FINAL

COAL ASH DETERMINATION SAMPLING REPORT

Naval Station Great Lakes
Great Lakes, Illinois

Navy Control Number 2006-009
Contract No. DAAA09-02-D-0024/30

Prepared for:

ON THE LINE

DEPARTMENT OF THE ARMY
HEADQUARTERS, JOINT MUNITIONS COMMAND
ROCK ISLAND, IL

Prepared by:

CABRERA SERVICES
RADIOLOGICAL · ENVIRONMENTAL · REMEDIATION

103 E. Mount Royal Ave., Suite 2B
Baltimore, Maryland

Cabrera Project No. 03-3040.30

March 2007

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ACRONYMS

AEC	U.S. Atomic Energy Commission
bgs	below ground surface
CA	known monazite sand contaminated area
CABRERA	Cabrera Services, Inc.
COC	chain of custody
DOE	U.S. Department of Energy
DRMO	Defense Reutilization and Marketing Office
EPA	U.S. Environmental Protection Agency
GPS	global positioning system
GWS	gamma walkover survey
HP	Health Physicist
m^2	square meters
NAD	normalized absolute difference
NaI	sodium iodide
NRC	U.S. Nuclear Regulatory Commission
pCi/g	picoCuries per gram
ppm	parts per million
PPV	Public Private Venture
QA	quality assurance
QC	quality control
RA	reference area
RCOC	radionuclide contaminant of concern
Site	Naval Station Great Lakes
SSHP	Site Safety and Health Plan
^{230}Th	thorium-230
^{232}Th	thorium-232
^{234}U	uranium-234
^{235}U	uranium-235
^{238}U	uranium-238
U.S.	United States
USGS	U.S. Geological Survey

EXECUTIVE SUMMARY

This report presents the results of the survey and data analysis conducted by Cabrera Services, Inc. (CABRERA) in Public Private Venture (PPV) areas of interest identified as 3A, 3B, 3C, 3D, 3E and 3F at the Naval Station Great Lakes in Great Lakes, Illinois. Previous surveys performed in these PPV areas using handheld instruments resulted in elevated gamma measurements in discrete locations. Therefore, it was necessary to perform additional sampling and analysis to further investigate the cause of the elevated gamma measurements.

The investigation performed required additional surveys, soil sampling and data analysis to determine if radioactive contamination present in these discrete soil locations is due to the presence of monazite sand or the result of other, non-licensed, material with similar naturally occurring radionuclides, such as coal ash. Through use of known naturally occurring radioactive material constituents in monazite sand, an expected ratio was established and a threshold for decisions regarding the presence of monazite sand in the areas of interest applied.

Soil sampling activities were performed within the six PPV areas of interest areas, as well as from a background reference area (RA) and the former monazite sand storage area (CA). Samples were analyzed by an offsite laboratory via alpha spectroscopy. Sufficient data was collected to establish radioactivity ratios for thorium-232 (^{232}Th) to uranium-238 (^{238}U) and select an appropriate activity ratio threshold above which the source can be concluded to be monazite sand.

It was concluded that activity ratios for ^{232}Th to ^{238}U above 1 indicated the presence of monazite sand, while ratios below 1 indicated the radioactivity was due to some other source, such as coal ash, building materials, or simply the natural radioactivity in soil. Activity ratios of ^{232}Th to ^{238}U in areas 3A, 3B, 3C, and 3F were all greater than 1, while the ratios for the same radionuclides in areas 3D and 3E were less than 1.

Based on the measured activity ratios for ^{232}Th to ^{238}U, verified using ratios for ^{232}Th to thorium-230 (^{230}Th), monazite sand is the most likely source of soil contamination in PPV areas 3A, 3B, 3C, and 3F. However, the ratios in soil from PPV areas 3D and 3E indicate the contaminant is not the result of presence of monazite sand.

1.0 INTRODUCTION

This report presents the results of the survey and data analysis conducted by Cabrera Services, Inc. (CABRERA) in Public Private Venture (PPV) areas of interest 3A, 3B, 3C, 3D, 3E and 3F, as shown in Figure 1-1, at the Naval Station Great Lakes (hereafter referred to as the 'Site') in Great Lakes, Illinois. The survey and data analysis was performed in January 2007 to determine if radioactive contamination present in discrete soil locations is due to the presence of monazite sand or the result of other, non-licensed material, with similar naturally occurring radionuclides, like coal ash. Activities described in this report were conducted in accordance with the *Sampling Plan For Task 3: Coal Ash Determination, Naval Station Great Lakes* (Sampling Plan) (CABRERA, 2006), which is presented in Appendix A. To accomplish this task, soil samples were obtained from the following locations:

- A non-impacted background reference area (RA);
- Former monazite sand storage area, Area 18 (CA); and
- PPV areas of interest 3A, 3B, 3C, 3D, 3E and 3F.

Soil samples collected were submitted to an off-site laboratory for analysis to determine the concentration of the naturally occurring radionuclides present in both the background soils as well as the soils in the areas of interest.

The sampling effort was intended to identify the concentrations of naturally occurring radioactivity in soil at the Site, specific to the locations in the following sections, and evaluate these concentrations in order to draw reasonable conclusions regarding the probable source of the contaminants (monazite sand or other source).

