FINAL REPORT

Radiological Remediation and Final Status Survey
Former Monazite Sand Storage Area

Naval Station Great Lakes – Great Lakes, Illinois

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EXECUTIVE SUMMARY

Cabrera Services, Inc. (CABRERA), under contract to the United States (U.S.) Army Joint Munitions Command (JMC), performed characterization, remediation, and final status survey (FSS) activities within the remaining areas of the former Monazite Sand Storage Area (FMSSA) at the Naval Station Great Lakes in Great Lakes, Illinois, hereafter referred to as the 'Site'. The Site is shown in the Site Location Map presented as Figure 1.

Field work performed during the 2007 calendar year was performed under previously prepared CABRERA work plans entitled, *Work Plan for the Characterization of the Recreation and Center Tank Areas and Radiological Remediation and Final Status Survey of the North Fence Area* (CABRERA, 2004b), *Work Plan for the Remediation of the Recreation and Center Tank Areas and Site Wide Final Status Survey* (CABRERA, 2004d), and *Public Private Venture Area Remediation Addendum* to *Work Plan for the Remediation of the Recreation and Center Tank Areas and Site Wide Final Status Survey* (CABRERA, 2007a). These Work Plans governed all field activities performed during this project. All activities were performed under the oversight of Naval Sea Systems Command Detachment (NAVSEADET) Radiological Affairs Support Organization (RASO).

The field activities described herein were performed concurrently with the remediation field activities within the Public Private Venture (PPV) area of the site. However, the results and conclusions discussed in this report only apply to the Former Monazite Sand Storage Area. The PPV area requires additional work to be completed and therefore results for these areas will be provided under separate cover. The FMSSA includes survey units (SU) 1, 2, 3, 4, 5 as shown on Figure 2, as well as SUs 17 and 18 (the latter two for the former soil stockpile).

Project activities performed during the most recent mobilization included:

- Gamma Walkover Surveys (GWS) in all accessible areas;
- Direct-push soil coring and downhole gamma logging (DGL);
- Surface and subsurface soil sampling at systematic and biased locations;
- On-site laboratory soil preparation and gamma spectroscopy analyses;
- Development and submission of site-specific derived concentration guideline level (DCGL) document for the Site. This document was approved by NRC Region 3 and thus allowed a 4 picoCuries per gram (pCi/g) Thorium-232 (^{232}Th) DCGL to be used henceforth;
- Excavation and remediation of Site soils containing ^{232}Th greater than the DCGL, including the soil stockpile remaining from remediation activities in the former monazite sand storage area performed in 2004. The stockpile was leveled with a *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM) (U.S. Nuclear Regulatory Commission [NRC], 2000) FSS performed in two sequential 1-foot lifts;
- Packaging and shipment of 102 tons of impacted excavated soils;
- Performance of a post-remediation, MARSSIM FSS within each SU.

- Site restoration activities, including backfill of completed excavation areas.

Soils exceeding the DCGL of 4 pCi/g ^{232}Th were packaged in 10 cubic yard (cy) soft-sided containers, (i.e., super-sacks). Each super-sack was found to hold approximately 8.5 tons of soil. The super-sacks were temporarily stored on-site, then transported to a nearby railhead in Kenosha, Wisconsin, where the containers were transloaded into gondola railcars. The wastes were profiled for disposal at the Waste Control Specialists (WCS) facility in Andrews, Texas, as unimportant quantities of source material (less than 0.05% by weight, or equivalent to 55 pCi/g of ^{232}Th). The highest concentration of ^{232}Th identified in these soils was 32 pCi/g.

FSS activities consisted of a 100% GWS and sample collection and analysis. Systematic and biased sampling consisted of soil sampling from 120 locations, with samples obtained via a direct-push rig with a macrocore sampler or through surface sampling methods.

All FSS sample results were shown to be below the Site DCGL of 4.0 pCi/g. The FSS data indicate that the Site is suitable for release for unrestricted use.

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ACRONYMS AND ABBREVIATIONS

^{228}Ac	actinium-228
AEC	Atomic Energy Commission
CABRERA	Cabrera Services, Inc.
CFR	Code of Federal Regulations
^{109}Cd	cadmium-109
^{60}Co	cobalt-60
cpm	counts per minute
^{137}Cs	cesium-137
cy	cubic yard
DCGL	Derived Concentration Guideline Level
DGL	Downhole Gamma Logging
DoD	Department of Defense
DOT	U.S. Department of Transportation
FMSSA	Former Monazite Sand Storage Area
FSS	Final Status Survey
g	gram
GM	Geiger-Mueller
GPS	Global Positioning System
GWS	Gamma Walkover Survey
HEPA	High-Efficiency Particulate Air
HPGe	High Purity Germanium
in	inch
JMC	U.S. Army Joint Munitions Command
keV	kiloelectron volt
m	meter
m/s	meters per second
MARLAP	Multi-Agency Radiological Laboratory Analytical Protocols
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDC	minimum detectable concentration
µR/h	microRoentgen per hour
NaI	sodium iodide
NIST	National Institute of Standards and Technology
NRC	U.S. Nuclear Regulatory Commission
NAVSEADET	Naval Sea Systems Command Detachment
PPV	Public Private Venture
pCi/g	picocurie per gram
QA	Quality Assurance
QC	Quality Control
^{226}Ra	radium-226
RASO	Radiological Affairs Support Office
ROC	Radionuclide(s) of Concern
SSSV	Surface Soil Screening Values
SSV	Soil Screening Values
SU	Survey Unit
TCLP	Toxicity Characteristic Leachate Procedure
^{232}Th	thorium-232
U.S.	United States
WAC	Waste Acceptance Criteria
WCS	Waste Control Specialists
Z_{Rep}	Z- Replicate

1.0 INTRODUCTION

Cabrera Services, Inc. (CABRERA) performed characterization, remediation, and Final Status Survey (FSS) activities within the Former Monazite Sand Storage Area (FMSSA) at the Naval Station Great Lakes in Great Lakes, Illinois (hereafter referred to as the Site). Activities during 2007 focused on areas of the Site requiring additional investigation, remediation, and FSS based on the results of the investigations performed in the 2003-2004 timeframe. These areas are referred to as survey units (SU) 1 through 5, 17, and 18 throughout this document. Remedial and survey activities were performed under contract to the US Army Joint Munitions Command (JMC) and the oversight of the US Navy's Naval Sea Systems Command Detachment (NAVSEADET) Radiological Affairs Support Organization (RASO).

