $^{241}$Pu | $^{90}$Sr |
|---|---|---|---|---|---|---|---|---|---|---|
| Investigation Level (pCi/g) | NA(4) | 1.4 | 1.4 | 1.2 | 0.19 | 1.4 | NA | 2.3 | 7.2 | 1.7 |
| Mean (pCi/g) | 1.1 | 41 | 50.3 | 0.38 | 0.006 | 0.005 | 17 | 0.006 | 0.078 | 1 |
| Median (pCi/g) | 0.87 | 1.3 | 2.7 | 0.3 | -0.004 | 0.003 | 17 | 0.003 | 0 | 0.07 |
| Standard Deviation (pCi/g) | 1.1 | 299 | 365.4 | 2 | 0.096 | 0.13 | 5.2 | 0.012 | 1.2 | 17 |
| Minimum (pCi/g) | 0.32 | 0.42 | -1.0 | -6.6 | -0.08 | -2.3 | 7.4 | -0.014 | -4.4 | -0.14 |
| Maximum (pCi/g) | 9.9(5) | 2710(5) | 3310.0(5) | 8(6) | 0.83(5) | 2(7) | 33(8) | 0.2(9) | 13(10) | 430(11) |
| Number of Samples | 82 | 82 | 82 | 682 | 82 | 682 | 82 | 682 | 682 | 682 |

Notes: (1) Thorium-232 ($^{232}$Th) based on the gamma emissions of its progeny Actinium-228 ($^{228}$Ac)
(2) Radium-226 ($^{226}$Ra) based on the gamma emissions of its progeny Bismuth-214 ($^{214}$Bi) in secular equilibrium with Radium-226
(3) $^{226}$Ra measured from the $^{226}$Ra 186 keV peak.
(4) Not Applicable
(5) Maximum value observed at Survey Unit (SU)11Surface Location 018
(6) Maximum value observed at SU 27 Surface Location 022
(7) Maximum value observed at SU 16 Surface Location 003
(8) Maximum value observed at SU 24 Surface Location 012
(9) Maximum value observed at SU 32 Surface Location 004
(10) Maximum value observed at SU 12 Surface Location 001
(11) Maximum value observed at SU 15 Surface Location 017

The maximum reported concentrations of $^{226}$Ra (3,310 pCi/g) and $^{214}$Bi (2,710 pCi/g) were identified in Gull Park in SU 11 (018), with the next highest value being 156 pCi/g ($^{226}$Ra) and 134 pCi/g ($^{214}$Bi) in SU 31 (017), Sea Launch Facility. These results agreed with the findings from the onsite analyses.

The difference between the mean (average) and the median for both $^{214}$Bi and $^{226}$Ra, and the maximum measured values indicate there is a potential for elevated concentrations of $^{226}$Ra at the site. The $^{90}$Sr summary also shows a maximum result indicating a potential for elevated concentrations of $^{90}$Sr at the site. Stronium-90 was identified at 17 samples collected from five adjoining SUs in Gull Park (SUs 11, 13, 14, 15 and 16) and two SUs in the Sea launch area (SUs 4 and 8) (see Tables 6.3-3 and 6.3-4 respectively). The highest $^{90}$Sr value was found at SU 17 location 007 (430 pCi/g).

The $^{137}$Cs and $^{239/240}$Pu results are consistent with ubiquitous distributions of manmade radionuclides in the environment and do not indicate the potential presence of contamination. The difference between the average results for each of the radionuclides indicates a potential bias compared to the results of the in situ gamma spectroscopy results (see Table 6.2-1), although the average and median values are consistent with the onsite sample results (see Table 6.3-1).

### *6.3.3 Gull Park Surface Soil Results*

A total of 292 surface soil samples were collected during systematic and bias surface soil sampling at locations in the Gull Park 16 SUs. With the exception of soil sample location 017 in SU 19; all 292 samples were sent to an offsite analytical laboratory for analysis by alpha spectrometry, gas flow proportional counting, and liquid scintillation. The surface soil sample from location 017 in SU 19 was only analyzed by the onsite gamma spectroscopy laboratory. In addition, a total of 40 out of 292 soil samples were sent to an offsite analytical laboratory for analysis by gamma spectroscopy. Out of the 16 SUs 10 SUs had sample locations which exceeded the IL (1.4 pCi/g) for $^{226}$Ra and 16 SUs had sampling locations exceeding the IL (1.7pCi/g) for $^{90}$Sr. Samples exceeding the ILs were investigate in accordance with the sampling plan and included additional analysis and or step out sampling using the onsite laboratory and or ISOCs. Table 6.3-3 lists all the results at sampling locations where one or more ILs were exceeded. The results for the offsite laboratory analyzed duplicate samples are provided in right column under their respective RCOC. Locations of surface soil samples in SU 11 through 18 are shown in Figure 6.2-1, SU 19 through 25 in Figure 6.2-2, and SU 33 in Figure 6.2-3.

**Table 6.3-3 Soil Analytical Results (pCi/g) for Locations with Radiological Contaminants of Concern (RCOC) Above ILs-Gull Park (SU11 through 25, and SU33)**

| SU[1] | Sample ID[2] | $^{28}$Ac | | $^{214}$Bi ($^{226}$Ra)[3][4] | | $^{137}$Cs | | $^{226}$Ra | | $^{241}$Am | | $^{14}$C | $^{3}$H | $^{239/249}$Pu | $^{241}$Pu | $^{90}$Sr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Dup[5] | | Dup | | Dup | | Dup | | Dup | | | | | |
| 11 | 008 | 0.8 | -[6] | 1.3 | - | 0.0 | - | 2.3 | - | 0.0 | - | 2.1 | 0.0 | 0.0 | -0.6 | 6.9 |
| 11 | 010 | 0.7 | - | 1.3 | - | 0.0 | - | 1.6 | - | 0.0 | - | 1.7 | 0.0 | 0.0 | -2.1 | 3.6 |
| 11 | 013 | 0.7 | - | 0.7 | - | 0.0 | - | 1.4 | - | 0.0 | - | -0.2 | 0.0 | 0.0 | -0.6 | 1.8 |
| 11 | 014 | 0.7 | 0.9 | 2.0 | 1.4 | 0.0 | 0.0 | 2.9 | 2.9 | -0.1 | 0.0 | -0.3 | 0.0 | 0.0 | 0.0 | 1.5 |
| 11 | 015 | 0.7 | 0.8 | 3.3 | 2.2 | 0.0 | 0.0 | 5.1 | 2.8 | -0.3 | 0.0 | -0.5 | 0.0 | 0.0 | -1.2 | 1.1 |
| 11 | 017 | 0.8 | - | 22.3 | - | 0.0 | - | 35.4 | - | 0.0 | - | 3.7 | 0.0 | 0.0 | 0.8 | 0.3 |
| 11 | 018 | -5.2 | 9.9 | 1346[7] | 2710 | 0.3 | 0.8 | 1692 | 3310 | -16 | 0.0 | 1.8 | 0.0 | 0.0 | 1.5 | 3.6 |
| 11 | 019 | 0.8 | 1.1 | 88 | 111 | -0.2 | 0.0 | 166 | 119 | -0.1 | 0.0 | -2.3 | 0.0 | 0.0 | 2.6 | 0.4 |
| 12 | 004 | 0.6 | - | 2.5 | - | 0.1 | - | 4.0 | - | 0.0 | - | 0.5 | 0.8 | 0.0 | 0.4 | 0.4 |
| 12 | 006 | 0.9 | - | 1.8 | - | 0.1 | - | 3.5 | - | 0.0 | - | -1.3 | 0.0 | 0.0 | 0.5 | 2.3 |
| 12 | 010 | 0.9 | 0.9 | 4.2 | 4.6 | 0.0 | 0.0 | 5.3 | 4.0 | -0.3 | 0.0 | 2.9 | 0.1 | 0.0 | -0.7 | 0.7 |
| 12 | 011 | 0.8 | - | 1.5 | - | 0.1 | - | 2.3 | - | 0.0 | - | 1.9 | 0.0 | 0.0 | 0.1 | 1.5 |
| 12 | 012 | 0.8 | 0.8 | 1.9 | 2.0 | 0.1 | 0.0 | 3.3 | -1.0 | -0.1 | 0.0 | 1.0 | 0.6 | 0.0 | -0.9 | 1.0 |
| 12 | 013 | 1.0 | - | 1.5 | - | 0.0 | - | -0.1 | - | 0.0 | - | -0.1 | 0.0 | 0.0 | -0.3 | 0.9 |
| 12 | 022 | 0.8 | - | 2.2 | - | 0.0 | - | 0.0 | - | 0.0 | - | 0.3 | 0.0 | 0.0 | -0.4 | 0.7 |
| 12 | 023 | 0.9 | - | 1.5 | - | 0.0 | - | 0.0 | - | 0.0 | - | -5.0 | 0.0 | 0.0 | 0.7 | 1.0 |
| 12 | 024 | 0.7 | - | 2.1 | - | 0.0 | - | 0.1 | - | 0.0 | - | -0.6 | 0.0 | 0.0 | 1.3 | 0.9 |
| 13 | 005 | 0.9 | 0.9 | 1.3 | 1.5 | 0.0 | 0.0 | 2.6 | 2.2 | 0.3 | 0.0 | 0.2 | 0.0 | 0.0 | -1.2 | 21.0 |
| 13 | 006 | 0.9 | 1.0 | 7.8 | 7.7 | 0.0 | 0.1 | 12.9 | 9.6 | -0.9 | 0.0 | 5.5 | 0.0 | 0.0 | -0.4 | 2.7 |
| 13 | 017 | 0.9 | - | 1.8 | - | 0.1 | - | 3.8 | - | 0.0 | - | -0.6 | 0.0 | 0.0 | 0.3 | 0.6 |
| 13 | 019 | 0.9 | - | 1.6 | - | 0.0 | - | 3.2 | - | 0.0 | - | -3.3 | 0.0 | 0.0 | 1.3 | 1.2 |
| 14 | 006 | 0.8 | 1.0 | 2.8 | 3.1 | 0.0 | 0.0 | 4.3 | 5.1 | -0.4 | 0.0 | 1.8 | 0.0 | 0.0 | -0.2 | 2.2 |
| 14 | 007 | 1.2 | - | 1.9 | - | 0.0 | - | 3.2 | - | 0.0 | - | 1.4 | 0.0 | 0.0 | -0.5 | 0.8 |
| 14 | 012 | 1.0 | - | 1.5 | - | 0.0 | - | 2.6 | - | 0.0 | - | -0.4 | 0.0 | 0.0 | -1.0 | 0.6 |
| 14 | 013 | 0.8 | - | 1.5 | - | 0.0 | - | 2.7 | - | 0.0 | - | -1.8 | 0.0 | 0.0 | -0.2 | 1.0 |
| 14 | 015 | 0.8 | 0.8 | 1.7 | 1.8 | 0.0 | 0.0 | 3.7 | 2.8 | 0.2 | 0.0 | 1.1 | 0.5 | 0.0 | -0.9 | 1.8 |

**Table 6.3-3 Soil Analytical Results (pCi/g) for Locations with Radiological Contaminants of Concern (RCOC) Above ILs- Gull Park (SU11 through 25, and SU33) (Continued)**

| SU[(1)] | Sample[(2)] ID | $^{28}$Ac | $^{214}$Bi ($^{226}$Ra)[(3)(4)] | $^{137}$Cs | $^{226}$Ra | $^{241}$Am | $^{14}$C | $^{3}$H | $^{239/249}$Pu | $^{241}$Pu | $^{90}$Sr | SU[(1)] | Sample[(2)] ID | $^{28}$Ac | $^{214}$Bi ($^{226}$Ra)[(3)(4)] | $^{137}$Cs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 018 | 0.9 | - | 1.2 | - | 0.0 | - | 2.9 | - | 0.0 | - | -1.0 | 0.0 | 0.0 | -0.2 | 2.9 |
| 14 | 020 | 0.9 | - | 2.6 | - | 0.1 | - | 3.7 | - | 0.0 | - | -0.3 | 0.0 | 0.0 | -0.1 | 0.3 |
| 14 | 021 | 0.8 | 0.6 | 7.4 | 10.4 | 0.1 | 0.0 | 12.9 | 14.3 | 0.3 | 0.0 | 1.3 | 0.0 | 0.0 | -0.7 | 1.0 |
| 14 | 023 | 0.6 | 0.6 | 3.4 | 5.9 | 0.0 | 0.0 | 7.3 | 7.1 | -0.1 | 0.0 | -2.9 | 0.0 | 0.0 | 0.4 | 1.0 |
| 14 | 024 | 0.8 | 0.9 | 2.0 | 3.1 | 0.1 | 0.0 | 3.5 | 4.0 | 0.1 | 0.0 | 0.6 | 0.0 | 0.0 | 0.4 | 1.4 |
| 15 | 001 | 1.0 | 1.2 | 7.0 | 1.8 | 0.0 | 0.1 | 8.5 | 3.1 | -0.2 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.3 |
| 15 | 007 | 1.0 | - | 1.7 | - | 0.1 | - | 2.6 | - | 0.0 | - | 2.4 | 0.0 | 0.0 | -0.1 | 2.0 |
| 15 | 012 | 0.9 | - | 2.2 | - | 0.0 | - | 3.2 | - | 0.0 | - | -0.1 | 0.0 | 0.0 | 0.6 | 2.6 |
| 15 | 013 | 0.8 | - | 3.0 | - | 0.0 | - | 4.7 | - | 0.0 | - | 1.6 | 0.0 | 0.0 | -0.7 | 1.1 |
| 15 | 018 | 1.0 | 0.9 | 10.5 | 11.7 | 0.0 | 0.1 | 14.2 | 15.2 | -0.5 | 0.0 | 3.6 | 0.0 | 0.0 | -0.4 | 0.6 |
| 15 | 019 | 0.9 | - | 3.4 | - | 0.0 | - | 5.4 | - | 0.0 | - | -1.7 | 0.0 | 0.0 | 0.6 | 0.6 |
| 15 | 024 | 0.9 | - | 2.5 | - | 0.0 | - | 3.8 | - | 0.0 | - | -2.5 | 0.0 | 0.1 | 6.9 | 60.0 |
| 15 | 026 | 0.8 | 0.9 | 15.4 | 45.2 | 0.0 | 0.0 | 35.4 | 56.9 | -0.7 | 0.1 | -2.8 | 0.0 | 0.0 | 0.7 | 1.1 |
| 15 | 029 | 0.8 | - | 1.9 | - | 0.0 | - | 3.1 | - | 0.0 | - | -1.2 | 0.0 | 0.0 | -0.4 | 1.4 |
| 15 | 030 | 0.8 | - | 2.3 | - | 0.0 | - | 3.5 | - | 0.0 | - | 1.1 | 0.0 | 0.0 | -0.4 | 1.6 |
| 15 | 031 | 0.6 | - | 1.5 | - | 0.0 | - | 2.6 | - | 0.0 | - | -1.0 | 0.0 | 0.0 | 0.1 | 0.7 |
| 15 | 032 | 0.9 | - | 1.5 | - | 0.0 | - | 2.3 | - | 0.0 | - | -2.6 | 0.0 | 0.0 | 1.3 | 0.4 |
| 15 | 033 | 0.9 | - | 2.5 | - | 0.0 | - | 4.8 | - | 0.0 | - | 1.0 | 0.0 | 0.0 | 0.7 | 1.9 |
| 16 | 003 | 0.7 | 0.8 | 2.5 | 1.7 | 0.0 | 0.0 | 3.5 | 2.2 | 0.1 | 0.0 | 0.1 | 2.0 | 0.0 | -1.5 | 11.1 |
| 16 | 017 | 0.9 | 1.1 | 6.1 | 9.0 | 0.0 | 0.0 | 12.2 | 11.1 | -0.4 | 0.0 | 0.8 | 0.0 | 0.0 | -1.4 | 0.3 |
| 17 | 002 | 0.8 | 0.6 | 2.7 | 3.5 | 0.0 | 0.0 | 4.4 | 4.8 | 0.1 | 0.0 | -0.1 | 0.1 | 0.0 | 0.0 | 1.4 |
| 17 | 007 | 0.8 | 0.8 | 1.9 | 2.3 | 0.0 | 0.0 | 3.4 | 3.3 | -0.2 | 0.0 | 0.3 | 0.1 | 0.0 | -0.5 | 0.8 |
| 17 | 009 | 0.8 | - | 1.7 | - | 0.0 | - | 2.5 | - | 0.0 | - | 0.6 | 0.0 | 0.0 | 0.0 | 0.8 |
| 17 | 022 | 0.7 | - | 1.8 | - | 0.0 | - | 2.9 | - | 0.0 | - | 4.1 | 0.0 | 0.0 | -0.2 | 0.7 |
| 18 | 001 | 0.9 | 0.7 | 2.8 | 3.4 | 0.0 | 0.0 | 5.2 | 5.5 | -0.4 | 0.0 | -0.2 | 0.0 | 0.0 | -1.0 | 1.2 |
| 18 | 002 | 0.9 | 0.8 | 3.6 | 3.7 | 0.1 | 0.0 | 5.6 | 4.7 | -0.3 | 0.0 | -0.3 | 0.0 | 0.0 | -1.9 | 0.2 |
| 18 | 005 | 0.9 | - | 3.2 | - | 0.0 | - | 4.4 | - | 0.0 | - | -0.6 | 0.0 | 0.0 | 0.1 | 1.0 |