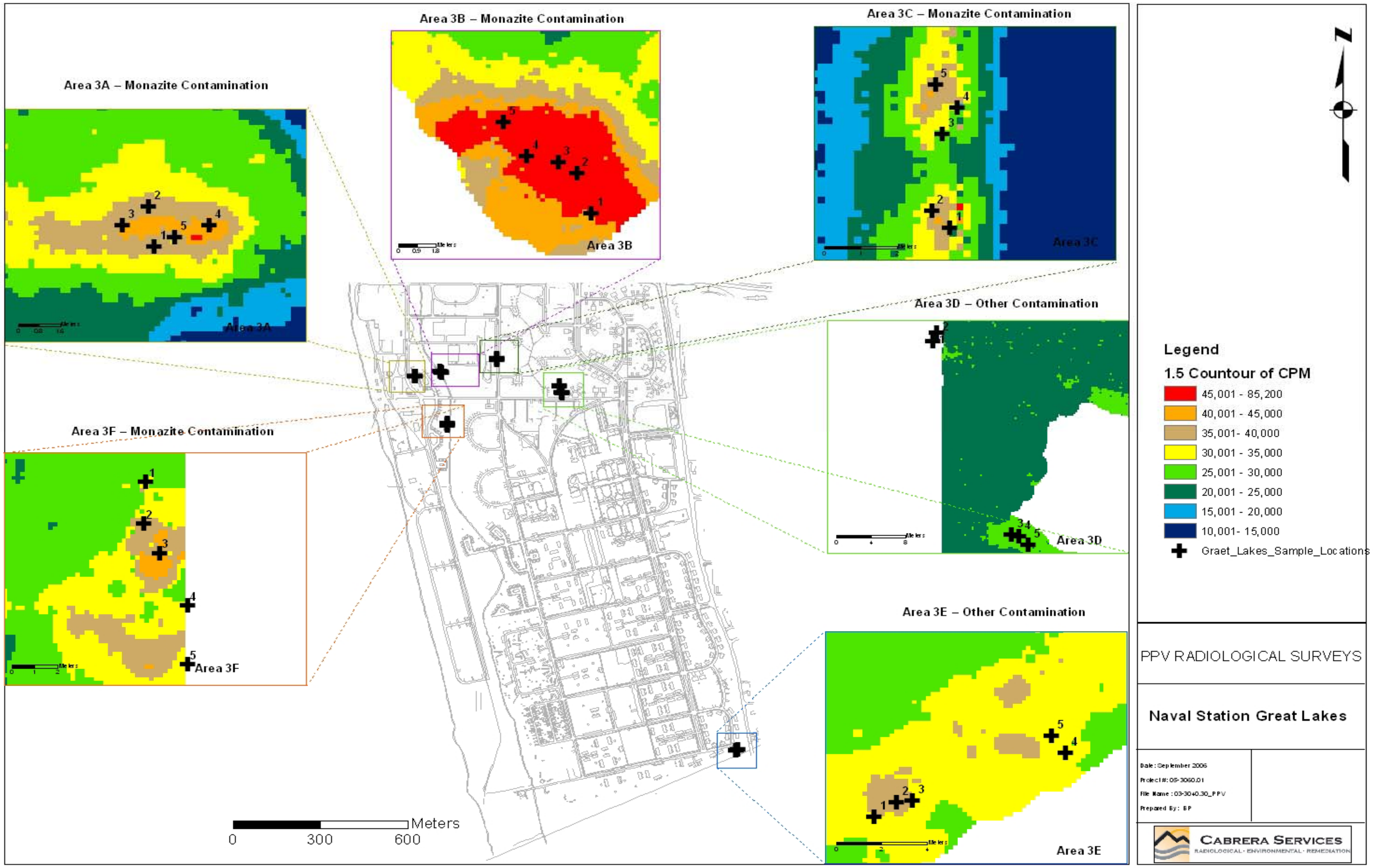

FIGURE 1-1: PPV SAMPLE LOCATIONS

The Sampling Plan provided for:

- Determination of the concentrations of natural radioactivity (natural thorium and natural uranium) in soil from non-impacted areas of the Site (RA background concentrations);
- Sufficient data to establish activity ratios for thorium-232 (^{232}Th) to uranium-238 (^{238}U) and ^{232}Th to natural uranium (which includes isotopes ^{238}U, uranium-235 [^{235}U], and uranium-234 [^{234}U]) in their natural relative abundances (see Table 1-21 and 1-2)] to select an appropriate activity ratio threshold above which the source can be concluded to be monazite sand;
- Analysis of soil samples obtained from an area of the Site known to contain or have previously contained monazite sand to verify appropriate selection of the threshold activity ratio(s); and
- Collection and analysis of soil samples from the six (6) PPV areas of interest and comparison of the analysis results, including activity ratios, to the activity ratio threshold established to determine the probable source of contaminants (monazite sand or other source).

1.1 Site History and Contaminants

1.1.1 Site History

In 1974 the United States (U.S.) Atomic Energy Commission (AEC) granted a license (license number STE-8179) to Engelhard Minerals & Chemicals to package and ship a strategic stockpile of monazite sand from the Site. This sand was reportedly shipped to Holland in 1974. In January 2000, the U.S. Nuclear Regulatory Commission (NRC) found residual monazite sand during a confirmatory survey of the previous AEC decommissioning of the Site. The NRC found elevated areas of gamma activity on the north side of the former monazite sand storage area along the fence near the Defense Reutilization and Marketing Office (DRMO) facility.

In the spring of 2000, Cabrera Services, Inc. (Cabrera) performed a detailed site characterization that confirmed the NRC findings and identified several other areas of elevated concentrations of ^{232}Th. Additional characterization and remediation activities were conducted through 2006.

In the form of a PPV, Forest City LLC is conducting renovation and development of the Forrestal Village housing area at the Site. This program will provide residential housing, available on a priority basis, to Navy personnel as well as the public. Because of the proximity of the housing area to the former monazite sand storage area, radiological screening surveys were performed in the proposed area of the PPV. Based on the survey results, six areas with elevated activity were identified (MACTEC, 2006). These locations were later verified by CABRERA.

1.1.2 Radiological Contaminants of Concern

The radiological contaminants of concern (RCOCs) associated with monazite sand are natural thorium and natural uranium. Since the monazite sand was stored in its natural, unprocessed form at the Site, the decay products associated with natural thorium and natural uranium remain in the same concentrations as would be found in locations where these sands occur in nature. Therefore, the decay or daughter products for both natural thorium and natural uranium would remain in secular equilibrium with the parent radionuclides. Although the fraction of natural uranium in monazite sand has been determined to be minimal, with inconsequential exposure results, it was determined that the fractions of natural thorium and natural uranium would be reasonable indicators of the source of contaminants in the PPV areas.

The parent radionuclide in the natural thorium decay chain, ^{232}Th, and the parent radionuclides in the two decay chains that comprise natural uranium, ^{238}U and ^{235}U, emit alpha particles. The daughter products in the natural thorium and natural uranium decay chains decay by emission of alpha or beta particles, some with accompanying emission of gamma rays. The decay schemes for both natural thorium and the natural uranium decay chains are provided in Figure 1-2 through Figure 1-4.