1.1 Background

Monazite is a rare earth phosphate containing a variety of rare earth oxides particularly cerium and thorium oxide. Thorium has wide industrial applications and has been mined as monazite sand since the 1930's. In 1964, the Atomic Energy Commission (AEC) granted license #STC-133 to the General Services Administration authorizing the storage and repackaging, as necessary, to store and transfer uranium and thorium solids at specific locations, including the Naval Station in Great Lakes. While this license is still presently active, the inclusion of the Naval Station Great Lakes was terminated in April 1981. In 1974, the AEC granted license #STE-8179 to Engelhard Minerals & Chemicals Corporation, authorizing the package and shipment of a strategic pile of monazite sand from the Site. It is reported that this sand was shipped to Holland that same year. The AEC also granted license #SMC-1207, authorizing "Repackaging of monazite sands in U.S. Department of Transportation (DOT) approved containers." These operations were confined to the following locations: Savannah Army Depot, Savannah, Illinois; Army Ammunitions Plant, Ravenna, Ohio; and U.S. Navy Administrative Command, Supply Depot (currently referred to as Naval Station Great Lakes), Great Lakes, Illinois. This former AEC license indicated that 1,826,153 pounds of monazite sand containing 9.226% of thorium oxide was held at the Naval Station prior to shipment off-site. Records show that monazite sand was shipped to W.R. Grace & Company, Chattanooga, Tennessee. The sand was shipped from Great Lakes and Savannah, Illinois from early September through mid-October 1974; and from Ravenna from early November through mid-November 1974. There is limited information on the extent of residual contamination resulting from these operations. No records have been found indicating that a closeout survey of the monazite sand storage area (current Site) was conducted, prior to CABRERA'S efforts beginning in 2000.

1.2 Previous Site Activities

Nuclear Regulatory Commission (NRC) Region III conducted an inspection in January of 2000, and found several locations of elevated gamma activity on the north side of the former monazite sand storage area near the northern boundary. Surface exposure rates of 80 microRoentgen per hour (µR/h) were observed along the North Fence Area northern boundary. CABRERA was contracted by the Navy to assess the area.

On March 8, 2000, CABRERA performed a detailed characterization which identified several locations of elevated gamma activity, and by gamma spectroscopy, identified the presence of thorium-232 (^{232}Th). CABRERA characterized the area formerly known as Tank Farm #5. The Tank Farm was surveyed and surface soil samples were collected and analyzed for ^{232}Th. Gamma radiation levels above the ambient level were identified along the north fence line in locations between and surrounding tanks H, L, and K (see Figure 3). During the survey, six soil samples were collected from areas where elevated gamma radiation levels were observed. These samples were analyzed for ^{232}Th using gamma spectroscopy. Analytical results for the samples indicated that ^{232}Th concentrations ranged from 0.93 picocurie per gram (pCi/g) to 64.31 pCi/g, with an average activity concentration of approximately 17 pCi/g. CABRERA also performed FSS activities during 2000, and released the areas surrounding the warehouse Building 8012. These released SUs were part of the area referred to as the construction zone. FSSs recommending unrestricted/restricted release were accepted by the NRC.

During the 2003 characterization survey, soil samples were collected from the soil pile and North Fence Area to provide information regarding chemical contaminants that could affect disposal options. Laboratory analyses performed were in accordance with U.S. Ecology Waste Acceptance Criteria (WAC) requirements. These analyses included a toxicity characteristic leachate procedure (TCLP), total metals, mercury, semi-volatiles, volatiles, chlorinated herbicides, and organochlorine pesticides. The sample analytical results were below Title 40 Code of Federal Regulations (CFR) Part 261 land disposal limits, indicating that no hazardous chemical constituents were identified.

In 2004, CABRERA was contracted to remove the soil pile and characterize the remaining soils. The soil pile, prior to remedial activities, covered an area approximately 100 feet by 50 feet and was approximately 16 feet high. The soil pile was reconfigured in order to ease remediation and to ensure uniformity between the SUs. The remediation occurred incrementally, as one foot lifts of soil from the pile. Each lift was evaluated as a Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) Class 1 SU prior to its removal. Most of the soil pile was suitable for release for unrestricted use, approximately 1,730 cubic yards (cy). This soil was beneficially reused to provide additional capping material for a nearby, on-site landfill. Approximately 70 cy of soil from the soil pile exceeded the Derived Concentration Guideline Level (DCGL) and were disposed off-site at the U.S. Ecology Grandview, Idaho facility as unimportant quantities of source material. The highest concentration of ^{232}Th identified in these soil pile soils was 2.7 pCi/g.

Characterization surveys were performed on the base of the soil pile and the one foot soil layer beneath it. ^{232}Th concentrations ranged from -0.13 to 1.1 pCi/g. The characterization surveys also identified elevated concentrations of radium-226 (^{226}Ra) at the base and beneath the soil pile (southeast corner), with concentrations as high as 120 pCi/g. During the sampling process, the remnants of a 'sound powered phone jack' containing radium, as characterized by Department of Defense (DoD) personnel, were found below ground level near the this area of the soil pile. The elevated ^{226}Ra results are likely due to contamination from this debris.

Additionally, the scope of CABRERA'S 2004 contract also included remediation and FSS of the North Fence Area. Following the direction of RASO, only characterization surveys were performed for the North Fence Area; however, these North Fence Area characterization

surveys were performed using MARSSIM FSS guidance and were to be used to support future North Fence Area FSS evaluations. Based on the survey results, approximately 170 cy of North Fence Area soils exceeded the DCGL of 1 pCi/g and were disposed of off-site at the U.S. Ecology Grandview, Idaho facility as unimportant quantities of source material. The highest concentration of ^{232}Th identified in these soils was 8.6 pCi/g.

