**FINAL REPORT**

# Radiological Final Status Survey Report Bomb Throwing Device Site - Soils

## Aberdeen Proving Ground, Aberdeen, MD

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# Executive Summary

Cabrera Services, Inc. (CABRERA), under contract to the U.S. Army Field Support Command (FSC), performed remedial activities, remedial support surveys, and Final Status Surveys (FSS) for the Bomb Throwing Device (BTD) site at the Aberdeen Proving Ground (APG), Maryland. This document provides the results of post-remediation surveys designed to describe the final radiological status of the site and demonstrates that the site is suitable for release for unrestricted use.

CABRERA conducted survey activities in accordance with the U.S. Nuclear Regulatory Commission (NRC) approved Final Status Survey (FSS) work plan, prepared by CABRERA and included as Appendix B of this report. This report specifically presents the results of the BTD site FSS activities, which were designed in accordance with the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) (NRC 2000) guidance.

The project had several major activities associated with the remediation and FSS including:

- Remediation of soils, debris, and structures within the confines of the BTD site,
- Deconstruction of structures on the BTD site,
- Removal of plate steel for on-site recycling,
- Removal and shipment of remediated soils and debris to Envirocare of Utah,
- Designation of the BTD land areas into MARSSIM Class 1 Survey Units,
- FSS of the BTD site soils and structures, and
- Determine that the dose from residual contamination at the site is not greater than the release criterion for each Survey Unit.

Final status surveys were performed over a land area of approximately 46,000 square meters and on access roads and several support buildings situated on the BTD site. This FSS report addresses only BTD site land areas; surveys performed on structures are addressed under separate cover. The radiological contaminant of concern was depleted uranium (DU). The derived concentration guideline ($DCGL_W$) for DU was determined to be 220 picocuries per gram (pCi/g) and, based on its isotopic weight ratio, 184 pCi/g for uranium-238 ($^{238}U$). An As Low As Reasonably Achievable (ALARA) target and remediation goal of 105 pCi/g DU and 88 pCi/g $^{238}U$ was established for this project as described in, "DCGL for BTD Soil Sample Area Addendum", included as Appendix A to this report.

The FSS established twenty-five (25) Class 1 survey units (SU). The final status survey consisted of a 100% gamma walkover survey and soil sample collection and laboratory analysis. Soil sample collection was limited to the surface, from 0 to 15 cm below grade.

All soil sample results are below the ALARA target of 88 pCi/g $^{238}U$. The results of the soil samples areas show the highest $^{238}U$ soil sample result was 80 pCi/g. The FSS gamma walkover survey for the BTD site shows all remediated areas are less than 35,000 cpm or less than the ALARA target of 88 pCi/g $^{238}U$. The FSS data indicates that the site is suitable for release for unrestricted use, without regard for former operations with licensed radioactive material.

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# Glossary of Acronyms and Abbreviations

| | |
|---|---|
| ALARA | As Low As Reasonably Achievable |
| APG | Aberdeen Proving Ground |
| ARL | Army Research Laboratory |
| ATC | Aberdeen Test Center |
| BARF | BTD Armor Reclamation Facility |
| BTD | Bomb Throwing Device |
| CABRERA | Cabrera Services, Inc. |
| cm | Centimeters |
| cpm | Counts Per Minute |
| DCGL or DCGLw | Derived Concentration Guideline Level |
| DU | Depleted Uranium |
| Enclosure | DU Test Enclosure Building |
| EPA | U.S. Environmental Protection Agency |
| FSC | U.S. Army Field Support Command |
| FSS | Final Status Survey |
| ft | Feet |
| GPS | Global Positioning System |
| GWS | Gamma Walkover Survey |
| HEPA | High Efficiency Particulate Air filter unit |
| LAB | Liquid Abrasive Blaster |
| LBGR | Lower Bound of the Grey Region |
| m | Meters |
| $m^2$ | Square meters |

| | |
|---|---|
| MARSSIM | Multi-Agency Radiation Survey And Site Investigation Manual |
| MDC | Minimum Detectable Concentration |
| μRem | Microrem |
| mrem | Millirem |
| NAD | Normalized Absolute Difference |
| NIST | National Institute of Standards and Technology |
| NRC | U. S. Nuclear Regulatory Commission |
| Paragon | Paragon Analytics, Inc. |
| pCi/g | Pico Curies per gram |
| PSA | Plate Storage Area |
| QA | Quality Assurance |
| QC | Quality Control |
| ROPC | Radionuclides of Potential Concern |
| SU | Survey Unit |
| TEDE | Total Effective Dose Equivalent |
| $^{234}U$ | Uranium-234 |
| $^{235}U$ | Uranium-235 |
| $^{238}U$ | Uranium-238 |
| Wash Racks | Wash Racks #2 and #3 |
| WESTON | Roy F. Weston |

# 1. INTRODUCTION

Cabrera Services, Inc. (CABRERA) is under contract to the United States Army Field Support Command (FSC) to provide support to the Aberdeen Test Center (ATC) at the Aberdeen Proving Ground (APG) in Aberdeen, MD. CABRERA performed facility demolition, remediation, and site wide radiological surveys of the Bomb Throwing Device site (BTD) to support consideration for unrestricted release. The BTD site consists of approximately 46,000 square meters of land on the APG used for the testing of Depleted Uranium (DU) munitions.