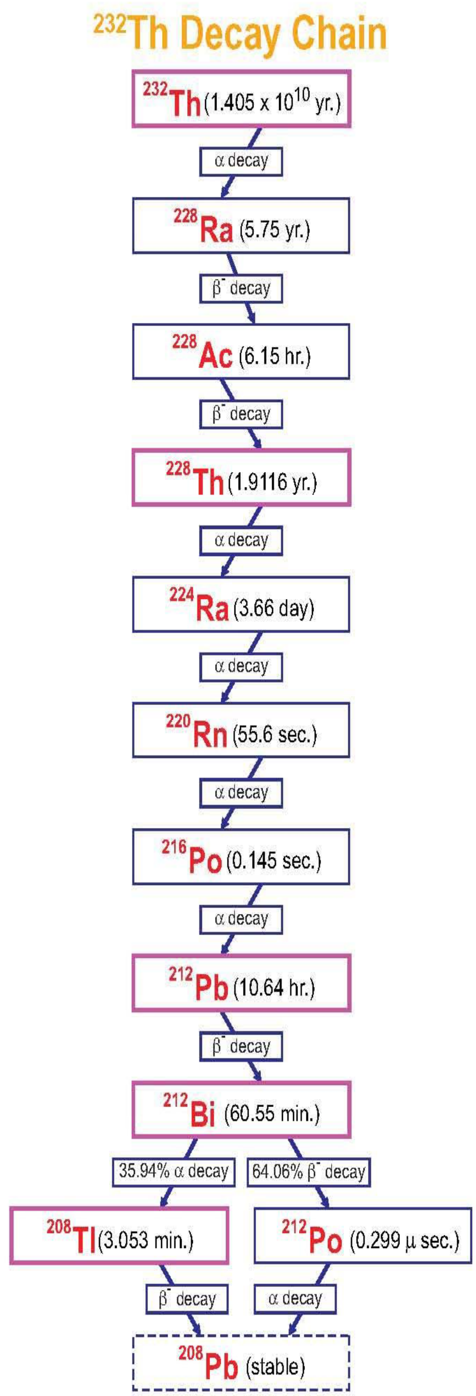

FIGURE 1-2: THORIUM-232 DECAY CHAIN

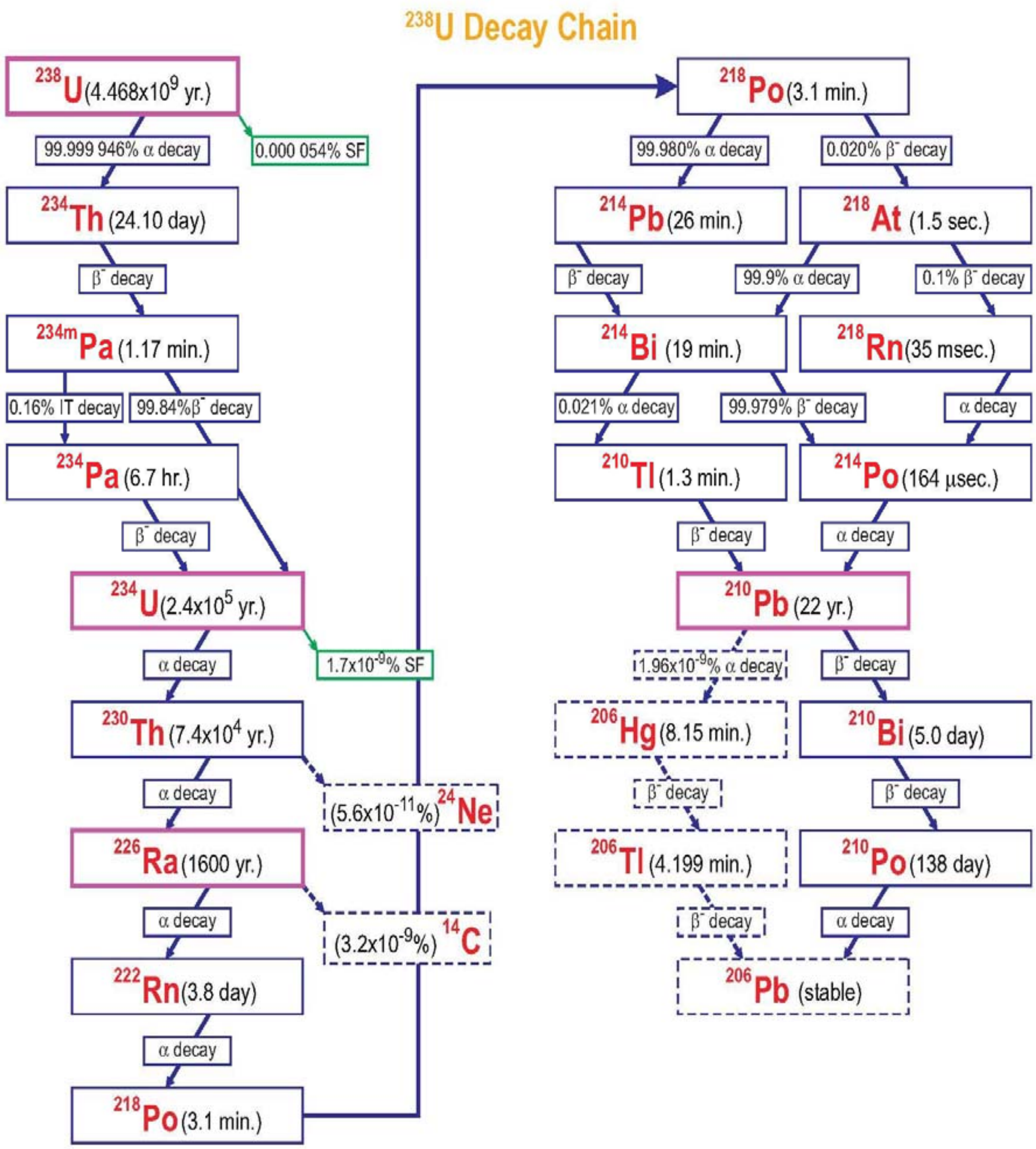

FIGURE 1-3: URANIUM-238 DECAY CHAIN

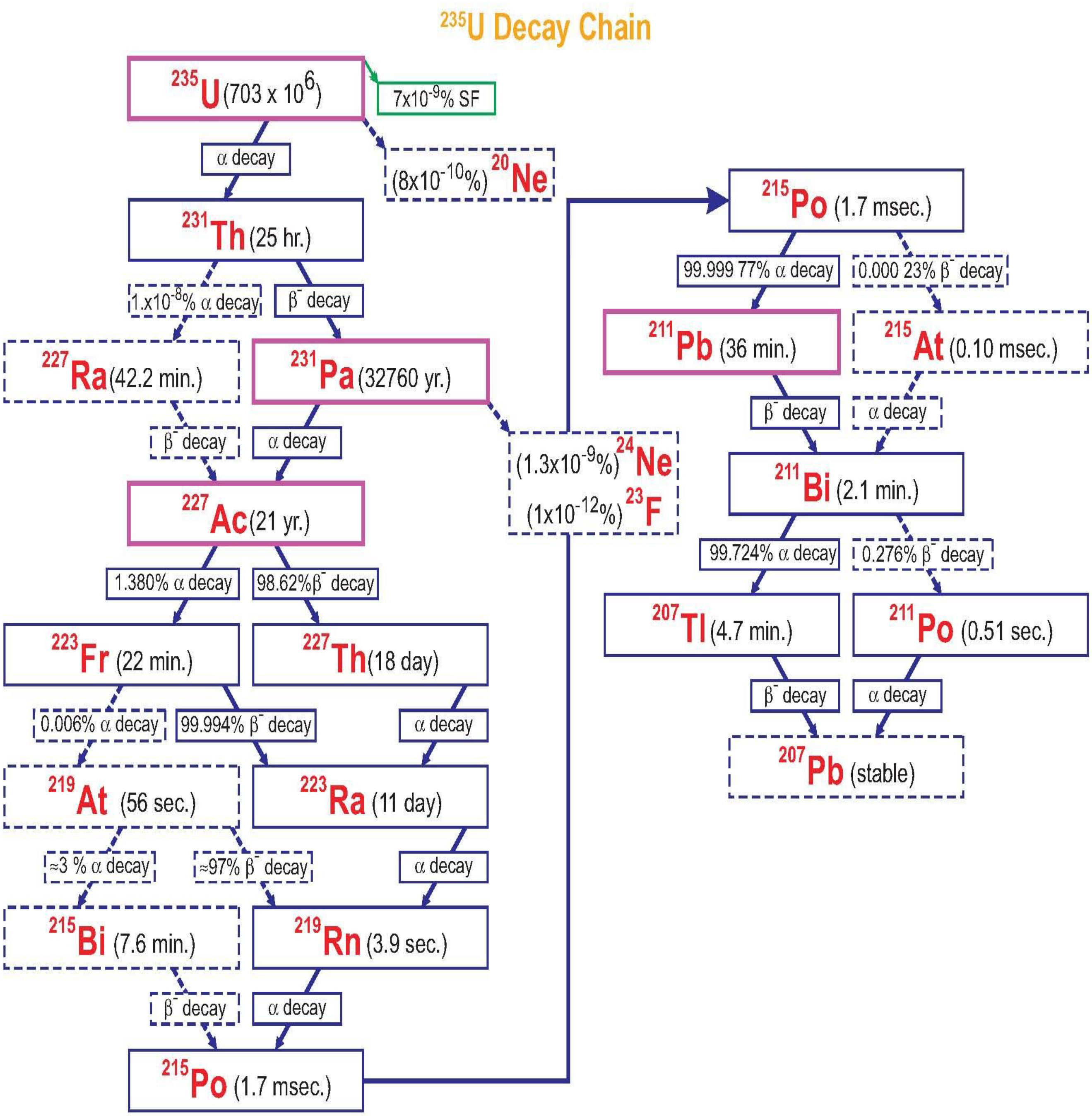

FIGURE 1-4: URANIUM-235 DECAY CHAIN

1.1.3 Determination of Natural Thorium Ratios[1]

Uranium and thorium are naturally occurring radioactive elements commonly found in small amounts in rocks, soil, sand, water, plants, and animals, including humans. The radioactivity of thorium and uranium in the environment is typically low and contributes to low levels of natural background radiation. A higher concentration of natural thorium (^{232}Th and decay progeny) is found in certain sands, such as monazite sand. Table 1-1 provides the specific activity and radiological half-life of ^{232}Th.

TABLE 1-1: THORIUM-232 RADIOLOGICAL INFORMATION

Specific Activity (Ci/g)	Half-life (years)
1.10E-07	1.405E10

Monazite sand also contains a small amount of natural uranium. The three primary uranium isotopes present in natural uranium are ^{238}U, ^{235}U, and ^{234}U. Table 1-2 provides the percentages of the uranium isotopes found in nature, as well as the specific activity and half-lives of the three isotopes of interest.

TABLE 1-2: NATURAL URANIUM RADIOLOGICAL INFORMATION

Radionuclide	Abundance (%)	Specific Activity (Ci/g)	Half-life (years)	Activity per Gram Natural Uranium (µCi/g)
U-238	99.28	3.30E-07	4.47E9	3.28E-1
U-235	0.72	2.10E-06	7.04E8	1.51E-2
U-234	0.0055	6.20E-03	2.44E5	3.41E-1

[1] Throughout this section, natural thorium refers to ^{232}Th, and natural uranium refers to the sum of the three uranium radionuclides (^{238}U, ^{235}U, and ^{234}U).

Monazite sand differs from most other environmental media in that it contains much higher concentrations of natural thorium, specifically ^{232}Th. The percentage of ^{232}Th in monazite sand has a range of 3 to 10 percent (%). The natural uranium content in the sand is typically much lower, in the range of 0.2 to 0.5 %. This higher concentration of ^{232}Th compared to natural uranium in monazite sand can be used as a mechanism to screen soil samples to determine if the radioactivity fractions are representative of this material. By comparing the ratio of ^{232}Th to natural uranium, or more simply comparing the ratio of ^{232}Th to ^{238}U, it can be determined whether the contaminants are due to monazite sand or another source of naturally occurring radioactivity. Table 1-3 and Table 1-4 provide examples of the ^{232}Th to natural uranium and ^{232}Th to ^{238}U activity ratios using the range of ^{232}Th and natural uranium abundance percentages provided above for monazite sands.

TABLE 1-3: MONAZITE SAND RADIOACTIVITY RATIOS (10% ^{232}Th, 0.2% NATURAL URANIUM)

Radionuclide	Radionuclide Activity per Gram Monazite Sand (µCi/g)	232Th : Radionuclide Ratio