As part of the removal action, CABRERA characterized the remainder of this portion of the Site, with results published in a Technical Memorandum. It was estimated that an additional 1,526 cy of material required remediation. As part of the previous activities, CABRERA performed remediation in the Center Tank Area and the area just south of the Center Tank Area referred to as the Recreation Area. FSSs in the Center Tank Area performed by CABRERA and scoping surveys completed by the NRC showed additional areas of contamination above the existing clean-up goal of 1 pCi/g above background [NRC default surface soil screening value (SSSV)]. This included some areas at the boundary of the original footprint remediated at a greater depth than anticipated and over a larger area than previously identified. Additionally, the NRC identified contamination up to 20 pCi/g at the headwall of a drainage pipe that empties into Skokie ditch. The headwall is in the northern portion of the industrial area.

In 2006, CABRERA performed radiological surveys which were used to develop the remediation approach used during these final activities. The Navy demolished Tank H and the nearby storage building so the 2007 remediation activities could be completed.

1.3 Radionuclide of Concern

The Radionuclide of Concern (ROC) associated with monazite sand is natural thorium and its decay products. The monazite stored at Site 18, was unaltered and unprocessed, thereby preserving the natural concentrations and secular equilibrium. There is no evidence of chemical or physical processes that would disturb this equilibrium.

Soil analysis results from the 2000 and 2004 characterization surveys (CABRERA 2000 and 2004a) confirmed the presence of ^{232}Th, in secular equilibrium with its progeny, as the Site ROC. Monazite sand typically contains 5-7% radioactive thorium and 0.1-0.3% radioactive uranium. Isotopes from the thorium series naturally dominate, and while uranium series radionuclides while expected to be present, are in concentrations low enough to not be considered Site ROCs. One discrete location at the Site contained ^{226}Ra; however, it was determined to be due to an isolated piece of equipment deposited there and not due to its presence within natural monazite sands. For this reason, radium was not considered a project ROC.

1.4 Derived Concentration Guideline Level

Historically, the DCGL used by CABRERA at the Great Lakes Naval facility was 1.1 pCi/g above ambient background for ^{232}Th. This was based on the use of the default soil screening value for ^{232}Th published in NUREG-5512, Vol. 3 (NRC, 1999). This value was used at the site between 2000 and 2007 for all characterization and remediation efforts.

In 2007, CABRERA prepared a site-specific DCGL evaluation for the Site, which calculated a ^{232}Th cleanup value of 4 pCi/g, based on a resident gardener scenario, to support the remaining remediation and FSS activities at the Site. This DCGL value, with support from JMC and RASO, was submitted to the NRC Region III and approved for use. All FSS data evaluated herein is therefore compared to this new 4 pCi/g DCGL value. The derivation of this DCGL is provided in detail in the *Final Site-Specific Derived Concentration Guideline Level* (CABRERA, 2007b), provided in Appendix G.

1.5 Site Reference Coordinate System

The Site reference coordinate system was designed to ensure sample and measurement locations are spatially identified such that each location is reliably reproducible. The basic unit of the coordinate system is meters. SU grids, Site boundaries, and other survey reference points are described by northing and easting coordinates, in meters, tied to the Illinois East State Plane Coordinate System, North American Datum 1983. References in this report to specific locations are of the form "xxx,xxx.x north, yyy,yyy.y east"; where xxx,xxx.x is the northing coordinate in meters and yyy,yyy.y is the easting coordinate in meters.

2.0 CHARACTERIZATION ACTIVITIES

Characterization was performed, prior to remedial activities, within SUs 3, 4, 5, 17, and 18. SU 2 was unable to be characterized due to the presence of a soil stockpile from previous remedial activities with an approximate volume of 875 cy (referred to later as SUs 17 and 18). Characterization activities consisted of gamma walkover survey (GWS), systematic and biased soil sampling, downhole gamma logging (DGL), and on-site gamma spectroscopy analysis. These surveys served to augment those previously collected by CABRERA between 2000 and 2004.

2.1 Gamma Walkover Surveys

As part of the characterization activities for Site 18, GWSs were performed over 100% of the accessible surfaces in each of the SUs. The purpose of the GWSs was to identify areas of elevated surface radioactivity. GWSs were performed using a Trimble XR-Pro and TSC 1 global positioning system (GPS) coupled to a Ludlum Model 44-10 2x2 Sodium Iodide (NaI) detector with a Ludlum Model 2221 scaler/ratemeter. All GPS positional data collection was done in real time using differential correction provided by either the satellite signal or the Coast Guard beacon signal. The GWS was performed following MARSSIM protocol, by walking straight parallel lines at a rate of approximately 0.5 meters per second (m/s) while moving the detector in a serpentine motion of approximately 1 meter wide and a consistent distance of approximately 2-4 inches above the ground surface. GWS data in gross counts per minute (cpm) from the scaler/ratemeter was automatically logged into the GPS unit at a rate of once per second. All GPS data was collected in U.S. State Plane Feet, Illinois East State Plane Coordinate System, North American Datum 1983. Upon survey completion, the data was downloaded from the GPS unit and sent to a data processing specialist for import into a geographical information system for processing and imaging.

2.2 Soil Sampling

Systematic surface and subsurface soil samples were taken at locations determined by a random start triangular grid-sampling pattern, in accordance with MARSSIM protocols. Samples were collected using a direct-push rig, e.g., Geoprobe®, to a total depth of 4 feet below ground surface, resulting in four 1-foot increments for each location. The entire core was inspected by a field geologist, who characterized the soil types and determined the increment level of the native soil.

A minimum of two intervals were analyzed from each core; the top-foot increment and a subsurface increment with the highest DGL reading. Each was prepared and analyzed in the CABRERA on-site gamma spectroscopy laboratory using a high purity germanium (HPGe) detector system. Those samples which exceeded the Site DCGL of 4 pCi/g were used to identify areas which required remediation.