**Table 6.3-3 Soil Analytical Results (pCi/g) for Locations with Radiological Contaminants of Concern (RCOC) Above ILs- Gull Park (SU11 through 25, and SU33) (Continued)**

| SU(1) | Sample(2) ID | $^{28}$Ac | $^{214}$Bi ($^{226}$Ra) (3)(4) | $^{137}$Cs | $^{226}$Ra | $^{241}$Am | $^{14}$C | $^{3}$H | $^{239/249}$Pu | $^{241}$Pu | $^{90}$Sr | SU(1) | Sample(2) ID | $^{28}$Ac | $^{214}$Bi ($^{226}$Ra) (3)(4) | $^{137}$Cs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | 007 | 0.8 | - | 2.4 | - | 0.0 | - | 4.5 | - | 0.0 | - | 1.2 | 0.1 | 0.0 | -0.8 | 1.3 |
| 19 | 014 | 0.9 | 0.4 | 0.5 | 1.8 | 0.1 | 0.0 | 1.3 | 3.7 | 0.1 | 0.0 | 1.8 | 0.0 | 0.0 | 0.6 | 0.0 |
| 33 | 009 | 1.7 | 1.7 | 0.9 | 1.5 | 0.0 | 0.0 | 2.5 | 1.4 | 0.4 | 0.0 | -0.2 | 0.0 | 0.0 | 1.2 | 0.1 |

Notes: (1) Survey Units
(2) The sample number given in consecutive order starting 001 (See Figures 6.2-1-6.2-7 and EDAs in Appendix E)
(3) Left Column, Radium-226 ($^{226}$Ra) based on the gamma emissions of its progeny Bismuth-214 ($^{214}$Bi) "not adjusted for ingrowth"
(4) Right Column, Radium-226 ($^{226}$Ra) based on the gamma emissions of its progeny Bismuth-214 ($^{214}$Bi) in secular equilibrium with Radium-226
(5) Duplicate samples send to the off-site laboratory for analysis per the DQOs
(6) Analysis were not required or performed
(7) Highest observed result for the Gull Park Area, a point source was recovered at this location

### *6.3.4 Sea Launch Facility Surface Soil Results*

A total of 256 surface soil samples were collected during systematic and bias surface soil sampling at locations in the Sea Launch Facility 14 SUs. A total of 244 systematic samples were send to an offsite laboratory for analysis by alpha spectrometry, gas flow proportional counting, and liquid scintillation. Step-out surface soil samples were collected to determine the extent of elevated gamma radioactivity for SU 4 (019, 020, 021, 022, 023, 024, and 025), SU 6 (019 and 020), and SU 31 (019, 020, and 021) were only analyzed by the onsite gamma spectroscopy laboratory in accordance with the decision rule criteria. In addition, out of 256 soil samples a total 35 duplicates were sent to an offsite analytical laboratory for analysis by gamma spectroscopy as described in Section 4.1.7 for QA/QC and determining $^{226}$Ra in growth factor (See Section 6.3.6).

Six of the 14 SUs at the Sea Launch Facility had sample locations which exceeded the IL (1.4 pCi/g) for $^{226}$Ra and two SUs exceeded the IL (1.7pCi/g) for $^{90}$Sr which required further investigation in accordance with the sampling plan. Table 6.3-4 lists all the results at sampling locations where one or more ILs were exceeded. The results for the offsite laboratory analyzed duplicate samples are provided in right column under their respective RCOC. Locations of surface soil samples in SU 1, SU 29, and SU 30 are shown in Figure 6.2-4, SU 2 through SU 10 in Figure 6.2-5, and SU 31 and SU 32 in Figure 6.2-6.

**Table 6.3-4 Soil Analytical Results (pCi/g) for Locations with Radiological Contaminants of Concern (RCOC) Above ILs- Sea Launch (SU1 through 10, and SU29 through 32)**

| SU[1] | Sample[2] ID | $^{28}$Ac | | $^{214}$Bi ($^{226}$Ra)[3][4] | | $^{137}$Cs | | $^{226}$Ra | | $^{241}$Am | | $^{14}$C | $^{3}$H | $^{239/249}$Pu | $^{241}$Pu | $^{90}$Sr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Dup[5] | | Dup | | Dup | | Dup | | Dup | | | | | |
| 4 | 011 | 0.84 | -- [6] | 1.07 | - | 0.03 | - | 1.57 | - | 0.01 | - | -0.30 | -0.02 | 0.01 | -0.70 | 2.59 |
| 4 | 017 | 0.83 | 0.80 | 37 | 95 | -0.03 | -0.08 | 49 | 116 | -0.94 | 0.00 | 0.10 | 0.03 | 0.00 | 1.10 | 0.24 |
| 4 | 018 | 0.94 | 1.04 | 8 | 14 | 0.02 | -0.01 | 17 | 17 | -0.35 | 0.01 | -3.40 | 0.01 | 0.01 | 1.40 | 0.07 |
| 5 | 017 | 1.03 | 1.03 | 1.72 | 1.72 | 0.00 | 0.00 | 2.80 | 2.80 | 0.00 | 0.00 | 2.80 | -0.03 | 0.00 | 1.00 | 0.32 |
| 8 | 001 | 0.72 | - | 0.74 | - | 0.02 | - | 1.24 | - | 0.02 | - | -0.90 | 0.02 | 0.00 | -0.70 | 11.9 |
| 9 | 019 | 1.92 | - | 1.61 | - | 0.00 | - | - | - | - | - | - | - | - | - | - |
| 10 | 013 | 0.82 | - | 1.47 | - | 0.06 | - | 1.68 | - | 0.01 | - | -3.50 | -0.01 | -0.01 | -0.80 | 0.34 |
| 10 | 017 | 0.86 | 0.75 | 38 | 71 | -0.17 | 0.03 | 88 | 78 | -0.26 | 0.01 | 3.30 | 0.00 | 0.01 | 2.20 | 0.30 |
| 29 | 007 | 0.67 | 0.56 | 1.71 | 1.68 | -0.01 | -0.02 | 2.99 | 2.80 | 0.03 | 0.00 | 0.80 | -0.03 | 0.00 | -0.90 | -0.01 |
| 29 | 018 | 0.72 | 0.74 | 22 | 20 | 0.35 | 0.01 | 34 | 24 | 0.04 | 0.01 | -0.50 | 0.02 | 0.01 | 0.80 | 0.54 |
| 31 | 017 | 0.45 | 0.74 | 361 | 134[7] | 5.45 | -0.08 | 458 | 156 | -8.52 | 0.01 | 0.10 | 0.00 | 0.01 | -0.40 | 0.51 |

Notes: (1) Survey Units

(2) The sample number given in consecutive order starting 001 (See Figures 6.2-1-6.2-7 and EDAs in Appendix E)

(3) Left Column, Radium-226 ($^{226}$Ra) based on the gamma emissions of its progeny Bismuth-214 ($^{214}$Bi) "not adjusted for ingrowth"

(4) Right Column, Radium-226 ($^{226}$Ra) based on the gamma emissions of its progeny Bismuth-214 ($^{214}$Bi) in secular equilibrium with Radium-226

(5) Duplicate samples send to the off-site laboratory for analysis per the DQOs

(6) Analysis were not required or performed

(7) The duplicate (offsite laboratory) was used as the highest observed result for the Sea Launch Area based on data quality decision rules, a point source was recovered at this location

### *6.3.5 Former Athletic Fields Surface Soil Results*

A total of 65 surface soil samples were collected from the three SUs at the former Athletic Fields, and all 65 samples were sent to an offsite analytical laboratory for analysis by alpha spectrometry, gas flow proportional counting, and liquid scintillation. A total of six soil samples were sent to an offsite analytical laboratory for analysis by gamma spectroscopy. None of the samples collected exceeded the ILs. Locations of surface soil samples in SU 26, SU 27, and SU 28 are shown in Figure 6.2-7.

### *6.3.6 Radium-226 In-growth Factor*

An in-growth factor was used to account for differences in results reported based on the onsite laboratory analysis of $^{214}$Bi ($^{226}$Ra) since the onsite method did not account for in-growth of decay products which was accomplished by the offsite procedures by establishing secular equilibrium prior to analysis. The radium in-growth factor was calculated as the ratio of the $^{214}$Bi concentration at secular equilibrium based on offsite laboratory results to the $^{214}$Bi concentration at the time of sample collection based on onsite laboratory results from the same sample.

The $^{214}$Bi concentration at secular equilibrium is estimated using the $^{214}$Bi concentration reported by the offsite analytical laboratory. The analytical laboratory sealed the soil samples inside airtight containers and waited until at least 8 half-lives of $^{222}$Rn had elapsed. After 8 half-lives, the $^{214}$Bi concentration is equal to more than 99.6 percent of the $^{226}$Ra concentration, so secular equilibrium has been established within the measurement error. The $^{214}$Bi concentration at the time of sample collection is estimated by the onsite laboratory $^{214}$Bi result. The $^{226}$Ra in-growth factor was calculated as the ratio between these two results.

A total of 81 soil samples were analyzed by gamma spectroscopy in the onsite laboratory and then sent to the analytical laboratory for gamma spectroscopy analysis. The $^{226}$Ra in-growth factor was calculated for each of these results. The data set was evaluated and seven outliers were identified and removed as not being representative of the average in-growth factor; six results reported unusually large ratios; and one sample reported an unusually low ratio.

**Table 6.3-5 Statistics for the 226Ra In-growth Factor**

| Statistical Quantity | Value[1] |
|---|---|
| Average | 1.19 |
| Standard Deviation | 0.211 |
| Median | 1.22 |
| Minimum | 0.683 |
| Maximum | 1.63 |
| Number of Samples | 74 |
| Note:[1] The radium in-growth factor is calculated as the ratio of the $^{214}$Bi concentration at secular equilibrium to the $^{214}$Bi concentration at the time of sample collection and is a unitless value. | |

Table 6.3-4 presents summary statistics for the 82 samples used to develop the $^{226}$Ra in-growth factor. When calculating dose estimates in Section 7 the average $^{214}$Bi ($^{226}$Ra) activity from the onsite laboratory was adjusted by multiplying by the in-growth factor of 1.19 to provide an estimate of the $^{226}$Ra activity in accordance with the *Work Plan* (Cabrera, 2008).

The spreadsheet used for calculating the in growth factor is provided in electronic file on Appendix D Dose Modeling File.

### 6.4 Identification and Removal of Radioactive Items

A total of 21 radioactive items (point sources) were removed from 19 locations as identified in Table 6.4-1 and Figure 6.4-1. These items included small pieces of material, including scraps of metal, unidentifiable items, and soil containing flecks of paint and grit. Two radioactive items were removed at each of two locations: SU 5 location 017 and SU 15 location 017.

Removal of radioactive items at SU 5 location 017 did not result in a significant reduction in radioactivity at this location. Soil was removed to a depth of three feet bgs and two radioactive items were removed. The borehole log reports 78,000 cpm at the surface and 7,000 cpm at one foot and two feet bgs. The average background reading in the subsurface was approximately 3,500 cpm. The subsurface sampling was restricted to three feet bgs because of refusal by the direct-push rig.

During this investigation two sample locations reported elevated concentrations of $^{226}$Ra in soil where no radioactive items were recovered; SU 6 location 017 and SU 13 location 006. The elevated activity at SU 6 location 017 was identified during the GWS and ISOCs. Soil samples were collected for onsite gamma analysis at intervals of 0-1, 1.5-2.5 and 7-8 feet bgs with values for $^{214}$Bi ($^{226}$Ra) reported as 0.77, 20.58 and 0.64 pCi/g respectively. A confirmation offsite laboratory analysis of the sample from the 2 feet interval reported a similar $^{214}$Bi ($^{226}$Ra) value of 28.7 pCi/g. Since site surface location was covered with three inches of asphalt there no attempt was made to remove the asphalt and identify radioactive items at this location.

The elevated activity at SU 13 location 006 was identified in the systematic sample, soil samples were collected for onsite gamma analysis at intervals of 0-1, 1.5-2.5 and 11-12 feet bgs with values for $^{214}$Bi ($^{226}$Ra) reported as 7.72, 4.06 and 0.996 pCi/g respectively. A confirmation offsite laboratory analysis of the sample from the 2 feet interval reported a similar $^{214}$Bi ($^{226}$Ra) value of 3.41 pCi/g. An investigation of the soil removed from this location during sampling failed to identify any radioactive items.

**Table 6.4-1 Radioactive Articles (Point Sources) Removed During Soil Sampling**

| Survey Unit | Location Number | Dose Rate on Contact of Article | Depth | $^{90}$Sr[1] (pCi/g) Soil Sample Result | $^{214}$Bi ($^{226}$Ra)[2] (pCi/g) Soil Sample Result |
|---|---|---|---|---|---|
| SU 04 | 017 | 800 µR/hr[3] | Surface[4] | 0.24 | 95 |
| SU 04 | 018 | 90 µR/hr | surface | 0.07 | 13.8 |
| SU 05 | 017 | 500 µR/hr | surface | -0.002 | 0.814 |
| SU 05 | 017 | 4 mR/hr[5] | 3 ft bgs[6] | 0.32 | 1.72 |
| SU 11 | 017 | 8 mR/hr | surface | 0.26 | 22.3 |
| SU 11 | 018 | 400 µR/hr | surface | 3.62 | 2710 |
| SU 11 | 019 | 5 mR/hr | surface | 0.36 | 111 |
| SU 11 | 020 | 4 mR/hr | surface | 0.23 | 0.74 |
| SU 13 | 005 | 1.3 mR/hr | surface | 0.3 | 1.54 |
| SU 14 | 017 | 1 mR/hr | surface | 0.63 | 1.35 |
| SU 15[7] | 017 | 35 µR/hr | surface | 430 | 1.33 |
| | | 100 µR/hr | | | |

**Table 6.4-1 Radioactive Articles (Point Sources) Removed During Soil Sampling (Continued)**

| Survey Unit | Location Number | Dose Rate on Contact of Article | Depth | $^{90}Sr$(1) (pCi/g) Soil Sample Result | $^{214}Bi$ ($^{226}Ra$)(2) (pCi/g) Soil Sample Result |
|---|---|---|---|---|---|
| SU 15 | 026 | 1.5 mR/hr | surface | 1.13 | 45.2 |
| SU 27 | 017 | 1.2 mR/hr | surface | 0.074 | 0.53 |
| SU 28 | 017 | 20 mR/hr | surface | -0.02 | 0.66 |
| SU 29 | 018 | 3 mR/hr | surface | 0.54 | 20.3 |
| SU 29 | 019 | 3 mR/hr | surface | 0.07 | 0.93 |
| SU 29 | 020 | 9 mR/hr | surface | 0.045 | 1.53 |
| SU 31 | 017 | 200 mR/hr | surface | 0.51 | 134 |
| SU 32 | 017 | 100 µR/hr | surface | 0.061 | 0.38 |
| SU 33 | 017 | 2 mR/hr | surface | 0.26 | 0.77 |

Notes: (1) Stronium-90 measured by the offsite laboratory
(2) Radium-226 ($^{226}Ra$) based on the gamma emissions of its progeny Bismuth-214 ($^{214}Bi$) "not adjusted for ingrowth"
(3) Dose Rate Measured onsite in microRoentgen per hour (µR/hr)
(4) Surface samples were collected from 0-1 feet below ground surface
(5) Dose Rate Measured onsite milliRoentgen per hour (mR/hr)
(6) Feet below ground surface (ft bgs)
(7) Two articles (point sources) were collected at this location

Table 6.4-1 lists the radioactive items that were identified and removed during sampling activities. Soil samples were collected after the point sources were removed so that the soil sample results would be representative of the site conditions after the point sources were removed. The locations where the radioactive point sources were found are shown in Figure 6.4-1. Pictures of the radioactive items are included in the Photo Log (Appendix E, Disk 1).