Natural U	1.4E-03	8:1
U-238	6.5E-04	17:1
Th-232	1.1E-02	1:1

TABLE 1-4: MONAZITE SAND RADIOACTIVITY RATIOS (3% ^{232}Th, 0.5% NATURAL URANIUM)

Radionuclide	Radionuclide Activity per Gram Monazite Sand (µCi/g)	^{232}Th:Radionuclide Ratio
Natural U	3.4E-03	1:1
U-238	1.6E-03	2:1
Th-232	3.3E-03	1:1

For comparison, the average ^{232}Th to ^{238}U activity ratio in soil in the U.S. is 1:1 and the average ^{232}Th to natural uranium (includes ^{238}U, ^{235}U and ^{234}U) activity ratio is 0.5:1 (NRC, 1994).

If the ratios found were not representative of monazite or the natural radioactivity in soil, it may be beneficial to understand potential alternate sources of activity, such as coal ash, building materials, etc. The natural radioactivity in coal ash (fly ash) varies significantly (a direct result of the variability in constituents of the coal itself). Quoting figures provided by the U.S. Environmental Protection Agency (EPA), a 1993 report states that the concentrations of natural thorium and natural uranium in coal ash is 3.2 parts per million (ppm) and 1.3 ppm, respectively (Gabbard, 1993). This equates to 3.2E-06 grams of thorium per gram of ash and 1.3E-06 grams natural uranium per gram of ash, resulting in a ^{232}Th to ^{238}U activity ratio of 0.8:1 and a ^{232}Th to natural uranium activity ratio of 0.4:1. The U.S. Geological Survey (USGS) states that the concentration of thorium and natural uranium in coal is approximately equal (USGS, 1997). This report also indicates that the thorium and natural uranium concentrations in coal ash, although increased by a factor of ten from the concentrations in coal, are similar. This results in a ^{232}Th to ^{238}U activity ratio of 0.3:1 and a ^{232}Th to natural uranium activity ratio of 0.2:1. The NRC reports that the natural uranium concentration in coal ash exceeds the ^{232}Th concentration by a factor of two to three (NRC, 2001). The U.S. Department of Energy (DOE) also reports that the natural uranium concentration in coal ash exceeds the ^{232}Th concentration by a factor of three (DOE, 1996). To summarize the information provided in all of these reports, the uranium radioactivity in coal ash should exceed that of ^{232}Th, which results in activity ratios less than 1.

Additionally, many building materials may exhibit higher concentrations of naturally occurring radioactivity and these concentrations may vary greatly. For example, concrete contains natural thorium and natural uranium primarily due to the aggregate used in the concrete, of which sand is a primary component. The average ^{232}Th to ^{238}U activity ratio in concrete used in the Chicago, Illinois area is 0.4:1, with an average ^{232}Th to natural uranium activity ratio of 0.2:1 (NRC, 1994).