3.0 REMEDIATION ACTIVITIES

Based on the results of surface and subsurface characterization soil samples, it was determined that small areas of soil in SUs 3, 4, 5, and 18 would exceed the new Site clean-up criterion. Historical records indicated that some soils within SU 1 would also require excavation and offsite disposal. GWS and on-site gamma spectroscopy analysis of excavation support samples were used to delineate the specific areas where soil was to be removed.

3.1 Survey Unit 1 Remediation Activities

Previous historical records indicated that a "sound-powered phone jack" containing ^{226}Ra had been buried in the vicinity of SU 1. While no coordinates existed, there was a benchmark (a cone) that delineated the location of the source. This position was supported by 2 x 2 NaI counts upwards of 150,000 cpm and physical evidence such as broken glass and metal. During excavation activities, 6" lifts with an area of 3 meters x 3 meters square were executed and soil was hand dug in the immediate vicinity of the jack. The remediated soils were live-loaded into a SuperSack lift-liner with an excavator. An investigation sample (SU1-IN1) was taken of the remediated soil, which showed a ^{226}Ra concentration of 29.8 pCi/g. Biased samples were also taken around the periphery of the localized excavation area to ensure the remaining soils all met the Site release criteria.

3.2 Survey Unit 2 Remediation Activities

No remediation of soils in SU 2 were required aside from the relocation of the soil stockpile located atop of the SU 2 soils.

3.3 Survey Units 3, 4, and 5 Remediation Activities

Characterization surveys prior to and including 2007 characterization sampling identified the areas requiring remediation within SUs 3, 4, and 5. Excavation areas were bounded using the coordinates of soil samples with results exceeding the DCGL. The areas were then systematically excavated until the remedial support samples all demonstrated results under 4 pCi/g.

3.4 Survey Units 17 and 18 Remediation Activities

The soil stockpile generated during 2004 remediation activities was temporarily staged within the boundaries of what was considered SU 2. As part of the 2007 remediation and FSS activities, this stockpile was initially leveled to 2 feet high using an excavator and front-end loader to allow two consecutive 'lifts' to be performed. The first 1 foot layer of the stockpile was surveyed as SU 17 with a 100% GWS and 14 systematic soil samples collected. Successful survey and removal of the first lift would lead to the initiation of the second lift's activities.

The GWS results for SU 17 showed an isolated area toward the center of the unit. Three biased samples were collected in this area, but all were shown to be below the DCGL (maximum ^{232}Th concentration of 2.18 pCi/g).

The GWS results for SU 18 showed a similar hotspot in the same isolated area as SU 17. The levels of the GWS and the results of the pre-remediation biased sample (SU18-B32, 32 pCi/g) indicated this area required remedial action. Approximately 10 cy of soil was removed from this area and loaded into a SuperSack lift-liner. The remainder of SU 18 was removed as clean and set aside for use as backfill upon successful completion of FSS activities.

3.5 Waste Packaging

All areas were remediated using a 330 Caterpillar excavator and a 924 Caterpillar front-end loader. The soils were excavated from each area and transferred directly into the bucket of the loader for transport to a central lift-liner packaging area. The lifting frame was placed in the central island of Vermont Court, with lift-liners placed into the frame as needed. The loader would bring excavated soils to the lifting frame location and load the liners. Once the liner was filled to capacity, it was zipped closed and lifted out of the frame using a 24,000-lb forklift. The filled bags were temporarily staged at the southern end of Vermont Court, on top of geotextile fabric. It was determined during the course of excavation activities that a single lift-liner could hold approximately 8.5 tons of excavated soil.

3.6 Waste Shipment and Disposal

Soils exceeding the DCGL of 4 pCi/g ^{232}Th were packaged in 10 cy soft-sided containers, (i.e., super-sacks). Each super-sack was found to hold approximately 8.5 tons of soil. The super-sacks were temporarily stored on-site, and then transported to a nearby railhead in Kenosha, Wisconsin, where the containers were transloaded into gondola railcars. The wastes were profiled for disposal at the U.S. Ecology facility in Grandview, Idaho as unimportant quantities of source material (less than 0.05% by weight, or equivalent to 55 pCi/g of ^{232}Th). The highest concentration of ^{232}Th identified in these soils was 32 pCi/g.

The soils shipped during 2007 were a combination of those remediated from the FMSSA as well as a portion of the soils remediated from within the PPV area. Since more remedial activities are scheduled within the Public Private Venture (PPV) area in 2008, a full discussion of the waste shipment and disposal operations will not be included here. This discussion, complete with copies of all waste manifests, will be provided with the PPV Final Closure Report.

4.0 FINAL STATUS SURVEY ACTIVITIES

An FSS was conducted after the remedial activities were complete. All activities were performed in accordance with the *Public Private Venture Area Remediation Addendum* to *Work Plan for the Remediation of the Recreation and Center Tank Areas and Site Wide Final Status Survey* (CABRERA, 2007a) which was developed using MARSSIM guidelines.

4.1 Gamma Walkover Survey

As part of the FSS activities for the Site, GWSs were performed over 100% of each of the SUs and after remediation was complete, GWS was performed over the excavation areas within SUs 3, 4, 5, 17, and 18. Prior GWS from characterizations were also used if the area was determined to be initially clean. In areas where the post-remediation GWS overlapped the pre-remediation data, the two data sets were merged with the post-remediation data given preference.

4.2 Systematic Surface Soil Sampling

Surface soil samples (to one foot) were collected in each of the SUs. The minimum number of systematic soil sample locations required in each of the SUs was established using MARSSIM guidance. Surface soil samples were collected in the SUs using a systematic triangular grid pattern with a random start point. Grid spacing was calculated for each SU based on the area of the SU. Random start point coordinates were established using a computer-generated random coordinate set. Systematic sample locations are shown in Figure 4 and the FSS results are presented in Appendix C. The chain of custody was maintained for the collected soil and the sample was transferred to the on-site laboratory.

4.3 Biased Soil Sampling

Surface soil samples were collected at biased locations to identify potential areas of elevated radioactivity. Biased surface soil samples were collected within the excavation areas and at previously remediated areas.