At the completion of survey activities, all of the radioactive items were placed inside of one 55-gallon steel drum for subsequent disposal as LLRW. All drums were sampled in for both chemical and radiochemistry, manifested and disposed to appropriate off site permitted disposal facility under a separated contract and task order.

## 6.5 Survey Unit Data Summaries

Individual data sets (EDA Files, Appendix E, Disk 2) were developed to describe the nature and extent of radioactivity for each SU. The reason for developing a single data set for each SU was that, for many SUs, more than one type of measurement was performed at the same location (i.e., in situ gamma spectroscopy, onsite gamma spectroscopy, and offsite gamma spectroscopy). The objective of developing summaries of SU data was to provide a single number estimating radionuclide concentrations in each SU. This quantitative number was then used to estimate the dose and risk from potential exposure to total residual radioactivity in each SU.

Quantitative results for the radiological data sets are limited to isotope-specific analyses. In situ, onsite laboratory, offsite laboratory gamma spectroscopy, and offsite laboratory alpha spectrometry results are quantitative. Radiological measurements for dosimetry and gross gamma measurements (walkover and borehole) are not considered quantitative for describing nature and extent of radioactivity.

It was necessary to assign priorities for selecting between multiple measurements at the same location. A hierarchy of analytical techniques was established to aid in selecting the most appropriate data for describing nature and extent of radioactivity. Offsite laboratories are certified and the data has the highest level of QC combined with lower uncertainty and higher precision. In addition, alpha spectrometry, gas-flow proportional and liquid scintillation results are only available from offsite laboratory analyses. Therefore, offsite laboratory results were assigned the highest priority. If verified and validated offsite laboratory results were available, they were included in the data set to describe nature and extent. Appendix C provides information on data quality, data verification, and data validation.

Onsite laboratory gamma spectroscopy results are comparable to offsite laboratory results. The same sample was measured using the same analytical method and same type of detector. The quality of the onsite laboratory data is acceptable to support the objectives of the survey. Onsite laboratory data was generally used to provide additional information on the nature and extent of radiation in areas where project ILs were exceeded. The reason for including the additional onsite laboratory results for gamma emitting radionuclides was to provide additional information on the nature and extent of radioactivity using all available data.

In situ gamma spectroscopy results are comparable to laboratory gamma spectroscopy results under certain conditions. In situ gamma spectroscopy uses the same analytical method and the same type of detector. However, because the analysis was performed in situ, the sample being measured was not the same. In situ gamma spectroscopy was used in lieu of collecting surface samples in areas of paved surfaces when no results above the project ILs were reported. In situ gamma spectroscopy analysis was also performed at locations were point sources were recovered during site investigation and characterization activities. If the gross gamma activity level was reduced by more than a factor of 10 by collecting a surface sample or removing a radioactive article (point source), the analytical laboratory result was not included in the final radiation exposure analysis data set because this number did not reflect the activity in the soil remaining at the site. In these cases an in situ gamma spectroscopy analysis was performed after sampling was completed to characterize the soil remaining at the site, and this value was included in the final radiation exposure analysis data set.

### *6.5.1 Summary Statistics*

Summary statistics were calculated for the nine RCOPCs listed in Table 1.4-1 and naturally occurring $^{40}$K for each SU data set. Bismuth-214 was used to estimate $^{226}$Ra concentrations, and Actinium-228 ($^{228}$Ac) is used to estimate $^{232}$Th concentrations. The average (mean), median, standard deviation, and range (minimum and maximum), were calculated for each RCOPC to describe the distribution of the data. Summary statistics tables for each SU are included electronically in Appendix E.

### *6.5.2 Graphical Data Review*

A graphical data review was performed to provide information on the distribution and structure of the data sets, similar to the calculation of summary statistics. Graphical representations of data sets often make it easier to identify patterns, relationships, and anomalies in the data. The graphical data review consisted of histograms of isotope activity and frequency, and cumulative frequency distributions (CFDs) graphs of isotope activity to z-scores. In addition, the site-specific data evaluation included contour plots of the GWS data z-scores where the GWS was performed.

Histograms, or frequency plots, are useful tools for examining the general shape of a distribution. A histogram quickly reveals any departures from symmetry, such as bimodality. Histograms were constructed for each radioisotope in the individual SU data sets.

Cumulative frequency distributions are useful tools for identifying outliers as well as identifying data sets with multiple distributions. A normally distributed data set will appear as a straight line in a CFD. Deviations from a straight line in the CFD help identify deviations from normality in the underlying data set. A curved line generally describes a skewed distribution, with an upward curve (often associated with contamination) and a downward curve. Abrupt changes in slope or jumps in the data generally indicate the presence of multiple distributions that may indicate potential contamination. Isolated points at the extreme ends of the CFD identify outliers. Histograms and CFDs for each SU data set are provided electronically by SU in the EDA files found of Appendix E, Disk 2.

### *6.5.3 Radionuclides of Concern*

Two RCOPC, $^{226}$Ra and $^{90}$Sr, exceeded project ILs and were identified as RCOC. Dose and risk analysis was performed using the laboratory results for $^{226}$Ra and $^{90}$Sr concentration in soil which is described in Section 7.0.

## 6.6 Borehole Logging

A total of 37 samples were collected from 33 boreholes installed at IR Sites 1 and 2. As described in the *SAP* (Cabrera, 2008), the boreholes were logged for gross gamma activity using a 1- by 1-inch NaI detector, screened for VOCs using a PID (as a precaution for health and safety reasons), and descriptions of subsurface soils were recorded. Soil samples were collected at the total depth of the boring (i.e., the bottom of the borehole), as well as at the water table. The samples were screened for photon-emitting radionuclides in an onsite laboratory, and then sent to an offsite laboratory for gamma spectroscopy and alpha spectrometry analysis.

VOCs were not detected in any of the subsurface areas by the PID screening. Exposure rate measurements taken at one meter above the boreholes generally ranged from approximately 5 to 10 µR/hr across the site; the maximum reading was 200 µR/hr recorded at SU 31 sample 017. Borehole logs are provided in Appendix E, Disk 1.

## 6.7 Subsurface Soil Sample Results

A total of 37 subsurface soil samples were collected from 33 boreholes at IR Sites 1 and 2. One sample was collected at the total depth of the boreholes in every SU; a second soil sample was collected at the water table from the boreholes in SU 6, SU 13, SU 28, and SU 33. The RCOCs in subsurface soil are the same as those identified in surface soil; $^{226}$Ra and $^{90}$Sr. Three samples exceeded the IL for $^{226}$Ra; at SU 5 Location 017 at 2- 3 feet bgs (1.72 pCi/g), SU 6 Location 017 at 1.5-2.5 feet bgs (28.7 pCi/g), and SU 13 Location 006 at 1.5-2.5 feet bgs (3.41 pCi/g). Stronium-90 did not exceed results the project IL in any of the subsurface sample locations and only three samples had concentrations above the MDCs; SU 5 Location 017 at 2-3 feet bgs (0.32 pCi/g), SU 6 Location 017 at 1.5-2.5 feet bgs (0.32 pCi/g), and SU 13 Location 006 at 11-12 feet bgs (0.5 pCi/g) as indicated in Table 6.7-1. The results of all the subsurface soil analyses are provided electronically in the individual SU EDA files in Appendix E, Disk 2.

**Table 6.7-1 Subsurface Soil Sampling Results**

| SU | Sample Location | Sample Interval ft bgs[1] | $^{214}Bi(^{226}Ra)$[2] pCi/g[3] IL[4]=1.4 | Sr-90[5] pCi/g IL=1.7 | Boring Depth ft bgs[6] | Water Table ft bgs |
|---|---|---|---|---|---|---|
| 01 | 005 | 0-1 | 0.549 | 0.067 | 8 | 8 |
| | | 7-8 | 0.610 | -0.02 | | |
| 02 | 011 | 0-1 | 0.730 | -0.052 | 8 | 8 |
| | | 7-8 | 0.702 | 0.047 | | |
| 03 | 017 | 0-1 | 0.733 | 0.094 | 8 | 8 |
| | | 7-8 | 0.659 | 0.03 | | |
| 04 | 005 | 0-1 | 0.833 | 0.007 | 10 | 10 |
| | | 9-10 | 0.614 | 0.101 | | |
| 05 | 017 | 0-1 | 0.814 | -0.002 | 3[7] | N/A[8] |
| | | 2-3 | 1.720 | 0.32 | | |
| 06 | 017 | 0-1 | 0.760 | 0.023 | 8 | 8 |
| | | 1.5-2.5 | 28.700 | 0.32 | | |
| | | 7-8 | 0.637 | -0.053 | | |
| 07 | 001 | 0-1 | 1.030 | 0.74 | 8 | 8 |
| | | 7-8 | 0.624 | 0.015 | | |
| 08 | 003 | 0-1 | 0.525 | 0.027 | 8 | 8 |
| | | 7-8 | 0.618 | 0.039 | | |
| 09 | 017 | 0-1 | 0.551 | 0.095 | 8 | 8 |
| | | 7-8 | 0.658 | 0.052 | | |
| 10 | 002 | 0-1 | 0.537 | -0.03 | 8 | 8 |
| | | 7-8 | 0.637 | 0.056 | | |
| 11 | 005 | 0-1 | 1.128 | 0.82 | 8 | 8 |
| | | 7-8 | 0.630 | -0.007 | | |
| 12 | 017 | 0-1 | 0.459 | 0.13 | 8 | 8 |
| | | 7-8 | 0.768 | 0.169 | | |
| 13 | 006 | 0-1 | 7.720 | 2.65 | 12 | 12 |
| | | 1.5-2.5 | 3.410 | 0.056 | | |
| | | 11-12 | 0.996 | 0.5 | | |
| 14 | 007 | 0-1 | 1.904 | 0.83 | 12 | 12 |
| | | 11-12 | 0.655 | 0.082 | | |
| 15 | 018 | 0-1 | 11.700 | 0.59 | 12 | 12 |
| | | 11-12 | 0.674 | 0.11 | | |
| 16 | 008 | 0-1 | 0.677 | 0.064 | 12 | 12 |
| | | 11-12 | 0.674 | 0.023 | | |
| 17 | 017 | 0-1 | 0.977 | 0.65 | 8 | 8 |
| | | 7-8 | 0.819 | 0.081 | | |
| 18 | 012 | 0-1 | 0.881 | 0.18 | 12 | 12 |
| | | 11-12 | 0.778 | 0.029 | | |
| 19 | 016 | 0-1 | 0.783 | 0.19 | 10 | 10 |
| | | 9-10 | 0.564 | 0.044 | | |

**Table 6.7-1 Subsurface Soil Sampling Results (Continued)**

| SU | Sample Location | Sample Interval ft bgs(1) | $^{214}Bi(^{226}Ra)$(2) pCi/g(3) IL(4)=1.4 | Sr-90(5) pCi/g IL=1.7 | Boring Depth ft bgs(6) | Water Table ft bgs |
|---|---|---|---|---|---|---|
| 20 | 017 | 0-1 | 0.830 | 0.02 | 8 | 8 |
| | | 7-8 | 0.884 | -0.01 | | |
| 21 | 017 | 0-1 | 0.875 | 0.083 | 8 | 8 |
| | | 7-8 | 0.746 | 0.038 | | |
| 22 | 014 | 0-1 | 0.993 | 0.08 | 8 | 8 |
| | | 7-8 | 0.644 | 0.04 | | |
| 23 | 006 | 0-1 | 1.260 | 0.136 | 8 | 8 |
| | | 7-8 | 0.553 | -0.027 | | |
| 24 | 017 | 0-1 | 1.071 | -0.02 | 8 | 8 |
| | | 7-8 | 0.616 | -0.013 | | |
| 25 | 003 | 0-1 | 1.123 | 0.009 | 12 | 12 |
| | | 11-12 | 0.598 | 0.18 | | |
| 26 | 009 | 0-1 | 0.588 | 0.016 | 10 | 10 |
| | | 9.5-10.5 | 0.557 | 0.021 | | |
| 27 | 017 | 0-1 | 0.530 | 0.074 | 12 | 12 |
| | | 11-12 | 0.629 | 0.022 | | |
| 28 | 017 | 0-1 | 0.661 | -0.02 | 10 | 10 |
| | | 1.5-2.5 | 0.648 | 0.048 | | |
| | | 9-10 | 0.610 | -0.014 | | |
| 29 | 016 | 0-1 | 1.284 | NS | 10 | 10 |
| | | 8.5-9.5 | 0.625 | 0.065 | | |
| 30 | 017 | 0-1 | 0.489 | -0.026 | 8 | 8 |
| | | 7-8 | 0.676 | 0.033 | | |
| 31 | 017 | 0-1 | 134.000 | 0.51 | 12 | 12 |
| | | 11-12 | 0.749 | -0.04 | | |
| 32 | 017 | 0-1 | 0.390 | 0.061 | 12 | 12 |
| | | 11-12 | 0.638 | 0.062 | | |
| 33 | 017 | 0-1 | 0.780 | 0.26 | 8 | 8 |
| | | 1.5-2.5 | 0.601 | 0.08 | | |
| | | 7-8 | 0.594 | 0.04 | | |

Notes: (1) Feet below ground surface (feet bgs)
(2) Radium-226 ($^{226}Ra$) based on the gamma emissions of its progeny Bismuth-214 ($^{214}Bi$) "not adjusted for ingrowth" $^{214}Bi(^{226}Ra)$
(3) PicoCuries per gram (pCi/g)
(4) Investigation Level (IL)
(5) Stonium-90 $^{90}Sr$ measured by the offsite laboratory
(6) Feet belowground surface (ft bgs)
(7) Boring terminated due to refusal
(8) Not applicable (N/A)

## 6.8 Groundwater Sample Results

A total of seven groundwater samples were collected from monitoring wells around the perimeter of the IR Sites 1 and 2. The locations of the monitoring wells are shown in Figure 3.1-3. The wells were purged prior to sample collection and groundwater samples were preserved with nitric acid prior to shipment to an analytical laboratory. The samples were analyzed for RCOPCs by gamma spectroscopy, alpha spectrometry, gas-flow proportional counting, and liquid scintillation. The results of the groundwater analyses are provided in Appendix E, Electronic Data Files, EDA Groundwater Data.

Groundwater sample results were compared directly to the ILs listed in Table 2.4-1. None of the results exceeded any of the project ILs and the laboratory MDCs achieved were much lower than the ILs for all RCOPCs. $^{90}$Sr results ranged from below detection to a value of 13 pCi/L at MW 1-16. $^{226}$Ra results ranged from below detection to 0.36 pCi/L at MW 1-06. The $^{90}$Sr result for sample MW 1-16 reported the result closest to an IL; 13 pCi/L with an IL of 500 pCi/L.