This document presents the results of the BTD land area Final Status Survey (FSS) activities, performed in accordance with Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) (NRC, 2000) guidance. This report addresses only BTD soils of approximately 46,000 square meters. Decommissioning of the BTD Armor Reclamation Facility (BARF), the Liquid Abrasive Blaster (LAB) housed within the BARF, Building 701, DU Test Enclosure Building (Enclosure), Enclosure building high efficiency particulate air filter unit (HEPA), Plate Storage Area (PSA), two concrete pads, Wash Rack Facility #2, Wash Rack Facility #3 (Wash Racks), and two steel storage structures located within the boundary of the BTD site will be addressed under separate cover.

## 1.1 Site History

Aberdeen Proving Ground, located in Aberdeen, MD, is an active U.S. Army testing and research facility. The Aberdeen Proving Ground (APG) lies along the western shore of the Chesapeake Bay in Harford and Baltimore Counties, MD, approximately 15 miles northeast of Baltimore. The APG covers a total of 72,516 acres (land and water) and consists of two distinct areas: the northern portion of APG, referred to as the Aberdeen Area; and the southern portion of APG, referred to as the Edgewood Area. The Aberdeen Area became a formal military post, designated as the APG, in 1917. Figure 1 shows the location of the BTD site relative to APG and surrounding towns.

The BTD site was used between 1982 and 1993 for the testing of DU munitions. In 1993, the site consisted of the BARF, the Enclosure building, the Enclosure building HEPA, the PSA, Wash Racks 2 and 3, access roads, and several support buildings situated on approximately 46,000 square meters of land. During use, munitions were fired at steel plate and other targets inside the DU Test Enclosure Building. The ATC tested DU munitions utilizing an enclosure with HEPA equipment, used to collect potentially contaminated air exiting the building.

Roy F. Weston (Weston) provided a radiological characterization for the BTD site in 2001 (Weston, 2001). The Weston characterization encompassed the BTD site and divided the site into Class 1, 2, and 3 areas. Soil samples were taken from each area and compared to the NRC soil screening value of 14 pCi/g for uranium-238. Both surface (0-0.25 ft) and subsurface samples (1-1.5 ft) were taken. All values exceeding the soil action level as described in this report were found to exist in the surface soil (0-0.25 ft). An exception was the presence of several subsurface samples taken in the vicinity of the DU Test Enclosure Building that showed levels of soil contamination in excess of the soil action level.

Prior to remediation of the site, approximately 40 tons of DU-contaminated armor plate was located within the Enclosure Building and surrounding grounds. Heavy equipment was used to transport the armor plates between the Enclosure Building and the PSA. As part of the remedial activities and subsequent to the removal of the armor plates, the Test Enclosure Building, the HEPA ventilation system, the footings for the Test Enclosure Building, the "White" Building, the "Rust" Building, and the Sabot Stripper were removed in their entirety.

## 1.2 General Summary of Decommissioning Activities

The BTD site decommissioning consisted of demolition, soil excavation, and removal of contaminated soil and demolition debris. As physical decommissioning actions were completed, FSSs were performed on both structures and land areas (this report addresses only land area FSSs). Much of the plate steel that was generated during site cleanup and demolition (primarily the Enclosure Building) was transferred to the Army Research Laboratory (ARL) facility, at APG Spesutie Island, for decontamination and recycling; a cost analysis performed by the Army indicated that it was less expensive than offsite disposal to recycle the material and that there was a beneficial reuse in support of APG's mission. Other demolition debris and excavated soil was considered unwanted radioactive material and was shipped via rail to Envirocare of Utah, an NRC licensed disposal facility, for shallow land burial.

- During initial mobilization in February 2003, the CABRERA field crew entered the BARF and dismantled, surveyed and removed the DU armor plate reclamation machine (Liquid Abrasive Blaster) housed within the BARF.

- In May 2003 CABRERA re-mobilized to perform FSS on the inside of the BARF, and demolish the Enclosure building. Most steel plate removed from the Enclosure Building was moved via APG-supplied transportation to the ARL Spesutie Island Facility for decontamination and beneficial reuse. Other steel/debris was containerized in intermodals for future rail shipment to Envirocare of Utah.