4.4 On-site Gamma Spectroscopy Laboratory

Following sample collection and logging, they were prepared for analysis by heating to dryness in a conventional oven. Once dry, the soil was sieved and ground to a consistent particle size to provide a homogeneous sample. All sieving and grinding operations were performed (inside a hood equipped with a high-efficiency particulate air (HEPA) filtration system. The completed sample was then packaged for counting in a 1-liter Marinelli container.

CABRERA performed on-site gamma spectroscopy sample analyses on soil all samples utilizing a coaxial HPGe detector. Prior to the performance of project sample analyses, the detector was calibrated using a mixed gamma standard traceable to the National Institute of Standards Technology (NIST).

The gamma spectroscopy system was operated by a trained operator in accordance with CABRERA'S Standard Operating Procedures. The operator performed spectral analysis during

each measurement, which encompassed the evaluation of spectra for problems such as peak shift, high dead-time and other potential inconsistencies in spectral structure. A qualified Health Physicist reviewed the integrity of the sample analysis results for each sample prior to submittal of final results to RASO for approval. This review encompassed the analysis of sample results for spectral energy shift, agreement between progeny activities assumed to be in secular equilibrium, the presence of potentially unidentified radionuclides, as well as other potential inconsistencies. Sample count times were determined to be fifteen minutes, in order to accomplish the sufficient minimum detectable concentrations (MDCs) to meet applicable Site clean up criterion.

CABRERA utilized a radionuclide library consisting of radionuclides present in natural background and cesium-137 (^{137}Cs), from global nuclear weapons testing fallout, to analyze the gamma spectral data. Radionuclide gamma/x-ray energies and yields were extracted from the National Nuclear Data Center NUDAT nuclear data database (version dated 22 August 2002). CABRERA gamma spectroscopy data reported for actinium-228 (^{228}Ac) was used to represent ^{232}Th activity concentrations under the assumption of secular equilibrium. Thus, references to ^{232}Th activity concentrations herein are based on the gamma spectroscopy results of ^{228}Ac. The ^{228}Ac gamma lines used to infer ^{232}Th activity concentration are 911.2 kiloelectron volts (keV) at 25.8% yield, 969.0 keV at 15.8% yield, and 338.3 keV at 11.3% yield, and several additional lower yielding gamma lines. The Onsite Gamma Spectroscopy Laboratory raw results are included as Appendix C.

Discussion of On-site Lab Quality Assurance and Quality Control (QA/QC) results are presented in Section 6.0, with QC data included as Appendix D.

5.0 FINAL STATUS SURVEY RESULTS

Evaluation of the FSS data compiled within each SU was performed using the MARSSIM Sign Test. The Sign Test was chosen since the levels of natural ^{232}Th in Site soils are at levels considered to be negligible in comparison to the new $DCGL_w$ of 4 pCi/g. Therefore, a background reference area was not required for the MARSSIM FSS evaluation of the data. The results of each SU sign test is summarized below in Table 5-1 with Sign Test Worksheets for each SU also included in Appendix A. Plots of the GWS results from within each SU are provided in the Figures section of this report.

5.1 Survey Unit 1

The FSS evaluation of SU 1 encompassed the performance of a GWS and the collection and gamma spectroscopy analysis of 21 systematic samples. Since no contoured Z-score value was greater than 3.0, no bias samples were necessary in SU 1. The ^{232}Th concentrations of the systematic samples ranged from 0.05 to 0.99 pCi/g, averaging 0.47 pCi/g with a standard deviation of 0.25 pCi/g. All FSS sample results for SU 1 were below the Site action level for ^{232}Th of 4 pCi/g. This SU passed the release criteria and is thereby suitable for unrestricted release.

5.2 Survey Unit 2

The FSS evaluation of SU 2 encompassed the performance of a GWS and the collection and gamma spectroscopy analysis of 20 systematic samples. Since no contoured Z-score value was greater than 3.0, no bias samples were necessary in SU 2. The ^{232}Th concentrations of the systematic samples ranged from 0.18 to 1.37 pCi/g, averaging 0.81 pCi/g with a standard deviation of 0.37 pCi/g. All FSS sample results for SU 2 were below the Site action level for ^{232}Th of 4 pCi/g. This SU passed the release criteria and is thereby suitable for unrestricted release.

5.3 Survey Unit 3

The FSS evaluation of SU 3 encompassed the performance of a GWS and the collection and gamma spectroscopy analysis of 18 systematic samples and 5 bias samples. The ^{232}Th concentrations of the systematic samples ranged from 0.56 to 1.70 pCi/g, averaging 0.92 with a standard deviation of 0.32. The ^{232}Th concentrations of the bias samples ranged from 0.67 to 3.90 pCi/g. All FSS sample results for SU 3 were below the Site action level for ^{232}Th of 4 pCi/g. This SU passed the release criteria and is thereby suitable for unrestricted release.

5.4 Survey Unit 4

The FSS evaluation of SU 4 encompassed the performance of a GWS and the collection and gamma spectroscopy analysis of 21 systematic samples and 2 bias samples. The ^{232}Th concentrations of the systematic samples ranged from 0.27 to 1.61 pCi/g, averaging 0.75 pCi/g with a standard deviation of 0.30 pCi/g. The ^{232}Th concentrations of the bias samples ranged from 0.82 to 1.08 pCi/g. All FSS sample results for SU 4 were below the Site action level for ^{232}Th of 4 pCi/g. This SU passed the release criteria and is thereby suitable for unrestricted release.

5.5 Survey Unit 5

The FSS evaluation of SU 5 encompassed the performance of a GWS and the collection and gamma spectroscopy analysis of 21 systematic samples and 3 bias samples. The ^{232}Th concentrations of the systematic samples ranged from 0.17 to 1.26 pCi/g, averaging 0.79 pCi/g with a standard deviation of 0.28 pCi/g. The ^{232}Th concentrations of the bias samples ranged from 0.98 to 2.39 pCi/g. All FSS sample results for SU 5 were below the Site action level for ^{232}Th of 4 pCi/g. This SU passed the release criteria and is thereby suitable for unrestricted release.