This Page Left Intentionally Blank

## 7.0 Radiation Exposure Analysis

Potential radiation exposure to the industrial worker at IR Sites 1 and 2 was estimated based on the nature and extent of radionuclides in surface soil described in Section 6.0. The purpose of this evaluation was to determine whether receptors under an industrial worker scenario at LBNC would potentially receive an unacceptable dose from exposure to residual radiation. The radiation exposure analysis was performed using the two RCOCs, $^{226}$Ra and $^{90}$Sr, identified during the radiological assessment with concentrations above the ILs. The $^{226}$Ra exposure analysis was performed using two separate onsite laboratory soil data sets for calculating radium activity in soil; (1) The $^{214}$Bi ($^{226}$Ra) data set utilized the $^{214}$Bi activity adjusted using the in-growth factor described in Section 6.3.6 to represent expected $^{226}$Ra activity in soil; and (2) $^{226}$Ra measured directly from the 186 keV gamma peak measured in the onsite laboratory. The procedures used in the following sections were applied to both data sets used for measuring $^{226}$Ra activity in soils.

### 7.1 Radiation Exposure Scenario

The radiation exposure scenario is consistent with the assumptions used to develop the project ILs. The exposure scenario assumes that residual radioactivity is distributed in a surface soil layer on the property that is used for industrial activities; it assumes continuous exposure via multiple exposure pathways to the critical group. The critical group is considered to consist of civilian personnel who work at the site. Within that population, the industrial worker was selected to represent all others. The industrial worker is one who works indoors and outdoors all work days at the site.

Table 7.1-1 lists site-specific exposure parameters. Potential exposure pathways for the industrial worker are: (1) external exposure to penetrating radiation, (2) inhalation exposure to re-suspended radiological contaminants in the soil (e.g., dust), and (3) inadvertent ingestion of radiologically contaminated soil. For radiological contaminants in groundwater, no exposure pathway is assumed for the industrial worker because groundwater at the site is not potable and is not extracted for drinking purposes. For dose modeling purposes, no ground cover (i.e., roads, buildings, asphalt parking lots, grass, etc.) is assumed to be present on the site. In reality, approximately two-thirds of IR Sites 1 and 2 are covered. These intentionally conservative assumptions overestimate the potential exposure of the workers to radiological contaminants potentially present in shallow soil at the site.

**Table 7.1-1 Site-Specific Exposure Parameters**

| Modeling Parameter | Industrial Worker |
|---|---|
| Exposure Pathways[(a)] | External gamma, inhalation, soil ingestion |
| Exposure Duration[(b)] | 25 years |
| Exposure Frequency[(b)] | 8 hours per day, 250 days per year |
| Source of Exposure[(a)] | Surface soil (to 1 foot bgs) |
| Area of Exposure[(c)] | 2,000 $m^2$ |
| Time indoors[(d)] | 6 hours/day |
| Time outdoors[(d)] | 2 hours/day |

**Table 7.1-1 Site-Specific Exposure Parameters (Continued)**

| Modeling Parameter | Industrial Worker |
|---|---|
| Air intake rate[(b)] | 0.83 cubic meters/hour |
| Soil intake rate[(b)] | 50 milligrams/day |
| Sources:<br>(a) Section 6.2.1 exposure scenario description.<br>(b) Tables 5.2.10 and 5.2.11, RI Report (Bechtel, 1996).<br>(c) EPA PRG calculation default value.<br>(d) Table 2.3, User's Manual for RESRAD Version 6 (DOE, 2001). | |

## 7.2 Dose Modeling

The dose associated with a concentration of 1 pCi/g was calculated for the radionuclides of concern. The dose factors (expressed as mrem/yr per pCi/g) were then used to estimate the total radiological dose for each SU (see Section 7.3).

Radiological dose was estimated using the DOE RESRAD exposure pathway model Version 6.5. A majority of the model default input parameters were, as a conservative measure, used to estimate the total dose. The site-specific input parameters used are listed in Table 7.1-1. The results of the dose modeling, expressed as TEDE, are summarized in Table 7.2-1.

The two radionuclides of concern identified during the data review that was modeled were: $^{226}$Ra and $^{90}$Sr. The $^{226}$Ra is assumed to be in secular equilibrium with its progeny. The maximum dose for both radionuclides occurs when the time is zero, so a $^{90}$Sr and $^{226}$Ra pCi/g to mrem conversion factor can be calculated. Doses were calculated for each radionuclide and then summed. The $^{90}$Sr conversion factor for 1 pCi/g equates to 4.3 x $10^{-3}$ mrem total effective dose equivalent (TEDE). The $^{226}$Ra conversion factor for 1 pCi/g equates to 1.8 mrem TEDE. The average soil sample result for each survey unit from the on-site soil laboratory (corrected to correlate to off-site laboratory) results was used to populate the models. The hierarchy for using each sample location was: Off-site laboratory results (approximately 10 percent of all samples), on-site laboratory results (corrected for in-growth), and In Situ Object Counting System (ISOCS) measurements. The ISOCS data was only used if elevated $^{226}$Ra adjacent was found next to initial measurements that exceeded investigation levels (i.e., step-outs).

**Table 7.2-1 Dose Modeling Results**

| Radionuclide Contaminant of Concern | Dose Factor (mrem/yr per pCi/g) |
|---|---|
| $^{226}$Ra | 1.8 |
| $^{90}$Sr | 4.3 x $10^{-3}$ |

A discussion of the dose modeling is provided in Appendix D. The dose was calculated for the entire site was to determine whether personnel working at LBNC could potentially receive an unacceptable dose from exposure to radiation. The radiation exposure analysis was performed for the radionuclides of concern identified during the radiological assessment; 226Ra and 90Sr. The outputs from the dose modeling, including all the input parameters used during modeling, are provided in Appendix D.

### 7.3 Survey Unit Dose Estimates

The dose factors for the radionuclides of concern listed in Table 7.2-1 ($^{226}$Ra and $^{90}$Sr) were used to estimate the total dose in each SU. The total dose estimates are conservative because the dose from natural background was also included; in addition, a majority of the input parameters were set at the model default values.

The dose factor for each radionuclide of concern was multiplied by the average activity of that radionuclide in each SU using ($^{226}$Ra and $^{90}$Sr) and $^{214}$Bi ($^{226}$Ra) and $^{90}$Sr). The total dose was estimated within each SU by summing the doses from all radionuclides of concern found in that SU. The results of the SU dose calculations are listed in Table 7.3-1.

Using the $^{214}$Bi ($^{226}$Ra) data the estimated total dose in 32 of the 33 SUs was less than 5 mrem/yr. The maximum estimated total dose of 12.6 mrem/yr was found in SU 31 at the Sea Launch Facility. Utilizing the $^{226}$Ra data the estimated total dose in 32 of the 33 SUs was also less than 5 mrem/yr. However, the maximum estimated total dose of using $^{226}$Ra was observed at SU 11 with a value of 6.05 mrem/yr and SU 31 at the Sea Launch Facility value was found to be 2.12 mrem/yr. The relatively elevated estimated dose at SU 31 using the $^{214}$Bi ($^{226}$Ra) data corresponds to an area of elevated activity identified during the radiological survey at location 017. There were no radioactive items located or removed from SU 31the area and the verification soil sample did not significantly reduce the amount of radioactivity. The maximum $^{90}$Sr dose, which was more than two orders of magnitude lower than the $^{226}$Ra dose, was calculated for SU 15 where radioactive items were removed at locations 017 and 026.

### 7.4 Survey Unit Risk Calculations

The doses for the RCOCs listed in Table 7.3-1 were used to estimate the total risk in each SU. The total risk is a conservative estimate of risk because the risk from natural background radiation was included.

The dose for each RCOC in each SU was multiplied by a radionuclide-specific risk per mrem/yr conversion factor. The risk associated with the IL for $^{90}$Sr corresponding to 25 mrem/yr is $1.5x10^{-07}$ as listed in Attachment A to Worksheet #11 of the SAP (Cabrera, 2008). This results in a conversion factor of $6.0x10^{-09}$ risk per mrem/yr for $^{90}$Sr. The risk associated with the IL for $^{226}$Ra at 25 mrem/yr is $2.3x10^{-05}$, resulting in a conversion factor of $9.2x10^{-07}$ for $^{226}$Ra.

The total risk for each SU was calculated by summing the risks from all RCOCs in the SU (Table 7.4-1) columns A and B. Column A is the total risk using the $^{226}$Ra dose calculated from the surrogate $^{214}$Bi and $^{90}$Sr whereas Column B is the total risk when using when using the $^{226}$Ra peak and $^{90}$Sr.

**Table 7.3-1 Survey Unit Total Dose Estimates**

| SU | RCOC[1] Average Activity (pCi/g) | | | TEDE[2] (mrem/yr) | | | Total TEDE (mrem/yr) | |
|---|---|---|---|---|---|---|---|---|
| | $^{214}$Bi ($^{226}$Ra)[3] | $^{226}$Ra[4] | $^{90}$Sr | $^{214}$Bi ($^{226}$Ra) | $^{226}$Ra | $^{90}$Sr | A[5] | B[6] |
| 01 | 0.64 | 1.18 | 0.02 | 1.15 | 2.09 | 8.60E-05 | 1.15 | 2.09 |
| 02 | 0.92 | 1.23 | 0.01 | 1.66 | 2.18 | 3.66E-05 | 1.66 | 2.18 |
| 03 | 0.73 | 1.15 | 0.05 | 1.31 | 2.03 | 1.99E-04 | 1.31 | 2.03 |
| 04 | 1.00 | 1.25 | 0.20 | 1.80 | 2.21 | 8.46E-04 | 1.80 | 2.21 |
| 05 | 0.82 | 1.44 | 0.03 | 1.48 | 2.55 | 1.29E-04 | 1.48 | 2.55 |
| 06 | 0.81 | 1.22 | 0.07 | 1.46 | 2.17 | 2.87E-04 | 1.46 | 2.17 |
| 07 | 0.73 | 1.08 | 0.08 | 1.31 | 1.92 | 3.53E-04 | 1.31 | 1.92 |
| 08 | 0.71 | 1.07 | 0.82 | 1.28 | 1.89 | 3.54E-03 | 1.28 | 1.89 |
| 09 | 0.77 | 0.97 | 0.20 | 1.39 | 1.71 | 8.43E-04 | 1.39 | 1.71 |
| 10 | 0.90 | 1.21 | 0.19 | 1.62 | 2.15 | 8.17E-04 | 1.62 | 2.15 |
| 11 | 1.30 | 3.42 | 1.00 | 2.34 | 6.05 | 4.31E-03 | 2.34 | 6.05 |
| 12 | 1.60 | 2.30 | 0.75 | 2.88 | 4.08 | 3.23E-03 | 2.88 | 4.08 |
| 13 | 1.43 | 1.86 | 1.40 | 2.57 | 3.30 | 6.02E-03 | 2.58 | 3.31 |
| 14 | 2.04 | 2.06 | 2.90 | 3.67 | 3.64 | 1.25E-02 | 3.68 | 3.65 |
| 15 | 2.08 | 2.63 | 17.00 | 3.74 | 4.65 | 7.31E-02 | 3.82 | 4.72 |
| 16 | 1.40 | 1.68 | 0.99 | 2.52 | 2.98 | 4.26E-03 | 2.52 | 2.98 |
| 17 | 1.30 | 1.84 | 0.31 | 2.34 | 3.26 | 1.33E-03 | 2.34 | 3.26 |
| 18 | 1.63 | 2.28 | 0.34 | 2.93 | 4.03 | 1.46E-03 | 2.94 | 4.03 |
| 19 | 0.78 | 1.37 | 0.11 | 1.40 | 2.43 | 4.73E-04 | 1.40 | 2.43 |
| 20 | 0.87 | 1.44 | 0.09 | 1.57 | 2.55 | 3.70E-04 | 1.57 | 2.55 |
| 21 | 0.93 | 1.60 | 0.06 | 1.67 | 2.84 | 2.71E-04 | 1.67 | 2.84 |
| 22 | 0.88 | 1.49 | 0.07 | 1.58 | 2.64 | 2.88E-04 | 1.58 | 2.64 |
| 23 | 0.79 | 1.29 | 0.08 | 1.42 | 2.29 | 3.48E-04 | 1.42 | 2.29 |
| 24 | 1.04 | 1.96 | 0.06 | 1.87 | 3.47 | 2.54E-04 | 1.87 | 3.47 |
| 25 | 1.20 | 2.28 | 0.02 | 2.16 | 4.03 | 9.03E-05 | 2.16 | 4.03 |
| 26 | 0.78 | 1.49 | 0.02 | 1.40 | 2.64 | 9.89E-05 | 1.40 | 2.64 |
| 27 | 0.68 | 1.34 | 0.03 | 1.22 | 2.37 | 1.42E-04 | 1.22 | 2.37 |
| 28 | 0.69 | 1.32 | 0.05 | 1.24 | 2.34 | 2.11E-04 | 1.24 | 2.34 |
| 29 | 0.98 | 1.39 | 0.11 | 1.76 | 2.47 | 4.73E-04 | 1.76 | 2.47 |
| 30 | 0.65 | 1.10 | 0.04 | 1.17 | 1.94 | 1.68E-04 | 1.17 | 1.94 |
| 31 | 7.01 | 1.20 | 0.05 | 12.6 | 2.12 | 2.28E-04 | 12.6 | 2.12 |
| 32 | 0.67 | 1.18 | 0.16 | 1.21 | 1.97 | 6.88E-04 | 1.21 | 1.97 |
| 33 | 0.94 | 1.23 | 0.11 | 1.69 | 2.54 | 4.73E-04 | 1.69 | 2.54 |

Notes : (1) Radiological Contaminants of Concern including $^{226}$Ra and $^{90}$Sr
(2) Total Effective Dose Equivalent
(3) $^{214}$Bi ($^{226}$Ra) approximated measurement of $^{226}$Ra based on $^{214}$Bi measured in the field and the observed ratio $^{226}$Ra & $^{214}$Bi measured by the Offsite Laboratory.
(4) $^{226}$Ra pCi/g data measured in the field using the 186 KeV (kiloelectronvolt) energy spectrograph line.
(5) Total Effective Dose Equivalent for RCOCs using $^{214}$Bi ($^{226}$Ra) and $^{90}$Sr
(6) Total Effective Dose Equivalent for RCOCs using $^{226}$Ra and $^{90}$Sr