- During June 2003, the CABRERA team performed remediation/FSS of Wash Racks 2 and 3, dismantled the two steel vault storage buildings (the 'White' and 'Rust' Buildings) and left the scrap steel piled for transfer to ARL or other use, as instructed by ATC personnel. Concurrent to the dismantling operations and through the month of August 2003, the CABRERA team completed the majority of the GWS, excavated contaminated soils, and stockpiled the remediated soil (approximately 1,200 cubic yards) into a laydown area within Survey Units 16 and 22. CABRERA demobilized at the end of August 2003.

- In February 2004, the CABRERA team returned to the BTD site and performed data collection for survey gaps and accomplished 95% of the remediated soil load out. The soil was packed into intermodal containers, and the intermodals were shipped via rail to Envirocare of Utah.

- In March through June 2004, the remainder of the soil was loaded/shipped to Envirocare for disposal and two concrete pad surfaces were remediated with a steel ball blast/HEPA vacuum system. One concrete pad behind Building 701 was previously covered by the

soil stockpile (in Survey Unit 16) and the other was the pad used to support the Enclosure Building HEPA system, which was removed during the Enclosure Building demolition. Following concrete cleaning, the surfaces were surveyed and land FSSs were performed in Survey Units 16 and 22.

- At the time of this writing, all soil/debris shipped via rail to Envirocare of Utah has been transferred to Envirocare of Utah and the Army is awaiting final disposition documentation.

## 1.3 General Approach to the BTD Remediation and FSS

The FSS investigations are designed using the approach outlined in MARSSIM (NRC, 2000).

- Development of Derived Concentrations Guideline Levels
- Selection of instrumentation and measurement techniques
- Identification of survey units and classify areas by contamination potential
- Estimation of the number of measurement locations
- Collection of data
- Evaluation of data

## 1.4 Radionuclides of Potential Concern (ROPCs)

Site Radionuclides of Potential Concern (ROPC) are limited to DU and short-lived progeny. The uranium ratios are based on isotopic uranium weight ratios used for shipments of routine DU waste from APG (BARG, 1995). The activity fractions are calculated from the isotopic weight ratios and the specific activity of each uranium isotope. The result is a Uranium-234 ($^{234}U$): Uranium-235 ($^{235}U$): Uranium-238 ($^{238}U$) ratio of 0.084 : 0.012 : 0.904. During DCGL development, a more conservative isotopic ratio was established to ensure adequate protectiveness. This composition, $^{234}U$: $^{235}U$: $^{238}U$ of 0.138 : 0.0234 : 0.839, is used to evaluate FSS data herein. See Appendix A, Section 2.1.3, for details.

## 2.0 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. Survey unit grids, site boundaries, and other survey reference points related to land areas are described by northing and easting coordinates, in meters, tied to North American Datum 1983 State Plane Maryland.

## 3.0 DERIVED CONCENTRATION GUIDELINE LEVEL

The Derived Concentration Guideline Level (DCGL) for the BTD Site soil is 220 pCi/g total DU (resident scenario) and 184 pCi/g $^{238}$U. The ALARA target level DCGL has been set at 88 pCi/g $^{238}$U. Application of this DCGL will ensure that the potential dose to the average member of the critical group will not exceed 25 millirem (mrem) in any one year over a 1,000-year period.

### Table 3-1. BTD Volumetric DCGL

| Parameter | Depleted Uranium Activity Concentration (pCi/g) | |
|---|---|---|
| | Total Uranium | $^{238}$U |
| DCGL | 220 | 184 |
| ALARA Target | 105 | 88 |

$^{238}$U derived from the isotopic activity ratio of 83.9%

The DCGL applied to the BTD Site was initially developed using data from the Transonic Range located at APG and was considered equivalent to the Transonic Range DCGL. A document submitted to the NRC (CABRERA), July 2004, "Final U.S. Army Garrison, Aberdeen Proving Ground Derived Uranium Guidelines For Depleted Uranium at the BTD Soil Sample Area Addendum" uses four assumed data sets to compare the DCGL at BTD with that at the Transonic site. These comparisons can be seen in Appendix A of this report. Using the most protective data run, APG-RES3, evaluation showed that based on the RESRAD version 6.22 computer code output, the BTD Site soil DCGL of 220 pCi/g total DU (resident scenario) is essentially equal to the Transonic Range soil DCGL. The ALARA principle of as-low-as-reasonably-achievable is applied to provide assurance that hypothetical doses are limited.

# 4.0 FINAL STATUS SURVEY DESIGN

## 4.1 Survey Unit Classification and Delineation

The focus of this FSS is the radiological assessment of surface soil over the entire 46,000 square meters BTD site. The land area associated with the BTD site consists of open grassy areas with one area of standing trees. Originating near the center of the BTD site is a wetland ravine. The ravine is approximately 140 meters in length, averaging up to several meters in width, and often has water covered surfaces. Water depths in the ravine range from several centimeters to approximately 15 centimeters. The CABRERA remediation and FSS conservatively assumes the entire site is a Class 1. As seen in Table 4-1 and in Figure 2, the BTD site was divided into 25 survey units.