As indicated in the previous paragraphs, the natural thorium and natural uranium concentrations used in the determination of the ratios presented are based on averages. It is important to note that the natural radioactivity in these materials varies greatly within the U.S and around the world. However, the higher ^{232}Th concentrations found in monazite sand distinguish this material from most other environmental media, and the ratios of ^{232}Th to ^{238}U and/or ^{232}Th to natural uranium may serve as a useful screening tool to determine if the radioactivity in soil at the Site is due to the presence of monazite sand or the result of other environmental media such as coal ash.

To minimize the impact of the variability of natural radioactivity concentrations in the media of interest (soil), the Sampling Plan (CABRERA, 2006) required collection of surface soil samples from a location within the Site that has no known history of containing monazite sand (i.e., background RA). Additional surface soil samples were collected from an area of the Site known to have contained monazite sand (previously impacted area). These samples were analyzed for natural thorium and natural uranium to determine the concentrations of the radionuclides of interest, as well as determine the ^{232}Th to ^{238}U and ^{232}Th to natural uranium activity ratios. The background concentrations of natural thorium and natural uranium in soil samples from the RA were used to correct the concentrations of these radionuclides in soil samples from the remaining six (6) areas of interest, as well as generate activity ratios of natural thorium to natural uranium in native, non-impacted soil. This information was then used to select an appropriate ratio threshold, above which can be concluded that the concentrations of natural radioactivity in soil are likely due to the presence of monazite sand.

Care must be exercised when evaluating soil sample results and resulting radioactivity ratios. This approach assumes the contaminant is homogenously distributed within the volume of soil sampled. Although a high ^{232}Th to ^{238}U or ^{232}Th to natural uranium activity ratio does provide reasonable assurance the contaminants are the result of monazite sand, analytical results with low ratios were evaluated as discussed in the following sections.

Additional activity ratios were also examined to verify preliminary conclusions using the ^{232}Th to ^{238}U ratios. Thorium-230 (^{230}Th) is in the decay chain of ^{238}U, as shown in Figure 1-3. The ^{232}Th to ^{230}Th ratios were investigated similar to the ^{232}Th to ^{238}U ratios. If the ratios were less than 1, the contamination was likely due to a source other than monazite sand. Conversely, if the ratio was more than one, the contamination was more likely due to the existence of monazite. The ^{232}Th to ^{230}Th ratio may provide more reliable results since both are determined using the same laboratory chemical extraction method, while ^{232}Th and ^{238}U are not.

2.0 SITE INSTRUMENTATION AND SURVEY TECHNIQUES

The purpose of this section is to describe sampling methodologies used for surface soil sample collection. Discrete surface soil sampling and offsite laboratory analyses were performed to measure concentrations of RCOCs in surface soil. The results were then used to determine the likely source of the contaminants (monazite sand or other). Chain of custody (COC) records for the samples sent offsite are presented in Appendix B. Project data was recorded in a field logbook and subsequently transferred to an electronic format, as presented in Appendix B.

2.1 Sampling Tasks

The sampling tasks performed in accordance with the Sampling Plan (CABRERA, 2006) included the following activities.

2.1.1 Gamma Surveys

Soil sample locations in each PPV area were determined based on the five most elevated gamma fluence measurements collected during previous gamma walkover surveys (GWS). Stationary gamma fluence measurements were performed during this field effort to confirm previous elevated locations and select appropriate sample locations.

Outdoor gamma fluence measurements were performed using a Ludlum Model 44-20, 3-inch by 3-inch, sodium iodide (NaI) detector coupled to a Ludlum 2221 rate meter. The detector was also coupled to a Trimble XR Pro global positioning system (GPS), when necessary, to record location coordinates and survey results simultaneously.

2.1.2 Volumetric Sample Collection

Soil samples were collected using hand auger and soil coring tools. Prior to the collection of each sample, the equipment was decontaminated by washing the surface with water and a brush to avoid cross-contamination between samples. During the collection of soil samples, large twigs, stones and other similar items were removed. Volumetric samples were collected from 0 to 30 centimeters below ground surface (bgs) and analyzed at an off-site laboratory.

3.0 RESULTS

Field sampling activities were performed within the Site areas specified in the following sections. Surface soil samples were collected from the background RA and the CA. Surface soil samples were also collected from the six (6) PPV areas of interest at biased locations identified from previous survey efforts (MACTEC, 2006).

To accomplish analytical data and ratio comparison, RA background concentrations were not subtracted from the sample results obtained from the CA or PPV areas. This is appropriate since the intent was to evaluate how close the results compare to expected ratios in the RA, as well as from pure monazite sand, to provide an indication of the most likely source of elevated radioactivity in soil.

Complete analytical results are presented in Appendix C. A summary of survey results is presented in Table 3-1. A summary of activity ratios is presented in Table 3-2.

TABLE 3-1: ANALYTICAL RESULTS SUMMARY

SU[1]	Number of samples	Thorium-232 Results			Uranium-238 Results			Thorium-230 Results		
		Average (pCi/g)	Standard Deviation	Max (pCi/g)	Average (pCi/g)	Standard Deviation	Max (pCi/g)	Average (pCi/g)	Standard Deviation	Max (pCi/g)
3A	5	4.33	1.43	6.70	1.32	0.17	1.59	1.63	0.19	1.90
3B	5	6.84	2.60	9.70	1.88	0.54	2.38	2.05	0.48	2.69
3C	5	6.95	1.78	9.10	1.62	0.38	2.02	1.95	0.23	2.29
3D	5	0.71	0.07	0.79	1.00	0.27	1.47	1.17	0.10	1.32
3E	5	1.52	0.05	1.57	2.52	0.22	2.83	2.50	0.22	2.79
3F	5	6.02	4.72	13.0	1.47	0.54	2.25	1.85	0.57	2.66
RA	5	1.00	0.14	1.20	1.03	0.09	1.15	1.45	0.16	1.64
CA	20	1.12	0.56	2.35	0.67	0.24	1.05	0.83	0.39	1.46

NOTES: 1. SU=Survey Unit; 3A~3F =Six PPV Areas of Interest; RA=Reference Area; CA=Known Monazite Sand Contaminated Area.