**Table 7.4-1 Survey Unit Risk Calculations**

| SU | TEDE[1] mrem/yr | | | RCOC Risk[2] | | | Total Risk | |
|---|---|---|---|---|---|---|---|---|
| | $^{214}Bi$ ($^{226}Ra$)[3] | $^{226}Ra$[4] | $^{90}Sr$ | $^{214}Bi$ ($^{226}Ra$) | $^{226}Ra$ | $^{90}Sr$ | A[5] | B[6] |
| 01 | 1.15 | 2.09 | 8.60E-05 | 1.06E-06 | 1.93E-06 | 5.16E-13 | 1.06E-06 | 1.93E-06 |
| 02 | 1.66 | 2.18 | 3.66E-05 | 1.53E-06 | 2.01E-06 | 2.20E-13 | 1.53E-06 | 2.01E-06 |
| 03 | 1.31 | 2.03 | 1.99E-04 | 1.21E-06 | 1.88E-06 | 1.19E-12 | 1.21E-06 | 1.88E-06 |
| 04 | 1.80 | 2.21 | 8.46E-04 | 1.66E-06 | 2.04E-06 | 5.08E-12 | 1.66E-06 | 2.04E-06 |
| 05 | 1.48 | 2.55 | 1.29E-04 | 1.36E-06 | 2.34E-06 | 7.74E-13 | 1.36E-06 | 2.34E-06 |
| 06 | 1.46 | 2.17 | 2.87E-04 | 1.34E-06 | 1.99E-06 | 1.72E-12 | 1.34E-06 | 1.99E-06 |
| 07 | 1.31 | 1.92 | 3.53E-04 | 1.21E-06 | 1.77E-06 | 2.12E-12 | 1.21E-06 | 1.77E-06 |
| 08 | 1.28 | 1.89 | 3.54E-03 | 1.18E-06 | 1.74E-06 | 2.12E-11 | 1.18E-06 | 1.74E-06 |
| 09 | 1.39 | 1.71 | 8.43E-04 | 1.28E-06 | 1.57E-06 | 5.06E-12 | 1.28E-06 | 1.57E-06 |
| 10 | 1.62 | 2.15 | 8.17E-04 | 1.49E-06 | 1.98E-06 | 4.90E-12 | 1.49E-06 | 1.98E-06 |
| 11 | 2.34 | 6.05 | 4.31E-03 | 2.15E-06 | 5.56E-06 | 2.59E-11 | 2.15E-06 | 5.56E-06 |
| 12 | 2.88 | 4.08 | 3.23E-03 | 2.65E-06 | 3.75E-06 | 1.94E-11 | 2.65E-06 | 3.75E-06 |
| 13 | 2.57 | 3.30 | 6.02E-03 | 2.36E-06 | 3.03E-06 | 3.61E-11 | 2.36E-06 | 3.03E-06 |
| 14 | 3.67 | 3.64 | 1.25E-02 | 3.38E-06 | 3.35E-06 | 7.50E-11 | 3.38E-06 | 3.35E-06 |
| 15 | 3.74 | 4.65 | 7.31E-02 | 3.44E-06 | 4.28E-06 | 4.39E-10 | 3.44E-06 | 4.28E-06 |
| 16 | 2.52 | 2.98 | 4.26E-03 | 2.32E-06 | 2.74E-06 | 2.56E-11 | 2.32E-06 | 2.74E-06 |
| 17 | 2.34 | 3.26 | 1.33E-03 | 2.15E-06 | 3E-06 | 7.98E-12 | 2.15E-06 | 3.00E-06 |
| 18 | 2.93 | 4.03 | 1.46E-03 | 2.70E-06 | 3.71E-06 | 8.76E-12 | 2.70E-06 | 3.71E-06 |
| 19 | 1.40 | 2.43 | 4.73E-04 | 1.29E-06 | 2.24E-06 | 2.84E-12 | 1.29E-06 | 2.24E-06 |
| 20 | 1.57 | 2.55 | 3.70E-04 | 1.44E-06 | 2.34E-06 | 2.22E-12 | 1.44E-06 | 2.34E-06 |
| 21 | 1.67 | 2.84 | 2.71E-04 | 1.54E-06 | 2.62E-06 | 1.63E-12 | 1.54E-06 | 2.62E-06 |
| 22 | 1.58 | 2.64 | 2.88E-04 | 1.45E-06 | 2.42E-06 | 1.73E-12 | 1.45E-06 | 2.42E-06 |
| 23 | 1.42 | 2.29 | 3.48E-04 | 1.31E-06 | 2.11E-06 | 2.09E-12 | 1.31E-06 | 2.11E-06 |
| 24 | 1.87 | 3.47 | 2.54E-04 | 1.72E-06 | 3.19E-06 | 1.52E-12 | 1.72E-06 | 3.19E-06 |
| 25 | 2.16 | 4.03 | 9.03E-05 | 1.99E-06 | 3.71E-06 | 5.42E-13 | 1.99E-06 | 3.71E-06 |
| 26 | 1.40 | 2.64 | 9.89E-05 | 1.29E-06 | 2.43E-06 | 5.93E-13 | 1.29E-06 | 2.43E-06 |
| 27 | 1.22 | 2.37 | 1.42E-04 | 1.12E-06 | 2.18E-06 | 8.52E-13 | 1.12E-06 | 2.18E-06 |

**Table 7.4-1 Survey Unit Risk Calculations (Continued)**

| SU | TEDE[1] mrem/yr | | | RCOC Risk[2] | | | Total Risk | |
|---|---|---|---|---|---|---|---|---|
| | $^{214}$Bi ($^{226}$Ra)[3] | $^{226}$Ra[4] | $^{90}$Sr | $^{214}$Bi ($^{226}$Ra) | $^{226}$Ra | $^{90}$Sr | A[5] | B[6] |
| 28 | 1.24 | 2.34 | 2.11E-04 | 1.14E-06 | 2.15E-06 | 1.27E-12 | 1.14E-06 | 2.15E-06 |
| 29 | 1.76 | 2.47 | 4.73E-04 | 1.62E-06 | 2.27E-06 | 2.84E-12 | 1.62E-06 | 2.27E-06 |
| 30 | 1.17 | 1.94 | 1.68E-04 | 1.08E-06 | 1.79E-06 | 1.01E-12 | 1.08E-06 | 1.79E-06 |
| 31 | 12.6 | 2.12 | 2.28E-04 | 1.16E-05 | 1.95E-06 | 1.37E-12 | 1.16E-05 | 1.95E-06 |
| 32 | 1.21 | 1.97 | 6.88E-04 | 1.11E-06 | 1.81E-06 | 4.13E-12 | 1.11E-06 | 1.81E-06 |
| 33 | 1.69 | 2.54 | 4.73E-04 | 1.55E-06 | 2.33E-06 | 2.84E-12 | 1.55E-06 | 2.33E-06 |

Notes: (1) Total Effective Dose Equivalents for RCOC (radiological contaminants of concern)
(2) Calculated individual Risk for each RCOC
(3)Total Effective Dose Equivalent (TEDE) for $^{214}$Bi ($^{226}$Ra) where approximated measurement of $^{226}$Ra based on ($^{214}$Bi) onsite lab and the observed ratio $^{226}$Ra & $^{214}$Bi measured in the offsite lab.
(4)TEDE of $^{226}$Ra using data measured in the field and the 186 KeV (kiloelectronvolt) energy line.
(5) Total Risk for RCOCs using $^{214}$Bi ($^{226}$Ra) and $^{90}$Sr
(6) Total Risk for RCOCs using $^{226}$Ra and $^{90}$Sr

The total risk is less than $1.2x10^{-06}$ in 32 of the 33 SUs. The maximum total risk of $1.16x10^{-05}$ is found in SU 31 at the Sea Launch Facility. The elevated risk at SU 31 results from an area of elevated activity that was identified during the radiological assessment but where no radioactive items were identified and after subsequent soil sampling, the activity was not significantly reduced. The maximum $^{90}$Sr risk was reported in SU 15, where radioactive items were removed at locations 017 and 026.

## 8.0 Conclusions

This Report presents the methods, procedures, and results obtained during the Radiological Assessment at LBNC IR Sites 1 and 2, which supports the overall conclusion that IR Sites 1 and 2 are protective of Industrial Worker health and safety from surficial residual radioactivity. The investigation evaluated the nature and extent of residual radioactivity in shallow soil and groundwater at the SUs in the Former Athletic Field, Sea Launch, and Gull Park Sites and evaluated potential risks to industrial worker receptors from potential exposure to residual radioactivity in surface soils (the top foot of soil) and in groundwater at the Sites.

The only RCOPCs detected in soil during this Radiological Assessment were $^{226}$Ra and $^{90}$Sr. $^{226}$Ra and $^{90}$Sr were detected in soil at concentrations exceeding background and investigation levels, but below concentrations that would pose unacceptable risks to Industrial workers. The majority of the $^{226}$Ra and $^{90}$Sr exceedances were observed in the SUs comprising Area II (see Figure 1.2-1) of Gull Park. A total of 22 discreet items were identified (and removed) during the surveys, indicating that site conditions are not indicative of a LLRW disposal site, but rather indicative of isolated and/or inadvertent disposal occurring on this 33-acre site (i.e., radiological items were discovered at a frequency of less than one item per acre in the top foot of soil). These 22 items were placed in a barrel and were properly disposed at an appropriately licensed waste facility. Two separate evaluations were perform for total TEDE ($^{226}$Ra and $^{90}$Sr ) and risks for each SU based on results from gamma spectroscopy on soil samples; the first using $^{226}$Ra calculated using the onsite laboratory $^{214}$Bi peak as a surrogate (and adjusted for in-growth), and the second using the onsite laboratory $^{226}$Ra gamma peak measurements. Both evaluations provided the same conclusion that Sites 1 and 2 were protective of human health for the industrial worker.

### 8.1 Nature and Extent of Radioactivity

The vast majority of the radioactivity identified in shallow soil at IR sites 1 and 2 was associated with small, discrete radioactive items that were identified, removed, and properly disposed off-site. Radiological surveys were conducted over 100 percent of the accessible areas at the Sites, and therefore, included all surficial locations where potential receptors could potentially be exposed to radioactive contamination and receive a measurable dose. A total of 22 items were identified during this investigation; indicating that site conditions are not indicative of a LLRW disposal site, but rather of isolated and/or inadvertent disposal occurring on this 33-acre site (i.e., radiological items were discovered at a frequency of less than one item per acre in the top foot of soil). In all but one SU surface soil contamination was removed during sampling and or removal of point sources and confirmed by a resurvey with ISOCs. At SU 31 location 017 no point source was recovered this is also the SU concentration of $^{214}$Bi ($^{226}$Ra) was reported at 7.01 pCi/g.

All but two $^{90}$Sr samples exceeding the IL were in Gull Park SUs 11 through 16 which conform to Area II identified during the RI (Bechtel, 1996). Area II was also used during the RA (Battelle, 2006) as a staging and laydown area during the excavation performed in Area III (see Figure 1.2-1). A large area of dispersed elevated gamma activity was identified in Area III which does not appear to be due to radioactive contamination and has been attributed to the imported backfill used during remedial activities in 2000-2001 to remove VOC contaminants. All of the radionuclides in this area are naturally occurring, and the activity is distributed uniformly throughout surface and subsurface soil. The backfill in this area consisted of 60 percent imported

fill and 40 percent clean backfill from stockpiles generated from excavation activities (Battelle, 2006).

Although no radioactive items were found in the subsurface soils (deeper than 1 foot bgs) two locations reported elevated concentrations of $^{226}$Ra in soil at depths of 2 feet bgs where no radioactive items were identified: SU 6 location 017 in the Sea Launch Facility Area and SU 13 location 006 in Gull Park. These areas are inaccessible during normal industrial related site activities and do not contribute to exposure, dose, or risk at the Site. However, restrictions preventing uncontrolled exposure in areas where radioactivity may be encountered are already in place in the form of lease restrictions, together with restrictions on any intrusive soil disturbance activities to ensure that soils from Sites 1 and 2 are managed properly. This includes exposed soils and soils beneath buildings and hardscape (asphalt and concrete) located on the property. Surface soil, asphalt, and concrete act as barriers and shields to reduce exposure from subsurface soil to insignificant levels at the sites. Any disturbance of the surface materials could result in potential exposures to radioactive material in subsurface soil, and additional permanent controls may be evaluated to the extent the land use controls in the existing ROD for Sites 1 and 2 are not deemed sufficiently protective in the long-term.

### *8.1.1 Groundwater Sampling Results*

A total of seven groundwater samples were collected from existing monitoring wells around the perimeter of the LBNC. The results from groundwater samples were compared directly to the ILs listed in Table 2.4-1; none of the results exceeded any of the project ILs. Four $^{90}$Sr results exceeded the MDC and two $^{239/240}$Pu results exceeded the MDC. The $^{90}$Sr result for sample MW 1-16 at 13 pCi/L was closest to an IL of 500 pCi/L.

### *8.1.2 Subsurface Soil Sampling Results*

A total of 37 subsurface soil samples were collected for characterization purposes only from 33 sampling locations at IR Sites 1 and 2. The RCOCs in subsurface soil are the same as those identified in surface soil; $^{226}$Ra and $^{90}$Sr. Three subsurface soil samples exceeded the IL for $^{226}$Ra. None of the $^{90}$Sr results exceeded the project IL; however, three samples reported results exceeding the MDC. These results indicate that with the exception of two locations where investigation results exceeded the IL, subsurface soil has not been impacted by radiological releases from activities at the Sites.

### *8.1.3 Human Health Dose and Risk*

Sufficient data were collected from 33 SUs to evaluate the potential risk and dose to receptors, under an industrial worker scenario, from potential exposure to residual radioactivity in surface soil and groundwater at IR Sites 1 and 2. The maximum potential total dose was estimated were 12.6 mrem/yr, in SU 31 using $^{214}$Bi ($^{226}$Ra) and 6.05 mrem/yr at SU11 when using the $^{226}$Ra onsite laboratory data, which are less than the regulatory limit of 25 mrem/yr. The total potential risk in SU 31 was estimated at $1.16 \times 10^{-05}$ when using and $5.56 \times 10^{-06}$ at SU 11. After reviewing field and lab analytical data as well as evaluation against the investigation levels and residual radioactivity the human health risk/dose assessment is acceptable. The investigative levels are risk/dose based below which no additional investigation regarding industrial worker scenario human health and risk will be required.

## 9.0 References

Battelle, 1999. *Feasibility Study for Installation Restoration Sites 1 and 2 Naval Station Long Beach, Long Beach, California,* Final, February 1999.

Battelle, 2000. *Record of Decision for Installation Restoration Sites 1 and 2, Naval Station Long Beach, Long Beach, California,* Final, June 2000.

Battelle, 2001. *Radiation Data Summary Report for Installation Restoration Sites 1 and 2, Long Beach Naval Complex, Long Beach California, Battelle Memorial Institute and Foster Wheeler Environmental Corporation,* Final, September 24, 2001.

Battelle, 2004. *Five-Year Review Report for Installation Restoration Sites 1-6A and 14 at Long Beach Naval Complex and OU-1 Former Palos Verdes Navy Housing*. December 2004.

Battelle, 2006. *Phase I Remedial Action, Soil and Debris Removal for Installation Restoration Sites 1 and 2 At Former Naval Station Long Beach Long Beach, California*. March 2006.

Bechtel, 1994a. *Comprehensive Baseline Survey (EBS) Naval Station Long Beach California,* Final. March 31, 1994.

Bechtel, 1994b. *Risk Assessment Work Plan Remedial Investigation/Feasibility Study, Sites 1, 2, 3, 4, 5, 6A and 7, Naval Station Long Beach California,* Final. September 30, 1994.

Bechtel, 1996. *Remedial Investigation (RI) Report, Installation Restoration Program for Sites 1 through 6A, Naval Station Long Beach, Long Beach, California*, Final. July 10, 1996.

Cabrera Services, Inc., 2008. *Final: Sampling and Analysis Plan for the Supplemental Radiological Assessment of Installation Restoration Sites 1 and 2 at the Long Beach Naval Complex Long Beach, California*. August 2008.

Digital, 1998. *Decommissioning Radiological Survey and Remediation Report for Long Beach Naval Complex*, Digital Systems International Corporation and Supervisor of Shipbuilding, Portsmouth, Virginia, Environmental Detachment, Vallejo, California, for NAVSEA 07R, Final, February 1998.

DOE, 2001. *User's Manual for RESRAD Version 6*. ANL/EAD-4. U.S. Department of Energy, Argonne National Laboratory. July 2001.

EPA, 2000. *Soil Screening Guidance for Radionuclides: User's Guide*, 540-R-00-007, U.S. Environmental Protection Agency, October 2000.

ICRP, 1983. *International Commission on Radiological Protection (ICRP) Publication 38, data sources, Radionuclide Transformations*.

LBNSY, 1997. *Historical Radiological Assessment (HRA),* Long Beach Naval Shipyard, Environmental Protection Division, Draft, August 1997.

MARSSIM, 2002. *Multi-Agency Radiation Survey and Site Investigation Manual. U.S. Environmental Protection Agency, U.S. Department of Defense, U.S. Department of Energy, U.S. Nuclear Regulatory Commissio*n, Revision 1. August 2002.

NEESA, 1983. *Initial Assessment Study of Naval Complex, Long Beach, California*, Naval Energy and Environmental Support Activity, August 1983.

NRC, 1999. "*Supplemental Information on the Implementation of the Final Rule on Radiological Criteria for License Termination*", 64 FR 68395, U.S. Nuclear Regulatory Commission, December 7, 1999.

SWRCB, 2005. *Water Quality Control Plan, Ocean Waters of California, California Ocean Plan*, State Water Resources Control Board, California Environmental Protection Agency, 1997.