5.6 Survey Unit 17

The FSS evaluation of SU 17 encompassed the performance of a GWS and the collection and gamma spectroscopy analysis of 14 systematic samples and 3 bias samples (SU17-B29, B30, and B31). The ^{232}Th concentrations of the systematic samples ranged from 1.01 to 1.61 pCi/g, averaging 1.36 pCi/g with a standard deviation of 0.17 pCi/g. The ^{232}Th concentrations of the bias samples ranged from 1.25 to 2.18 pCi/g, all below the Site DCGL for ^{232}Th of 4 pCi/g. This lift was removed completely as meeting the release criteria and is thereby suitable for restricted reuse as backfill on-site.

5.7 Survey Unit 18

The FSS evaluation of SU 18 included the performance of a GWS and the collection and gamma spectroscopy analysis of 14 systematic samples and one bias sample post-remediation (SU18-B33). The ^{232}Th concentrations of the systematic samples ranged from 1.01 to 1.93 pCi/g, averaging 1.25 pCi/g with a standard deviation of 0.25 pCi/g. The ^{232}Th concentration of the bias sample was 1.43 pCi/g. All FSS sample results for SU 18 were below the Site action level for ^{232}Th of 4 pCi/g. This lift was removed completely as meeting the release criteria and is thereby suitable for restricted reuse as backfill on-site.

TABLE 5-1: FSS SUMMARY STATISTICS

Survey Unit Statistic	Survey Unit						
	SU-1	**SU-2**	**SU-3**	**SU-4**	**SU-5**	**SU-17**	**SU-18**
Sample Size, n	21	20	18	21	21	14[1]	14[1]
Prospective Assumed Sigma	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Sample Average	0.47	0.81	0.92	0.75	0.79	1.36	1.25
Sample Maximum	0.99	1.37	1.70	1.61	1.26	1.61	1.93
Sample Minimum	0.05	0.18	0.56	0.27	0.17	1.01	1.01
Sample Retrospective Sigma	0.25	0.37	0.32	0.30	0.28	0.17	0.25
Bias Sample Maximum	N/A	N/A	3.90	1.08	2.39	2.18	1.53[2]
Bias Sample Minimum	N/A	N/A	0.67	0.82	0.98	1.25	1.53[2]
Sign Test Results (Pass or Fail)	Pass	Pass	Pass	Pass	Pass	Pass	Pass

Notes:
1. The number of samples was reduced for SU-17 & SU-18 as these were the soil stockpiles from previous remediation efforts.
2. Only one bias sample was collected for SU 18

6.0 SITE RESTORATION

Upon completion of all FSS activities, a Backfill Request Authorization Letter was submitted to RASO for approval. Upon concurrence from RASO that all remediation and survey objectives had been met, each open excavation was back-filled with borrow-source gravel back to grade level. In areas where additional investigations are planned for 2008, geotextile fabric was used to demarcate the boundary of where successful remediation and FSS had been completed.

Copies of each Backfill Request Letter are provided in Appendix F.

7.0 QUALITY ASSURANCE / QUALITY CONTROL

7.1 CABRERA On-site Laboratory Quality Control Results

7.1.1 System Calibration

The CABRERA Laboratory HPGe detector was calibrated with a NIST traceable multi-line gamma Marinelli standard prior to the performance of project sample analyses. The Marinelli standard used for the system efficiency calibration consisted of a geometry identical to the sample geometry, with a density approximate to the average density of the project samples.

7.1.2 Daily Quality Control Checks

Cadmium-109 (^{109}Cd) and cobalt-60 (^{60}Co) sources were used to perform daily Quality Control (QC) activities. Analysis of the QC standards was performed each day sample analyses were conducted in order to evaluate the detector performance against established gamma spectroscopy QC criteria for the project. The QC criteria consisted of detector resolution, using measurement of Full Width at Half Maximum, peak energy measurements, and decay corrected activity concentration measurements. Each criterion was evaluated for ^{109}Cd at 88.1 keV and ^{60}Co at 1332.5 keV. Daily QC results passed comparison criteria for each day that project sample analyses were performed. Results for all daily QC checks are provided in Appendix D.

The Quality Control Charts show a tendency toward the end of the project (last week of November) for a decrease in the efficiency approaching the action level. However, the results were still within acceptable limits so the resulting data was accepted without qualification.

7.1.3 Laboratory Blanks

The CABRERA Laboratory performed blank analyses to test analytical accuracy and to estimate the extent of bias in the measurements. CABRERA prepared blanks consisting of a media similar to the samples and free of radiological contamination. Blank analyses were performed weekly in accordance with the laboratory's written procedures. Blank sample analysis results for ^{232}Th were all less than the analytical MDC, indicating that laboratory sample processing and handling did not introduce a positive bias in the sample results.

7.1.4 Laboratory Replicate Sample Analyses

CABRERA performed replicate analyses for 5% of the samples analyzed in the CABRERA Laboratory. Replicate analyses entailed repeating the analysis of a previously analyzed sample and comparing the results statistically using a Z-Replicate method as recommended in Chapter 18 of the Multi-Agency Radiological Laboratory Analytical Protocols (MARLAP) manual. Z_{Rep} evaluates a sample result against a duplicate (or QA sample), including the stated uncertainties of each sample. The formula for Z_{Rep} is:

$$Z_{\mathrm{Re}\,plicate} = \frac{Sample - Duplicate}{\sqrt{\sigma^2_{Sample} + \sigma^2_{Duplicate}}}$$

Where:

Sample	=	first sample value (original),
Duplicate	=	second sample value (duplicate),
Sample	=	total propagated measurement uncertainty of the sample, and
Duplicate	=	total propagated measurement uncertainty of the duplicate

The calculated Z_{Rep} results should be compared to a performance criteria of ±2.57. Duplicate analyses that result in a Z_{Rep} outside of ±2.57 should be investigated for possible discrepancies in analytical precision or sources of disagreement within the following assumptions:

- The sample measurement and duplicate or replicate measurement are of the same normally distributed population;
- The standard deviations represent the true standard deviation of the measured population

Results of the CABRERA on-site Laboratory replicate evaluations for are provided in Table 7-1. All on-site laboratory replicate samples passed the requisite Z-score evaluation.