TABLE 3-2: ACTIVITY RATIOS SUMMARY

SU[1]	Number of samples	Th-232 to U-238 Ratio			Indicated Contaminant Source	Th-232 to Th-230 Ratio			Indicated Contaminant Source
		Average	Standard Deviation	Max		Average	Standard Deviation	Max	
3A	5	3.22	0.67	4.21	Monazite	2.62	0.58	3.53	Monazite
3B	5	3.54	0.69	4.13	Monazite	3.28	0.92	4.08	Monazite
3C	5	4.45	1.36	5.91	Monazite	3.52	0.55	4.09	Monazite
3D	5	0.74	0.15	0.87	Other[2]	0.60	0.04	0.66	Other[2]
3E	5	0.61	0.07	0.70	Other[2]	0.61	0.07	0.72	Other[2]
3F	5	3.63	1.60	5.78	Monazite	2.92	1.48	4.89	Monazite
RA	5	0.98	0.22	1.30	N/A[3]	0.69	0.06	0.75	N/A[3]
CA	20	1.68	0.63	2.94	Monazite	1.44	0.57	2.67	Monazite

NOTES: 1. SU=Survey Unit; 3A~3F =Six PPV Areas of Interest; RA=Reference Area; CA=Known Monazite Sand Contaminated Area.
2. May include coal ash, building materials, or other sources of natural radioactivity.
3. Reference areas are assumed to be free of contaminants.

3.1 Background Reference Area

The RA used during the Area 18 (CA) remediation was also used for this study. Five (5) surface soil samples [0 to 30 centimeters bgs] were obtained from random locations selected by the sampling team. These locations were selected from portions of the area that were relatively flat. Locations that were avoided include lower portions of downward sloping soil, as well as ditches and the base of creek banks where contaminants may concentrate.

The ^{232}Th results averaged 1.00 picocurie per gram (pCi/g), with a standard deviation of 0.14 pCi/g and a maximum of 1.20 pCi/g. The ^{238}U results averaged 1.03 pCi/g, with a standard deviation of 0.09 pCi/g and a maximum of 1.15 pCi/g.

The ^{232}Th to ^{238}U activity ratios averaged 0.98, with a standard deviation of 0.22 and a maximum of 1.30. The ^{232}Th to ^{230}Th ratios were slightly different, with an average of 0.69, standard deviation of 0.06 and maximum of 0.75.

3.2 Known Monazite Sand Contaminated Area

Monazite sand was previously stored at a location in the northwestern section of the Site (CA). The sampling team used handheld radiological instrumentation to identify locations within this area that exhibited elevated radioactivity for selection of 20 biased sample locations.

The ^{232}Th results averaged 1.12 pCi/g, with a standard deviation of 0.56 pCi/g and a maximum of 2.35 pCi/g. The ^{238}U results averaged 0.67 pCi/g, with a standard deviation of 0.24 pCi/g and a maximum of 1.05 pCi/g.

The ^{232}Th to ^{238}U activity ratios averaged 1.68, with a standard deviation of 0.63 and a maximum of 2.94. The ^{232}Th to ^{230}Th ratios were similar, with an average activity ratio of 1.44, standard deviation of 0.57 and maximum of 2.67.

Note: Of the 20 samples obtained in the CA, five had ^{232}Th to ^{238}U activity ratios less than 1, and seven had ^{232}Th to ^{230}Th ratios less than 1. This indicates that any remaining monazite contamination present may not be uniformly distributed. However, as a whole, the results are indicative of ratios expected from monazite sand.

3.3 Six Areas of Interest (PPV Areas)

3.3.1 Area 3A

This area is in the vicinity of a four- unit housing complex. The radiological contour map generated from a previous survey indicates two areas of elevated radioactivity in soil, one area of approximately 200 square meters (m^2) on the north side of the housing unit and a smaller area of approximately 100 m^2 on the east side of the same housing unit, in the vicinity of a carport. Soil samples could not be collected at the smaller area east of the housing unit because the elevated area was located under concrete pavement. Five (5) surface soil samples were collected from the area north of the housing unit in Area 3A (refer to Figure 1-1). Locations were selected using the five highest survey locations previously identified. During field activities, CABRERA personnel noted that the soil seemed to lack material consistent with coal ash or slag.

The ^{232}Th results averaged 4.33 pCi/g, with a standard deviation of 1.43 pCi/g and a maximum of 6.70 pCi/g. The ^{238}U results averaged 1.32 pCi/g with a standard deviation of 0.17 pCi/g and a maximum of 1.59 pCi/g.

The ^{232}Th to ^{238}U activity ratios averaged 3.22 with a standard deviation of 0.67 and a maximum of 4.21. The ^{232}Th to ^{230}Th ratios were also very similar, with an average of 2.62, standard deviation of 0.58 and maximum of 3.53. All of the five selected locations had ^{232}Th to ^{238}U and

^{232}Th to ^{230}Th activity ratios greater than 1. Therefore, the contaminant source at this location is monazite sand.

3.3.2 Area 3B

This area is in the vicinity of a ball field. The radiological contour map generated from a previous survey indicates a large area of approximately 1,500 m^2 with elevated radioactivity in soil. The most significant radioactivity was found on the northwest side of the ball field in an area where a creek borders the survey area. Five (5) surface soil samples were collected from Area 3B (refer to Figure 1-1). Locations were selected using the five highest survey locations previously identified. During field activities, CABRERA personnel noted the presence of slag material in the soil.

The ^{232}Th results averaged 6.84 pCi/g, with a standard deviation of 2.60 pCi/g and a maximum of 9.70 pCi/g. The ^{238}U results averaged 1.88 pCi/g, with a standard deviation of 0.54 pCi/g and a maximum of 2.38 pCi/g.

The ^{232}Th to ^{238}U activity ratios averaged 3.54, with a standard deviation of 0.69 and a maximum of 4.13. The ^{232}Th to ^{230}Th ratios were also very similar, with an average of 3.28, standard deviation of 0.92 and maximum of 4.08. All of the five selected locations had ^{232}Th to ^{238}U and ^{232}Th to ^{230}Th activity ratios greater than 1. Therefore, although there appeared to be slag like material in the soil at this location, analytical data indicates the contaminant source is monazite sand.

3.3.3 Area 3C

This area is on the east and west sides of Great Lakes Drive. The radiological contour map generated from a previous survey indicates three (3) locations of elevated radioactivity on the west side of Great Lakes Drive, between the pavement and sidewalk. Collectively, these areas cover approximately 100 m^2. A second, smaller area of elevated radioactivity, approximately 25 m^2, is found on the east side of the street. Five (5) surface soil samples were collected from Area 3C (refer to Figure 1-1). Locations were selected using the five highest survey locations previously identified. During field activities, CABRERA personnel noted that the soil consisted mostly of clay and lacked material consistent with coal ash or slag.

The ^{232}Th results averaged 6.95 pCi/g, with a standard deviation of 1.78 pCi/g and a maximum of 9.10 pCi/g. The ^{238}U results averaged 1.62 pCi/g, with a standard deviation of 0.38 pCi/g and a maximum of 2.02 pCi/g.

The ^{232}Th to ^{238}U activity ratios averaged 4.45, with a standard deviation of 1.36 and a maximum of 5.91. The ^{232}Th to ^{230}Th ratios were also very similar, with an average of 3.52, standard deviation of 0.55 and maximum of 4.09. All of the five selected locations had ^{232}Th to ^{238}U and ^{232}Th to ^{230}Th activity ratios greater than 1. Therefore, the contaminant source at this location is monazite sand.