# Figures

This Page Left Intentionally Blank


**Figure 1.0-1 Site Location Map**

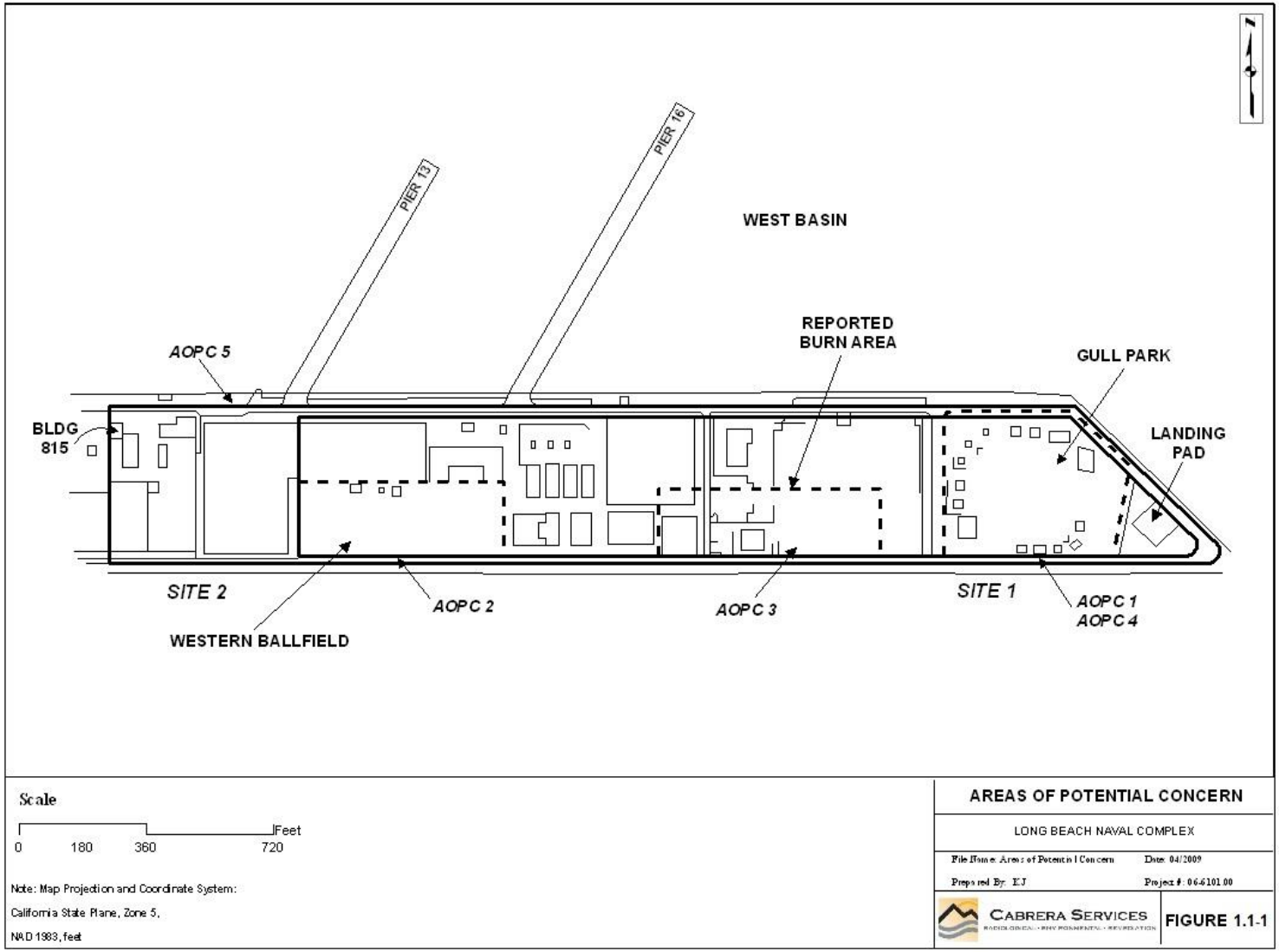


**Figure 1.1-1 Areas of Potential Concern**

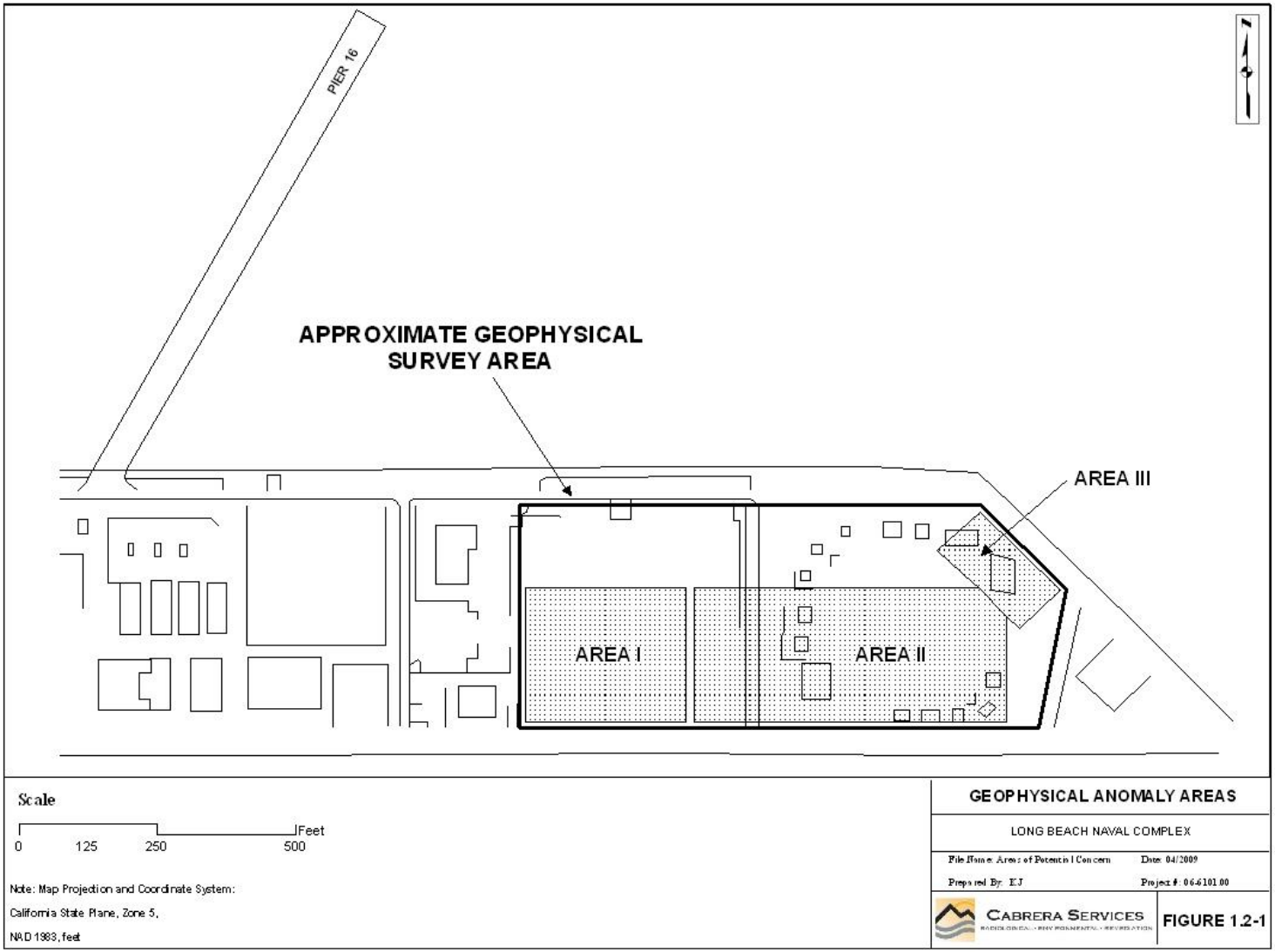


**Figure 1.2-1 Geophysical Anomaly Areas**

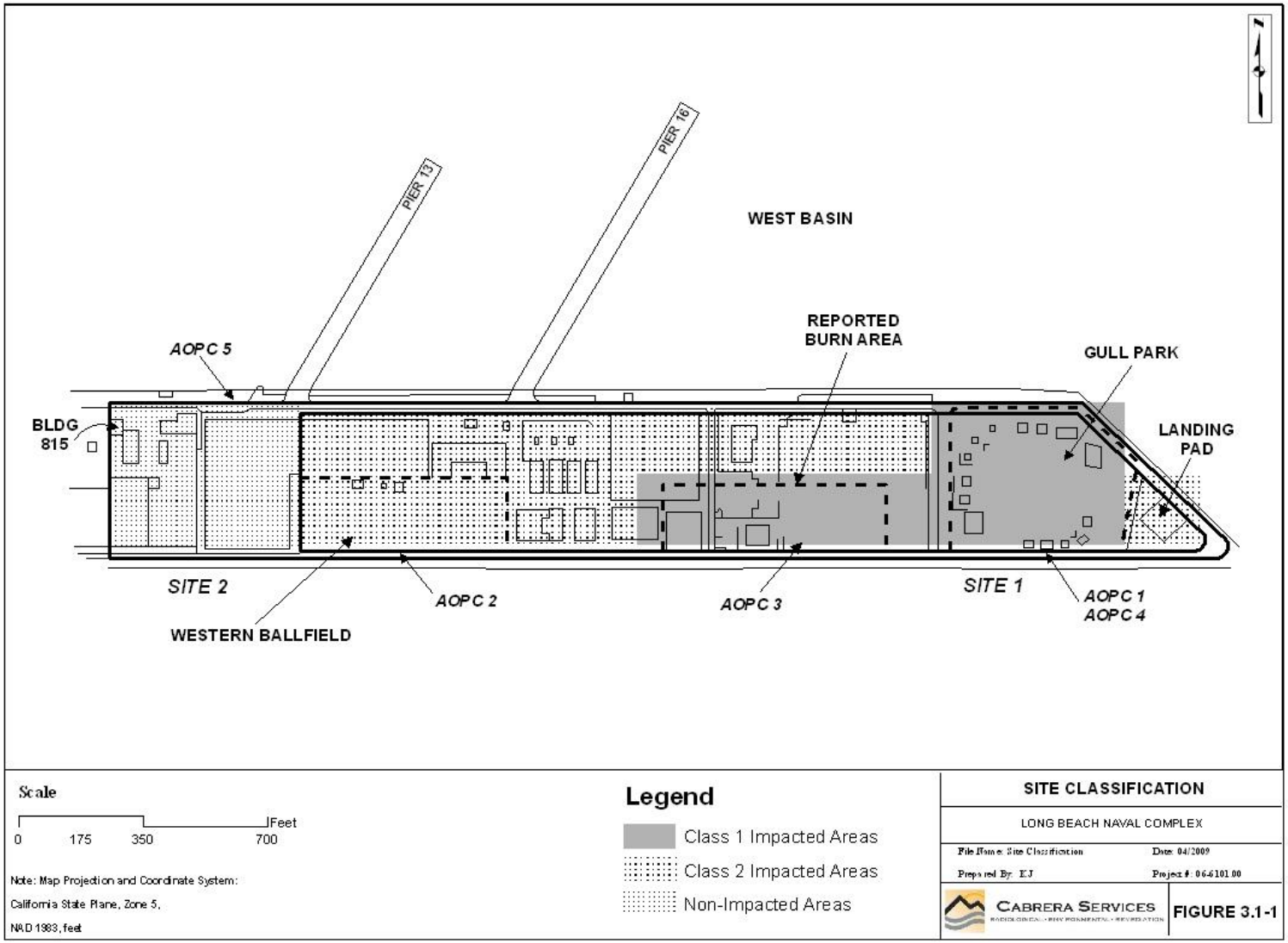


**Figure 3.1-1 Site Classification**

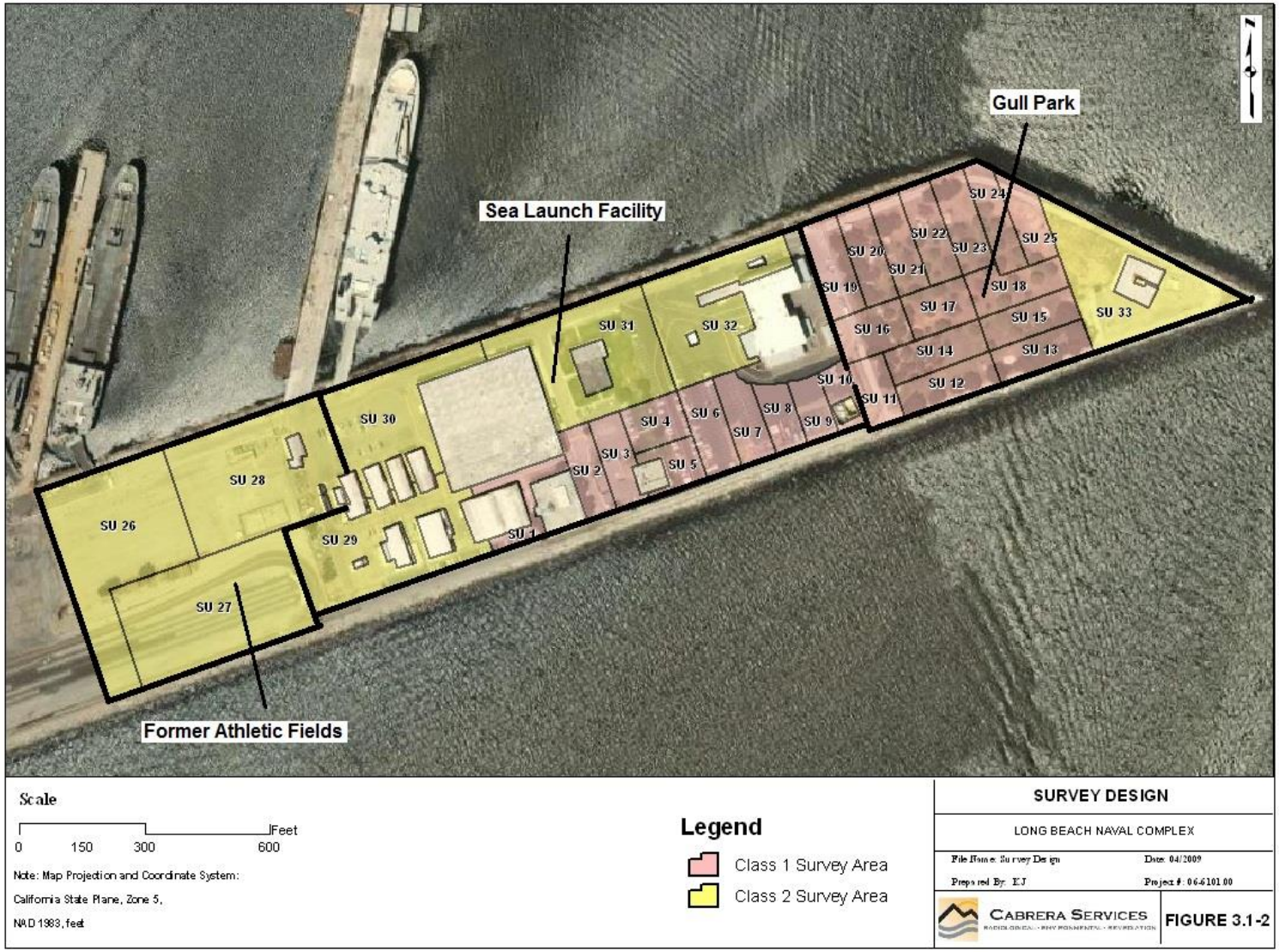


**Figure 3.1-2 Survey Design**

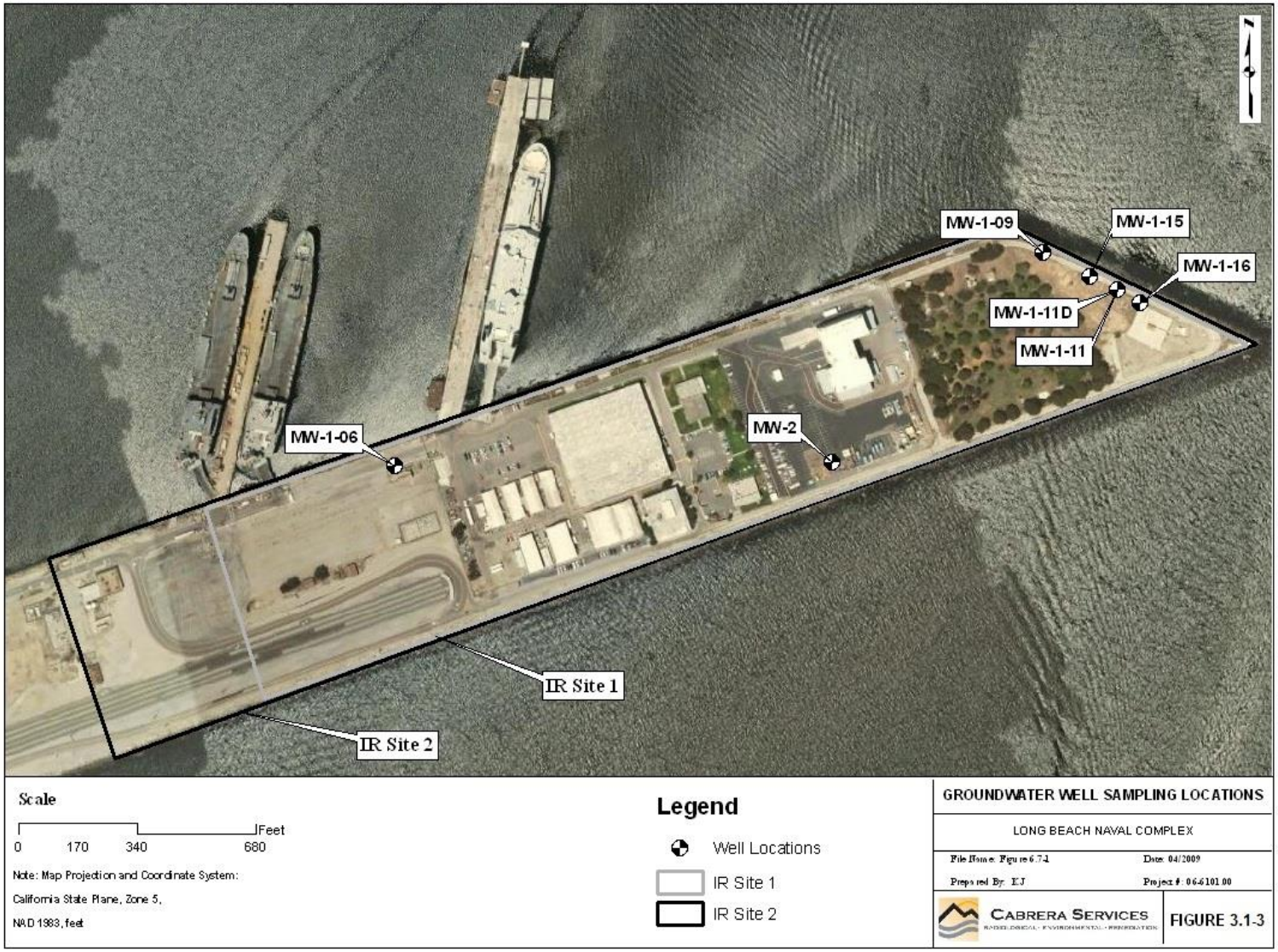


**Figure 3.1-3 Groundwater Well Sample Locations**

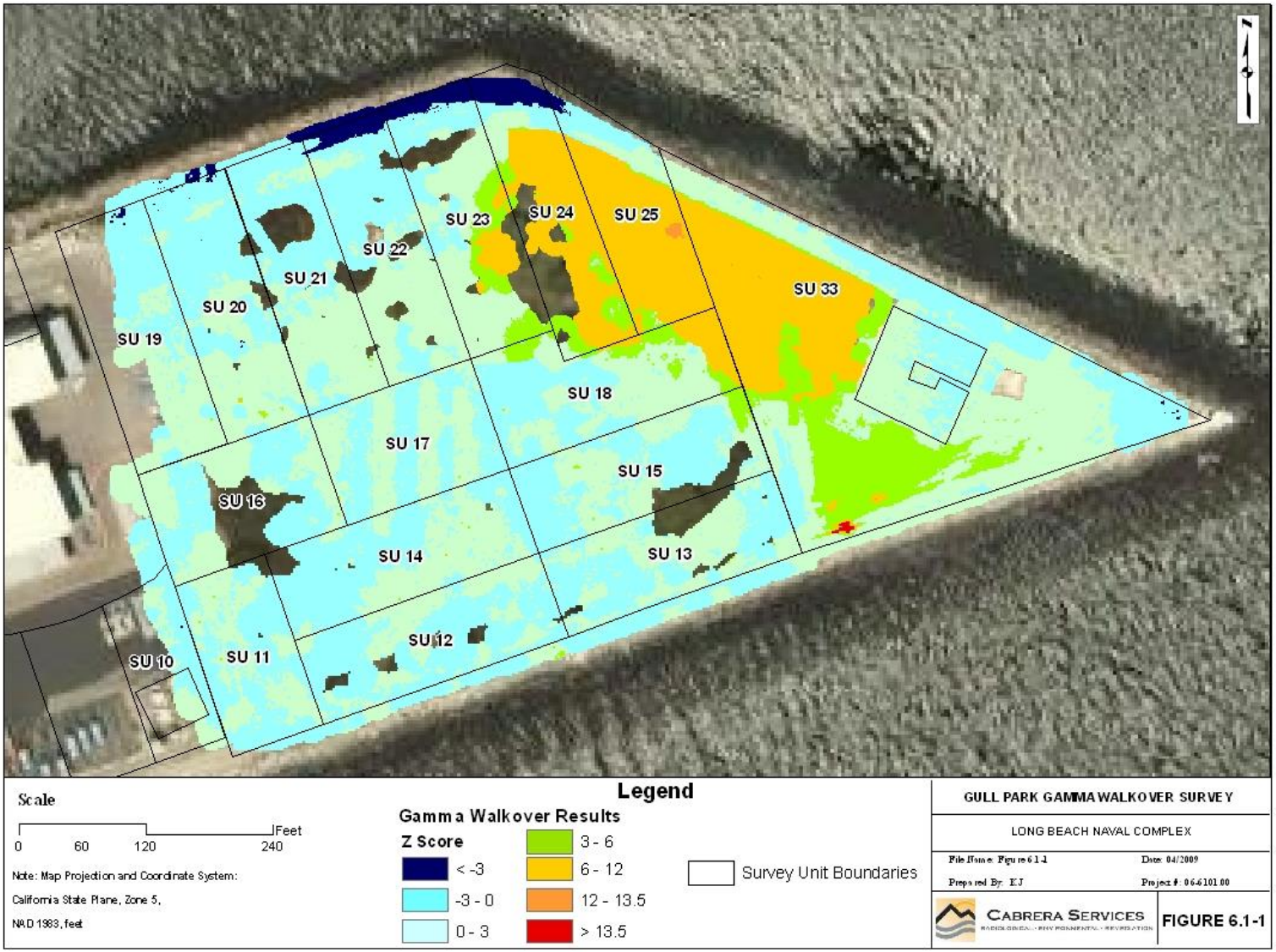


**Figure 6.1-1 Gull Park GWS Results**

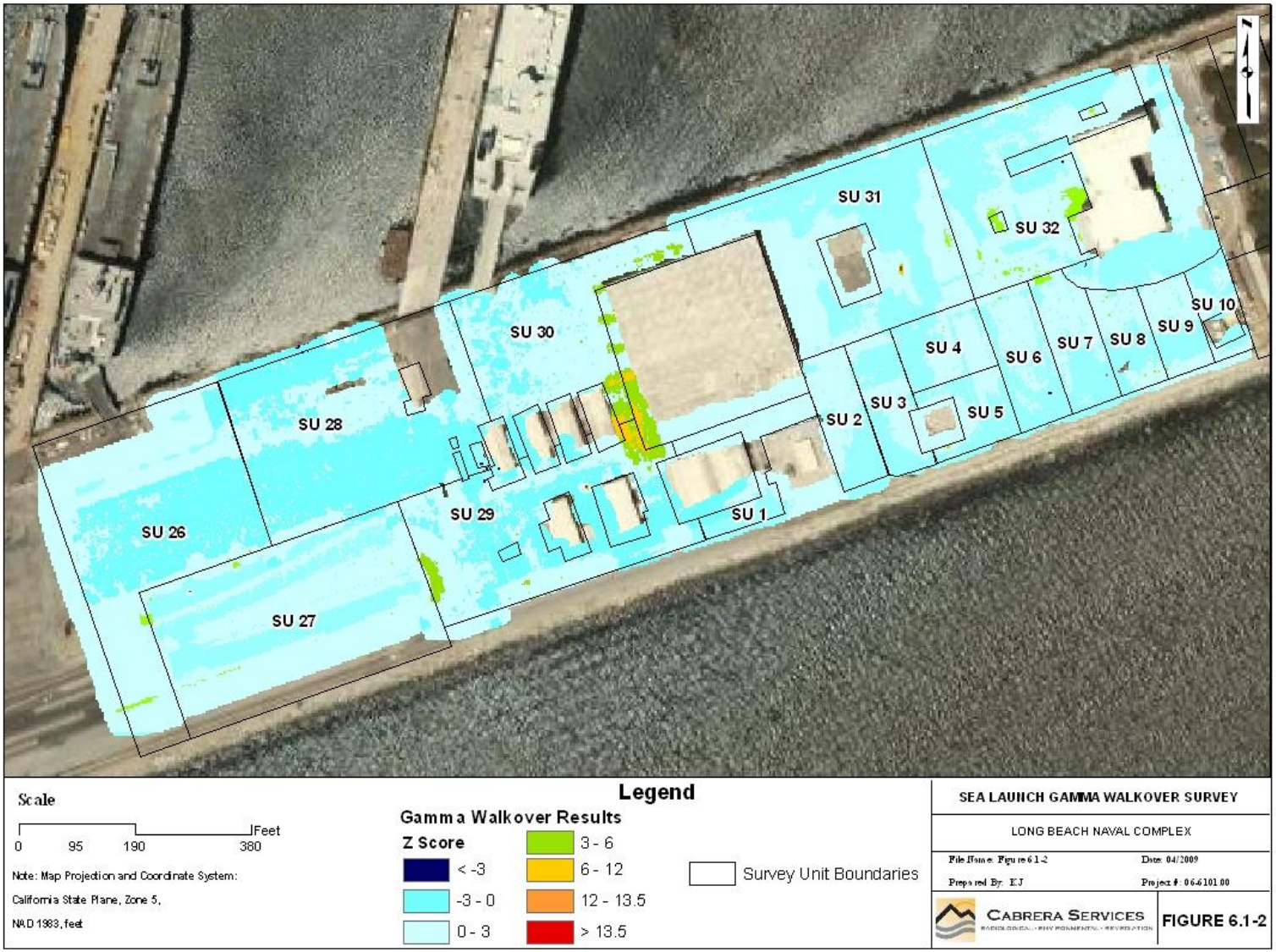


**Figure 6.1-2 Former Athletic Field and Sea Launch GWS Results**

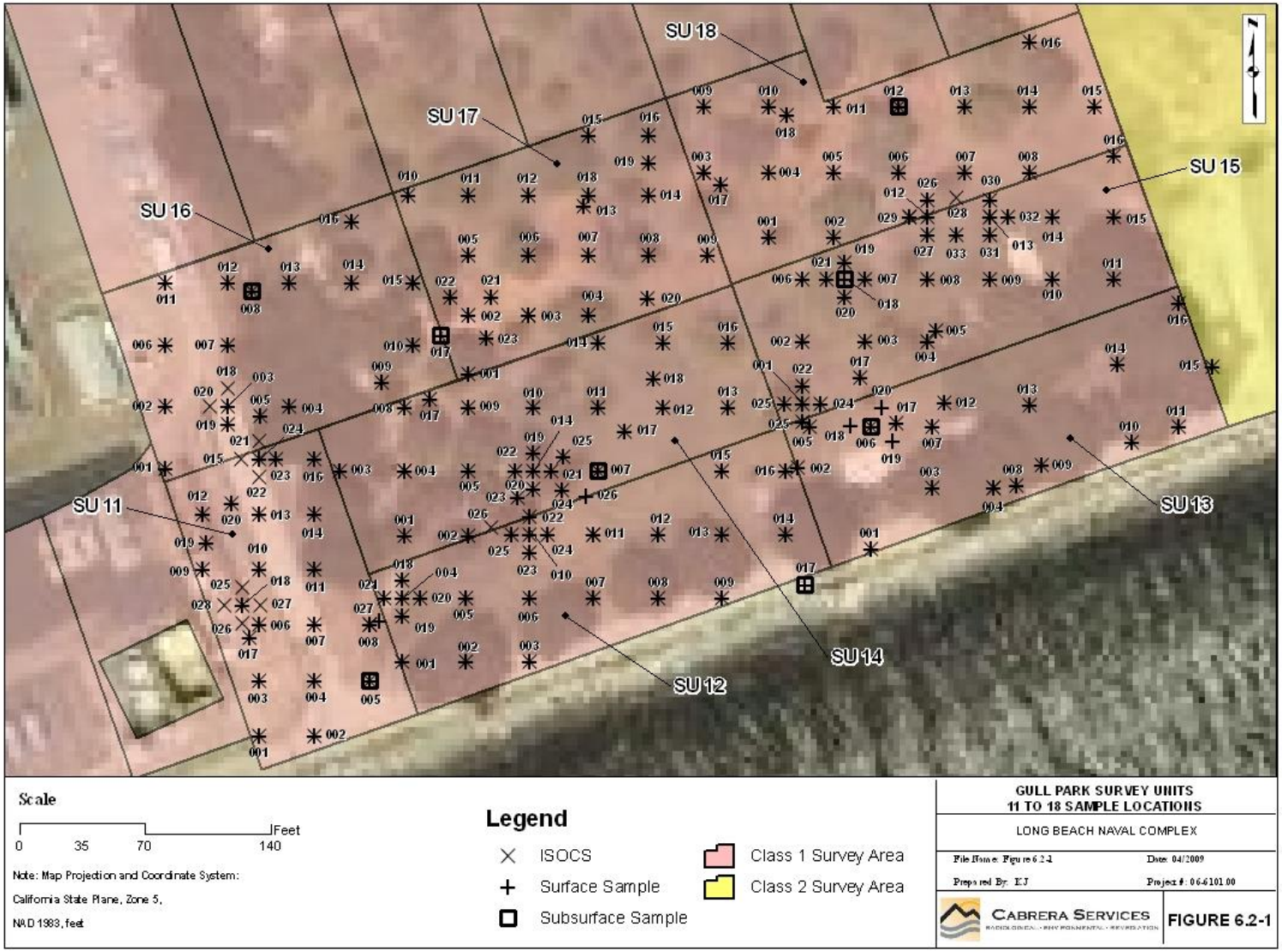


**Figure 6.2-1 Gull Park Sample Locations in SU 11 through 18**

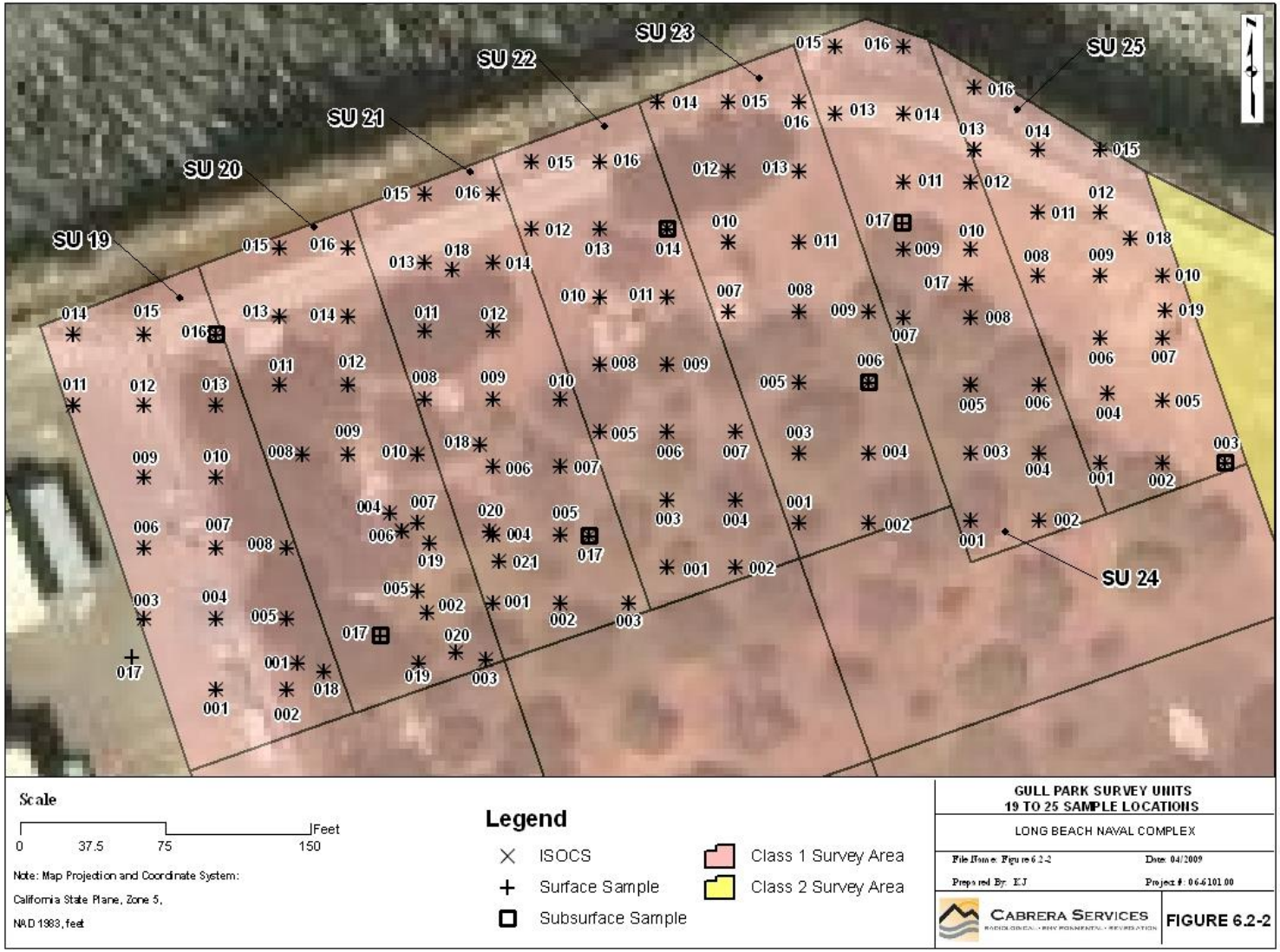


**Figure 6.2-2 Gull Park Sample Locations in SU 19 through 25**

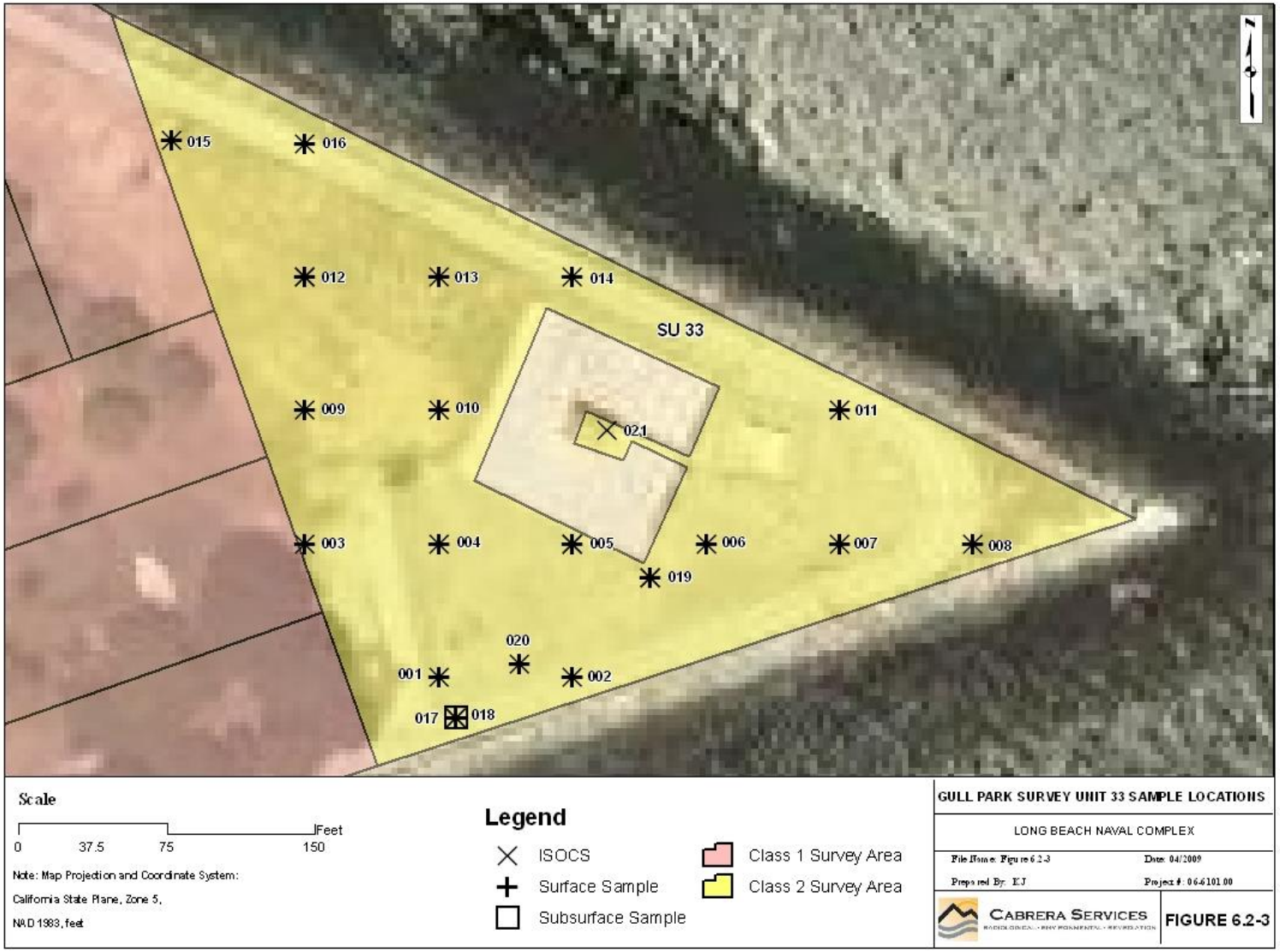