7.1.5 Off-site Laboratory Cross-Check Duplicate Analyses

Test America performed cross-check gamma spectroscopy analyses on 10% of the soil samples collected and analyzed by the CABRERA Laboratory. Results of both laboratories were compared using the Z-Replicate (Z_{Rep}) method as described in Section 7.1.4. The results of the laboratory comparisons for all SUs are provided in Table 7-2 . Test America laboratory data packages are included as Appendix E.

Of the samples evaluated during the off-site cross-check 10 (or 40%) were found to have a Z_{Rep} greater than the tolerance level of 2.57. It was later discovered that Test America utilized only 350-g aliquot samples (out of the ~1500g provided) to perform their analyses. We feel this sub-sampling introduced additional sample bias caused by heterogeneity within the total volume. Depending on whether the off-site lab sampled either localized “pockets” of contamination (or not), their results may have been preferentially biased versus the aggregate average reported via the entire sample mass in the on-site laboratory.

It should be noted that of these 10 failures, five had Z_{Rep} values between 2.65 and 3.27, with very low relative ^{232}Th concentrations (< 2 pCi/g). These samples displayed a distribution of both positive and negative results, indicating only slight impact of the heterogeneity. The remaining five had higher variation, but also higher concentrations of ^{232}Th, which likely are correlated with the relative impact of the heterogeneity. Although this stated failure rate is abnormally high, CABRERA feels that it is primarily due to preparation bias and should not attributable to the accuracy of the CABRERA Laboratory. For this reason, we feel no additional data qualification is warranted.

TABLE 7-1: SUMMARY OF ON-SITE LABORATORY QA REPLICATE SAMPLE COMPARISON

Original Sample Result			Replicate Sample Results			Z-Score	Z-Score Pass/Fail (<2.57)
Sample ID	Result	Uncert	Sample ID	Result	Uncert		
SU1-8-PR	ND	--	SU1-8-PR Dup	ND	--	N/A	N/A
SU1-13-PR	ND	--	SU1-13-PR Dup	3.46E-01	0.09	N/A	N/A
SU2-26-PR	7.36E-01	0.13	SU2-26-PR Dup	7.47E-01	0.13	0.06	Pass
SU2-35-PR	9.62E-01	0.11	SU2-35-PR Dup	8.87E-01	0.12	0.45	Pass
SU3-52-1	1.12E+00	0.17	SU3-52-1 Dup	9.79E-01	0.16	0.61	Pass
SU3-58-1	6.22E-01	0.11	SU3-58-1 Dup	5.19E-01	0.13	0.59	Pass
SU4-71-1	8.13E-01	0.16	SU4-71-1 Dup	6.32E-01	0.15	0.84	Pass
SU4-75-1	ND	--	SU4-75-1 Dup	ND	--	N/A	N/A
SU4-79-1	1.05E+00	0.15	SU4-79-1 Dup	1.01E+00	0.15	0.18	Pass
SU5-85-1	7.48E-01	0.18	SU5-85-1 Dup	ND	--	N/A	N/A
SU5-91-3	6.51E-01	0.13	SU5-91-3 Dup	7.29E-01	0.13	0.42	Pass
SU5-93-2	1.02E+00	0.17	SU5-93-2 Dup	9.93E-01	0.16	0.14	Pass
SU5-101-2	8.51E-01	0.15	SU5-101-2 Dup	8.34E-01	0.14	0.08	Pass
SU5-104-1	1.18E+00	0.17	SU5-104-1 Dup	1.14E+00	0.18	0.16	Pass
SU5-105-1	5.83E-01	0.16	SU5-105-1 Dup	5.20E-01	0.15	0.30	Pass
SU5B-052 PR	9.83E-01	0.13	SU5B-052 PR Dup	9.59E-01	0.14	0.13	Pass
SU17-05-1	1.18E+00	0.13	SU17-05-1 Dup	1.18E+00	0.15	0.01	Pass
SU17-10-1	1.61E+00	0.18	SU17-10-1-Dup	1.30E+00	0.17	1.26	Pass
SU17-14-1	1.01E+00	0.13	SU17-14-1-Dup	9.96E-01	0.14	0.07	Pass
SU17-B29-1	1.25E+00	0.15	SU17-B29-1 Dup	1.34E+00	0.14	0.44	Pass
SU18-07-1	1.07E+00	0.16	SU18-07-1 Dup	1.03E+00	0.16	0.18	Pass
SU18-11-1	1.01E+00	0.15	SU18-11-1 Dup	1.15E+00	0.15	0.68	Pass

Note: ND = Not Detected

TABLE 7-2: COMPARISON OF ON-SITE LAB RESULTS WITH OFF-SITE LABORATORY QA RESULTS

Sample ID	Off-site Lab Sample Results		On-site Lab Sample Results		Z-Score	Z-Score Pass/Fail (<2.57)
	Result	Uncert	Result	Uncert		
SU1-14-PR	0.80	0.15	0.99	0.08	1.11	Pass
SU2-25-PR	0.98	0.11	1.29	0.07	2.36	Pass
SU2-31-PR	1.00	0.13	0.98	0.06	0.14	Pass
SU3-43-1	1.48	0.15	1.70	0.12	1.13	Pass
SU3-52-2	1.10	0.16	1.36	0.10	1.39	Pass
SU3-55-1	1.20	0.12	1.59	0.08	2.73	***Fail***
SU3B-049 PR	4.60	0.26	3.90	0.11	2.53	Pass
SU4-64-2	1.00	0.11	1.63	0.10	4.32	***Fail***
SU4-65-1	0.63	0.10	1.11	0.09	3.57	***Fail***
SU4-67-2	1.11	0.14	1.03	0.08	0.50	Pass
SU4-76-1	1.13	0.13	1.61	0.09	3.05	Fail
SU4-79-3	1.07	0.12	1.24	0.08	1.20	Pass
SU5-88-1	0.74	0.12	1.15	0.08	2.83	***Fail***
SU5-93-1	1.12	0.18	1.13	0.10	0.06	Pass
SU5-93-2	1.11	0.16	1.02	0.09	0.48	Pass
SU5-103-1	1.41	0.13	1.10	0.09	1.97	Pass
SU5B-054 PR	3.04	0.22	2.39	0.11	2.65	***Fail***
SU17-07-1	1.41	0.14	1.58	0.09	1.04	Pass
SU17-10-1	1.47	0.17	1.61	0.09	0.75	Pass
SU17-12-1	1.68	0.19	1.60	0.09	0.40	Pass
SU17-B30-1	4.16	0.32	2.18	0.09	5.98	***Fail***
SU18-04-1	1.08	0.15	1.59	0.09	2.95	***Fail***
SU18-06-1	2.62	0.20	1.93	0.08	3.27	***Fail***
SU18-B32-1	40.10	1.45	32.18	0.35	5.31	***Fail***
SU18-B33-1	2.05	0.24	1.53	0.16	1.79	Pass