3.3.4 Area 3D

This is an area surrounding a duplex housing unit. The radiological contour map generated from a previous survey indicates an area of elevated radioactivity exists on the southwest side of the structure, approximately 50 m^2 in size. Five (5) surface soil samples were collected from the location of elevated radioactivity in Area 3D (see Figure 1-1). Locations were selected using the five highest survey locations previously identified. During field activities, CABRERA personnel noted that the soil consisted mostly of clay and lacked visual indication of material consistent with coal ash or slag.

The ^{232}Th result averaged 0.71 pCi/g, with a standard deviation of 0.07 pCi/g and a maximum of 0.79 pCi/g. The ^{238}U result averaged 1.0 pCi/g, with a standard deviation of 0.27 pCi/g and a maximum of 1.47 pCi/g.

The ^{232}Th to ^{238}U activity ratio averaged 0.74, with a standard deviation of 0.15 and a maximum of 0.87. The ^{232}Th to ^{230}Th ratios were also very similar, with an average of 0.60, standard deviation of 0.04 and maximum of 0.66. All of the five selected locations had ^{232}Th to ^{238}U and ^{232}Th to ^{230}Th activity ratios less than 1. Therefore, monazite sand contamination is not present at this location. Although the ^{232}Th to ^{238}U ratios indicate the contaminant source may be coal ash or other material, such as building materials, the ^{232}Th to ^{230}Th ratios are not significantly different than the same ratios from the RA for natural radioactivity in soil.

3.3.5 Area 3E

This area is in the southeast corner of the housing area property boundary. The radiological contour map generated from a previous survey indicates an area of elevated radioactivity, approximately 200 m^2 in size, exists on the downward slope of this area. Five (5) surface soil samples were collected from the location of elevated radioactivity in Area 3E (refer to Figure 1-1). Locations were selected using the five highest survey locations previously identified. During field activities, CABRERA personnel noted that the soil consisted entirely of material consistent with ash.

The ^{232}Th result averaged 1.52 pCi/g, with a standard deviation of 0.05 pCi/g and a maximum of 1.57 pCi/g. The ^{238}U result averaged 2.52 pCi/g, with a standard deviation of 0.22 pCi/g and a maximum of 2.83 pCi/g.

The ^{232}Th to ^{238}U activity ratio averaged 0.61, with a standard deviation of 0.67 and a maximum of 0.70. The ^{232}Th to ^{230}Th ratios were also very similar, with an average of 0.61, standard deviation of 0.07 and a maximum of 0.72. All of the five selected locations had ^{232}Th to ^{238}U and ^{232}Th to ^{230}Th activity ratios less than 1. Therefore, monazite sand contamination is not present at this location. Although the ^{232}Th to ^{238}U ratios indicate the contaminant source may be coal ash or other material, such as building materials, the ^{232}Th to ^{230}Th ratios are not significantly different than the same ratios from the RA for natural radioactivity in soil.

3.3.6 Area 3F

This area is on the west side of a creek, south of the area identified in Area 3B. The radiological contour map generated from a previous survey indicates this area of elevated radioactivity covers approximately 400 m^2. Five (5) surface soil samples were collected from the location of elevated radioactivity in Area 3F (refer to Figure 1-1). Locations were selected using the five highest survey locations previously identified. During field activities, CABRERA personnel noted that slag material was present in the soil.

The ^{232}Th result averaged 6.02 pCi/g, with a standard deviation of 4.72 pCi/g and a maximum of 13.0 pCi/g. The ^{238}U result averaged 1.47 pCi/g, with a standard deviation of 0.54 pCi/g and a maximum of 2.25 pCi/g.

The ^{232}Th to ^{238}U activity ratio averaged 3.63, with a standard deviation of 1.60 and a maximum of 5.78. The ^{232}Th to ^{230}Th ratios were also very similar, with an average of 2.92, standard deviation of 1.48 and maximum of 4.89. All of the five selected locations had ^{232}Th to ^{238}U and

^{232}Th to ^{230}Th activity ratios greater than 1. Therefore, although material in soil at this location appeared contain slag material, analytical data indicates the contaminant source is monazite sand.

3.3.7 Summary

During evaluation of sample results, potential sources of error were considered. Sample analytical results and radionuclide ratios from PPV areas 3A, 3B, 3C and 3F clearly indicate natural thorium predominates, as would be expected from soil contaminated with monazite sand. However, for PPV areas 3D and 3E, where these results are more indicative of other sources of contaminants, it becomes more important to assure error was not introduced in the sampling method, particularly via dilution of the sample with surrounding uncontaminated soil which may have skewed the results, resulting in ratios less than 1.

If error had been introduced due to dilution, it would be expected that the variation (standard deviation) in sample results, i.e., analytical results and radionuclide ratios, would be higher than those found in the other areas. However, the samples from PPV areas 3D and 3E exhibited the lowest variation of all PPV area samples, for both radionuclide concentrations and ratios, with the exception of ^{238}U and ^{230}Th concentrations in PPV area 3A which had a lower standard deviation than PPV area 3E.

One possible reason for such low distribution would have been the samples were not distributed far enough apart. However, from review of the distribution of sample locations in Figure 3-1 this does not appear to be the case. Therefore, it is concluded that the samples from these 2 PPV areas are representative of the radionuclide concentration and ratios, with dilution likely not a significant contributor to potential error in the conclusion.

4.0 SURVEY QUALITY ASSURANCE/QUALITY CONTROL

Activities associated with this Sampling Report were performed in accordance with written procedures and/or protocols in order to ensure consistent, repeatable results. Implementation of Quality Assurance (QA) measures for this report is described herein.

Only qualified and trained personnel operated the equipment and instrumentation used in the field activities specified in this report. Personnel were trained in the technical, quality control, and health and safety aspects of the project, as well as in the calibration, maintenance, and operating procedures for their assigned equipment.

4.1 Instrumentation Requirements

The CABRERA Project Health Physicist (HP) was responsible for determining the instrumentation required to complete the requirements of this characterization survey. Only instrumentation approved by the CABRERA Project HP was used to collect radiological data. The CABRERA Project HP was responsible for ensuring individuals were appropriately trained to use project instrumentation and other equipment, and that instrumentation met the required detection sensitivities. Survey instruments were operated in accordance with either a written procedure or manufacturers' manual, as determined by the CABRERA Project HP.

Instrument quality control (QC) checks were performed during the characterization survey as presented in the Sampling Plan (CABRERA, 2006; see Appendix A). Instruments used to obtain radiological data, including GPS equipment, were inspected for physical damage, current calibration and erroneous readings in accordance with applicable procedures and/or protocols. Calibration sheets for instruments used during field activities are presented in Appendix D. The individual performing these tasks documented the results in accordance with the associated instrument procedure and/or protocols. Any instrumentation not meeting the specified requirements of calibration, inspection, or response check required removal from operation (none needed to be removed). The instrumentation QC data results are presented in Appendix D.