**Figure 6.2-3 Gull Park Sample Locations in SU 33**

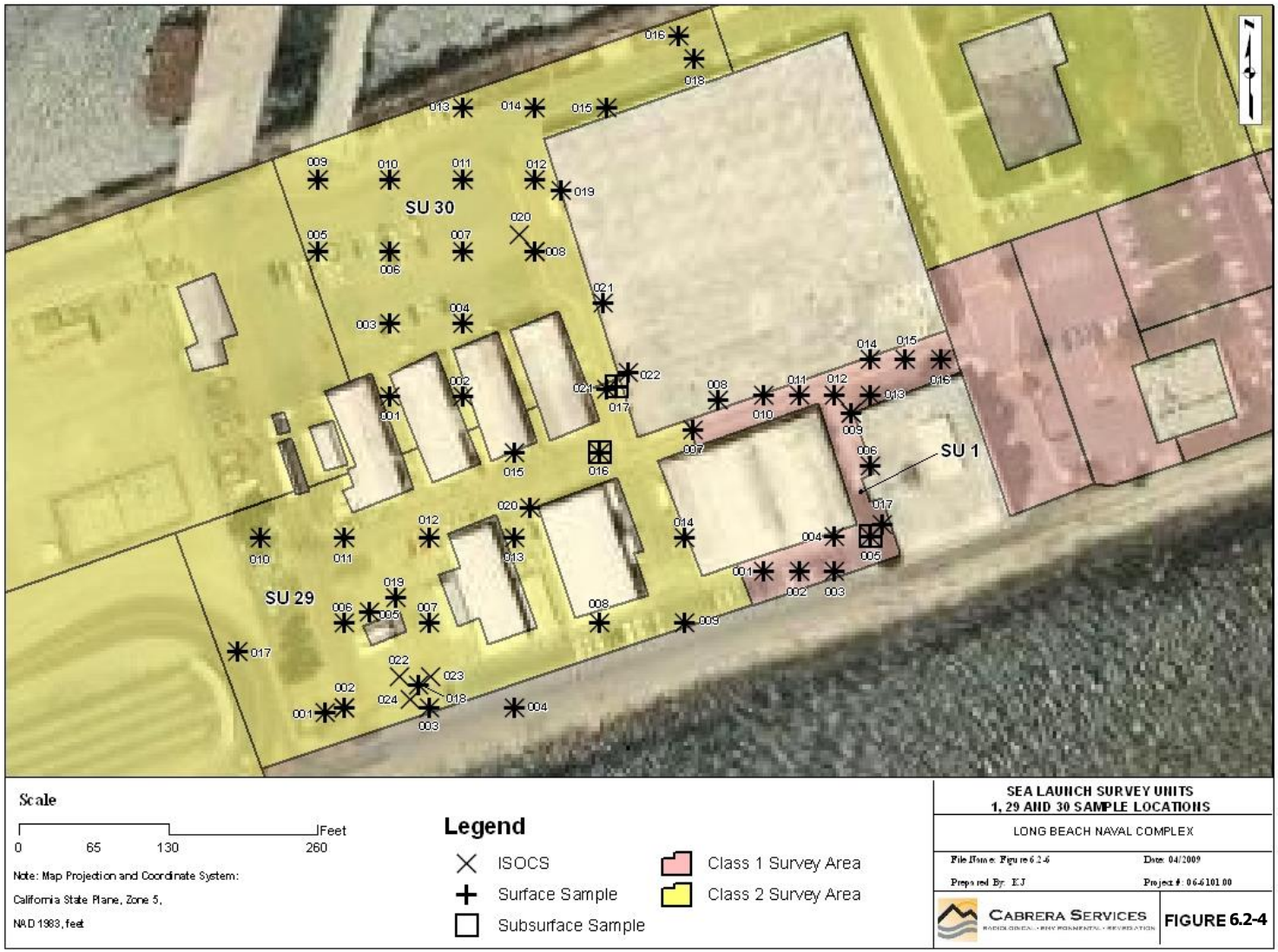


**Figure 6.2-4 Sea Launch Facility Sample Locations in SU 01, SU 29 and SU 30**


Note Sample location 018 located in SU 8 is part of the data set for SU 9 that in the field was believed to be SU 9 and later determined to be physically located in SU 8.

**Figure 6.2-5 Sea Launch Facility Sample Locations in SU 2 through 10**


**Figure 6.2-6 Sea Launch Facility Sample Locations in SU 31 and SU 32**

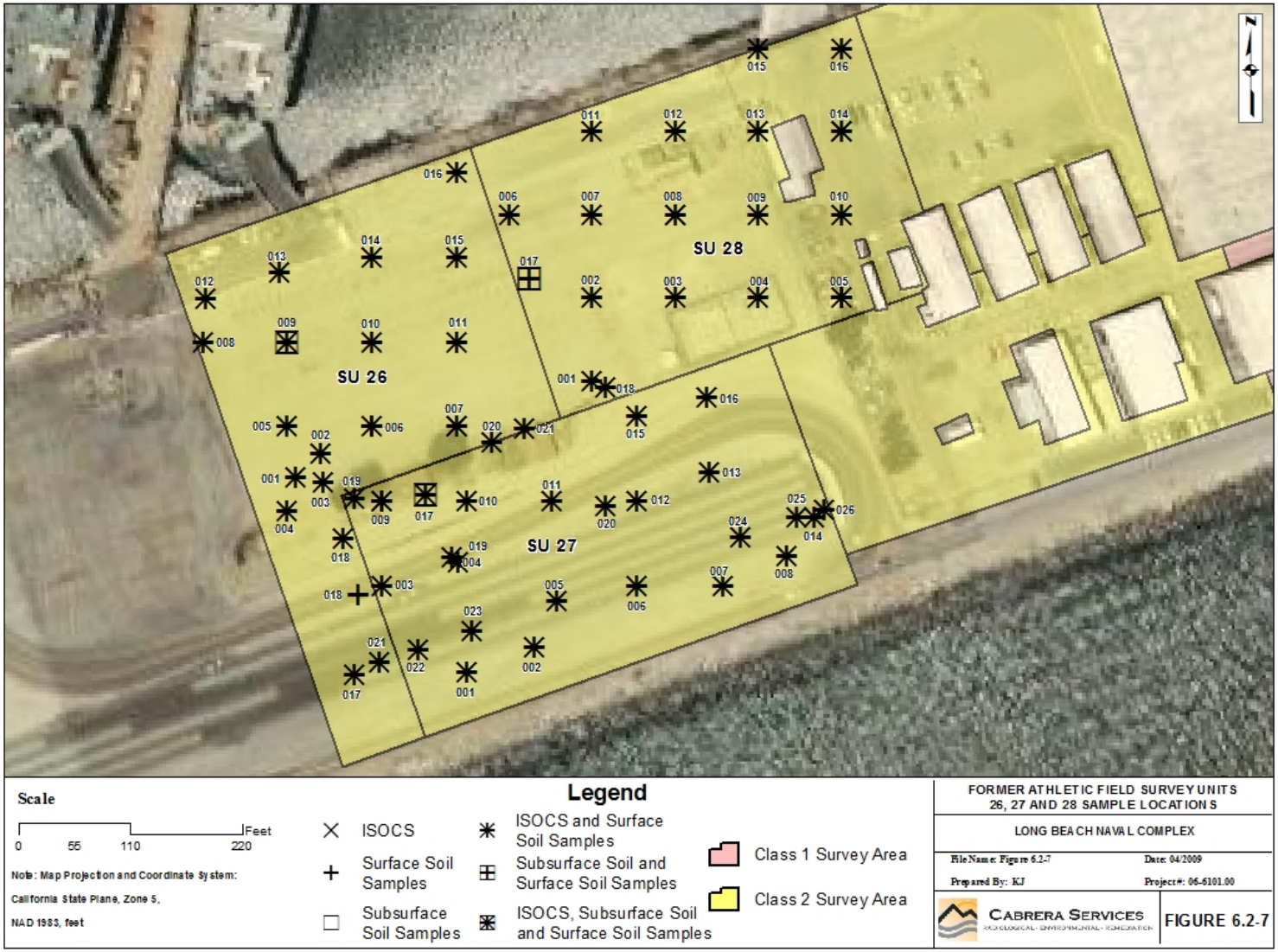


**Figure 6.2-7 Former Athletic Field Sample Locations in SU 26 through SU 28**


**Figure 6.4-1 Locations of Articles (Point Sources) Found in Survey Units**

# Appendix A
# Instrumentation Inventory
# (on CD)

This Page Left Intentionally Blank

# Appendix B
# Instrument Calibration Documentation
# (on CD)

This Page Left Intentionally Blank

# Appendix C
# Quality Control and Quality Assurance Analysis
# (on CD)

This Page Left Intentionally Blank

# Appendix D
# Dose Modeling Report
# (on CD)

This Page Left Intentionally Blank

# Appendix E

## Electronic Data Files (Disk 1 through 5 on CD)

**Disk 1:** a) Borehole Log Sheets
b) Offsite, Onsite, ISOCS™, and Subsurface Raw Data
c) Photographs and Photo Log
d) QC Charts
e) Sample Logs
f) Smear Results
g) Standard Operating Procedures (SOPs)

**Disk 2:** Survey Unit Exploratory Data Analysis (EDAs) Data Files

**Disk 3:** Electronic Data Delivery (EDD) Files Part 1

**Disk 4:** EDD Files Part 2

**Disk 5:** EDD Files Part 3

This Page Left Intentionally Blank

# Appendix F

## Response to Regulatory Review Comments
## Draft Supplemental Radiological Assessment of
## Installation Restoration Sites 1 and 2 Long Beach Naval Complex
## June 2009
## (on CD)

This Page Left Intentionally Blank