Note: All results in pCi/g

7.2 Field Instrumentation QC Results

Data collection activities were performed in accordance with written procedures and/or protocols in order to ensure consistent, repeatable results. The Field Site Manager ensured that individuals were appropriately trained to use project instrumentation and other equipment, and that instrumentation met the required detection sensitivities.

7.2.1 Calibration Requirements

Radiological instruments were used to scan soil surfaces, equipment, personnel, and clothing for radiological contamination. Current calibration/maintenance records were kept on-site for review and inspection (included in Appendix B). The records include, at a minimum, the following:

- equipment identification (model and serial number)
- manufacturer
- date of last calibration
- calibration due date

Instrumentation was maintained and calibrated to manufacturers' specifications to ensure that required traceability, sensitivity, accuracy and precision of the equipment/instruments were maintained. Instruments were calibrated at a facility possessing appropriate NRC and/or Agreement State licenses for performing calibrations using NIST traceable sources. Copies of these calibration certificates are included in Appendix B.

7.2.2 QC Source and Background Checks

Prior to daily use, instruments were QC checked by comparing the instruments' response to a designated radiation source and to ambient background. Prior to the commencement of field operations a reference location was used for performance of these checks. Background checks were performed in an identical fashion with the source removed. At the start of the field activities, this procedure was repeated ten times to establish an average instrument response.

During QC checks, instruments used to obtain qualitative radiological data were inspected for physical damage, current calibration, and erroneous readings in accordance with applicable procedures and protocols.

Instrument response to the designated QC check source was evaluated against the average established at the start of the field activities. Performance criteria of ± 20% of this average were used as an investigation action level for qualitative field instruments, such as a Ludlum 44-20 3x3 NaI, a 44-9 Geiger-Mueller (GM) detector, and a Ludlum 43-93 dual-phosphor scintillator probe.

Performance criteria of ± 2 sigma as an investigation level and ± 3 sigma as an action level were used for quantitative instruments, i.e., instruments used for formal reporting or release

purposes. These instruments included the stationary smear counting instruments (Ludlum 2929 with a 43-10-1 probes).

During this work evolution, several Ludlum 2929 smear counters were used (see QC sheets in Appendix B). One of the instruments was incorrectly diagnosed as failing due to upward trends in detector count rates, causing daily QC failures. However, it was determined that the increases in background were from increases in monazite sand inventory in stored samples in the room below. These samples were contributing to elevated ambient background dose rate in the counting room. Once this was determined, the samples were moved, and the instruments were restored to a normal operating condition. All QC checks were within the established performance criteria as shown on control charts, included as Appendix B to this report.

7.3 GPS Daily Field Checks

At the start of the field effort the average easting and northing GPS position data was also established. These checks were always performed at the same location and were logged in the GPS unit. During subsequent routine checks, GPS position data was compared to the established averages. All measurements were within the criteria, as shown on control charts included as Appendix B to this report.

8.0 CONCLUSION

CABRERA performed characterization, remediation, and FSS activities within the former FMSSA at the Naval Station Great Lakes in Great Lakes, Illinois. Activities performed included GWS in all accessible areas, direct-push soil coring and DGL to characterize soils at depth, surface and subsurface soil sampling at systematic and biased locations, and on-site preparation and analysis of samples in a field gamma spectroscopy laboratory.

CABRERA also developed and submitted a site-specific DCGL document for the Site to NRC Region 3. This document was approved for use and thus allowed a 4 pCi/g ^{232}Th DCGL to be used for FSS purposes. This value replaced the former NRC Soil Screening Values (SSV) as the Site DCGL (1.1 pCi/g ^{232}Th above background).

Remediation of contaminated soils at the Site led to the packaging and shipment of 102 tons of impacted excavated soils to waste control specialists (WCS) in Andrews, Texas, as unimportant quantities of source material (less than 0.05% by weight, or equivalent to 55 pCi/g of ^{232}Th). Soft-sided 'Super Sack" lift liner containers were used for all waste packaging activities. As these lift-liners were sealed, each was temporarily stored in a central location on-site until they could be transported to a nearby railhead in Kenosha, Wisconsin. The lift-liners were then trans-loaded into gondola railcars and manifested to WCS. The highest concentration of ^{232}Th identified in the remediated soils was 32 pCi/g.

FSS activities consisted of a 100% GWS and sample collection and analysis. Systematic and biased sampling consisted of soil sampling from 120 locations, with samples obtained via a direct-push rig with a macrocore sampler or through surface sampling methods. All FSS sample results were shown to be below the Site DCGL of 4.0 pCi/g. The FSS data indicate that the SUs investigated within the FMSSA are suitable for release for unrestricted use.

9.0 REFERENCES

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FIGURES

APPENDICES

APPENDIX A

SIGN TEST WORKSHEETS

APPENDIX B

HP INSTRUMENTATION QUALITY CONTROL

APPENDIX C

CABRERA LABORATORY RAW RESULTS

APPENDIX D

CABRERA LABORATORY QUALITY CONTROL RESULTS

APPENDIX E

TEST AMERICA LABORATORY QA SAMPLE RESULTS

APPENDIX F

BACKFILL REQUEST AUTHORIZATION REQUEST LETTERS FOR SUs 1, 3, 4 and 5

APPENDIX G

SITE-SPECIFIC DCGL DOCUMENT SUBMISSION