4.1.1 Calibration Requirements

Instruments used during the characterization survey had current calibration and maintenance records onsite for review and inspection. The records included the following:

- Name of the equipment;

- Equipment identification (model and serial number);
- Manufacturer;
- Date of calibration; and
- 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 under current calibration.

4.1.2 Instrument QC Source Checks

Prior to daily use, project instrumentation was QC checked by comparing instrument response to a benchmark response. Prior to the commencement of field operations, reference locations were selected for performance of these checks; subsequent QC checks were performed at these locations. QC source checks consisted of a 1-minute integrated count with the designated source positioned in a reproducible geometry performed at the reference location. Prior to the start of initial surveys, this procedure was repeated at least ten times to establish average instrument response.

4.1.2.1 Direct Radiation Measurement Instrumentation QC

Detectors used for direct radiation measurements included the Ludlum 43-93, Ludlum 44-20 and Ludlum 44-9. Instrument responses to designated QC check sources were recorded and evaluated against the average established at the start of the field activities. An acceptance criterion of ± 20% was required for the Ludlum 44-20 and Ludlum 44-9, and ± 3σ for Ludlum 43-93. A QC count outside the respective acceptance criterion required informing the field lead, a detector evaluation and could have resulted in the detection system being removed from service for corrective action.

4.1.3 Duplicate Sample Analyses

CABRERA collected duplicate samples for 5% of all analytical samples, as presented in the Sampling Plan (CABRERA, 2006a). The samples were numbered using a unique identifier. Analyses of laboratory duplicates were compared to the initial analytical results by determining a Normalized Absolute Difference (NAD) value for each data set by the following equation:

$$\text{Normalized Absolute Difference}_{\text{Duplicate}} = \frac{\left|\text{Sample - Duplicate}\right|}{\sqrt{\sigma^2_{\text{Sample}} + \sigma^2_{\text{Duplicate}}}}$$

where:

Sample = first sample value (original),

Duplicate = second sample value (duplicate),

σ_{Sample} = counting uncertainty of the sample, and

$\sigma_{\text{Duplicate}}$ = counting uncertainty of the duplicate

The calculated NAD results were compared to a performance criteria of less than or equal to 1.96. Calculated NAD values less than or equal to 1.96 were considered acceptable and values greater than 1.96 were investigated for possible discrepancies in analytical precision, or for sources of disagreement with the following assumptions of the test:

- The sample measurement and duplicate or replicate measurement are of the same normally distributed population.
- The standard deviations, σ_{Sample} and $\sigma_{\text{Duplicate}}$, represent the true standard deviation of the measured population.

There were three laboratory samples, or approximately 5% of the total number of samples collected, analyzed as duplicates. All laboratory measurement passed the calculated NAD performance criteria of less than or equal to 1.96. The results are presented in Appendix D.

5.0 HEALTH AND SAFETY

Health and safety measures were employed during conduct of survey activities, in accordance with the project Site Safety and Health Plan (SSHP) (CABRERA, 2001).

Daily health and safety activities were performed in accordance with the project SSHP, including conducting Daily Tailgate Safety meetings, prior to the performance of survey activities each day. These daily safety meetings allowed for discussion of daily safety measures required based on the activities planned for each day. Daily Safety Tailgate Meeting records are provided in Appendix E. The SSHP was reviewed by CABRERA project and sub-contractor personnel prior to the performance of survey activities. CABRERA project and sub-contractor personnel signed a form acknowledging that they read and understood the SSHP; this form is provided in Appendix E. No reported injuries took place during the survey field effort.

6.0 SUMMARY OF RESULTS AND CONCLUSIONS

Field sampling activities were conducted at the Site to determine if radioactive contamination present in the areas of interest is due to the presence of monazite sand or simply the result of other, non-licensed material, with similar naturally occurring radionuclides.

Soil sampling activities were performed within the Site at the six (6) PPV areas of interest areas (3A through 3F), as well as from the RA and CA. Samples were analyzed by an offsite laboratory via alpha spectroscopy. Sufficient data was collected to establish radioactivity ratios for ^{232}Th to ^{238}U and select an appropriate activity ratio threshold above which the source can be concluded to be monazite sand.

It was concluded that activity ratios for ^{232}Th to ^{238}U above 1 indicated the presence of monazite sand, while ratios below 1 indicated the radioactivity was due to some other source, such as coal ash, building materials, or simply the natural radioactivity in soil. Activity ratios of ^{232}Th to ^{238}U in areas 3A, 3B, 3C, and 3F were all greater than 1 (3.22, 3.54, 4.45, and 3.63, respectively), while the ratios for the same radionuclides in areas 3D and 3E were less than 1 (0.74 and 0.61, respectively).

Based on the measured activity ratios for ^{232}Th to ^{238}U, verified using ratios for ^{232}Th to ^{230}Th, monazite sand is the source of soil contamination in PPV areas 3A, 3B, 3C, and 3F. However, the ratios in soil from PPV areas 3D and 3E indicate the contaminant is not the result of presence of monazite sand.

7.0 REFERENCES

(CABRERA, 2001) *"Site Safety and Health Plan, Naval Station Great Lakes, Great Lakes, Illinois,* Contract DAAA09-02-D-0024/30.

(CABRERA, 2006) *"Sampling Plan For Task 3: Coal Ash Determination, Naval Station Great Lakes, Great Lakes, Illinois,* Contract DAAA09-02-D-0024/30.

(DOE, 1996) *Naturally Occurring and Accelerator Produced Radioactive Material*, U.S. Department of Energy, Office of Environmental Management, dated 1996.

(EPA, 1993) Oak Ridge National Laboratory Review, *Coal Combustion: Nuclear Resource or Danger*, report by Mr. Alex Gabbard, dated July, 1993.

(MACTEC, 2006) *Forrestal Village Phased-Approach Radiological Survey Report In Support of the Phase II Environmental Assessment, NAVSTA Great Lakes, Naval Region Midwest Family Housing Privatization*, MACTEC, dated February, 2006.

(NRC, 1994) NUREG-1501, *Background as a Residual Radioactivity Criterion for Decommissioning*, *Draft Report*, U.S. Nuclear Regulatory Commission, dated August, 1994.

(NRC, 2001) NRC SECY-01-0057, Policy Issue, *Partial Response to SRM COMEXM-00-0002 – "Expansion of NRC Statutory Authority Over Medical Use of Naturally Occurring and Accelerator-Produced Radioactive Material (NARM)"*, U.S. Nuclear Regulatory Commission, dated March, 2001.

(USGS, 1997) *Radioactive Elements in Coal and Fly Ash: Abundance, Forms, and Environmental Significance*, dated October, 1997.

APPENDIX A

SAMPLING PLAN FOR TASK 3: COAL ASH DETERMINATION

APPENDIX B

FIELD SURVEY SUPPORTING DOCUMENTATION

APPENDIX C
ANALYTICAL RESULTS

APPENDIX D
QA/QC RECORDS

APPENDIX E

HEALTH AND SAFETY RECORDS