## 4.2 Determination of N (Number of Required Measurement Locations)

The minimum number of measurement locations required is dependent on the distribution of site residual radionuclide concentrations relative to the DCGL and acceptable decision error limits ($\alpha$ and $\beta$).

The relative shift describes the relationship of site residual radionuclide concentrations to the DCGL and is calculated using the guidance found in Section 5.5.2.3 of MARSSIM. Since the amount of naturally occurring $^{238}U$ contaminant present in the soil (majority of DU) is a small fraction of the DCGL it may be considered to be insignificant. The relative shift is calculated as follows:

$$\Delta/\sigma = \frac{\text{DCGL - LBGR}}{\sigma}$$

Where: DCGL = Derived Concentration Guideline Level

LBGR = concentration at the lower bound of the gray region. The Lower Bound of the Grey Region (LBGR) is the concentration at which the survey unit has an acceptable probability of passing the statistical tests.

$\sigma$ = an estimate of the standard deviation of the concentration of residual radioactivity in the survey unit (which includes real spatial variability in the concentration as well as the precision of the measurement system).

The ALARA DCGL for surface soil radioactivity is 105 pCi/g DU. The LBGR is estimated at 52.5 pCi/g DU, which is half of the DCGL as suggested by MARSSIM. Using an estimated coefficient of variation of 30 percent and the LBGR as an estimate of the sample mean, a sigma value of 15.8 pCi/g DU is calculated. Using the parameters discussed above, the relative shift is calculated as 3.3.

The number of suggested measurement locations per survey unit is 14 as provided by MARSSIM Table 5.5 (Sign Test) given a relative shift of 3.0 and an error rate for both Type I and Type II errors of five percent (i.e., $\alpha = \beta = 0.05$).

### *4.2.1 Elevated Measurement Criterion ($DCGL_{EMC}$)*

MARSSIM states that, for Class 1 survey units, a dose area factor should be used to evaluate the magnitude by which the concentration within a small area of elevated activity can exceed the DCGL while maintaining compliance with the release criterion. For the purpose of ALARA, the DCGL will be used as the $DCGL_{EMC}$ for soil. This corresponds to an area factor of one. Since the soil $MDC_{SCAN}$ values are sensitive enough to identify a concentration that is less than half of their respective DCGL, it is unlikely that small areas of elevated activity exceeding the release criterion would be missed during scanning.

### *4.2.2 Soil Sample Locations*

Depending on survey unit size, 13 to 17 soil samples were collected within each survey unit for a total of 379 samples. The sample collection depths were 0-15 cm. Measurement locations in the survey units were established using a random start point in a systematic triangular grid. The grid spacing for each survey units was determined, based on the measured area of the survey unit, using the following equation (Equation 5-7 from MARSSIM).

$$L = \sqrt{\frac{\mathrm{A}}{0.866\ \mathrm{N}}}$$

Where: L = rectangular grid spacing for survey unit

A = area of survey unit

N = number measurement locations

Survey unit areas, and the associated grid spacing, (L), using the equation above are presented in Table 4-1. Maps showing the BTD soil sample location identifiers by survey unit based on this spacing are presented in Figures 4 through 7.

## Table 4-1. Survey Units

| SURVEY UNIT CLASS 1 | AREA, $m^2$ | NUMBER OF DATA POINTS, n | GRID SPACING, L, m |
|---|---|---|---|
| #1 | 1235 | 16 | 10.1 |
| #2 | 1596 | 15 | 11.5 |
| #3 | 1558 | 17 | 11.3 |
| #4 | 1835 | 15 | 12.3 |
| #5 | 1944 | 14 | 12.7 |
| #6 | 1995 | 14 | 12.8 |
| #7 | 2000 | 15 | 12.8 |
| #8 | 2000 | 15 | 12.8 |
| #9 | 1461 | 15 | 10.5 |
| #10 | 1652 | 17 | 11.7 |
| #11 | 1899 | 13 | 12.5 |
| #12 | 2000 | 15 | 12.8 |
| #13 | 2000 | 15 | 12.8 |
| #14 | 2000 | 14 | 12.8 |
| #15 | 2000 | 15 | 12.8 |
| #16 | 2188 | 15 | 12.8 |
| #17 | 1588 | 15 | 11.5 |
| #18 | 2000 | 15 | 12.8 |
| #19 | 2000 | 15 | 12.8 |
| #20 | 2000 | 14 | 12.6 |
| #21 | 2050 | 15 | 12.7 |
| #22 | 1968 | 17 | 12.8 |
| #23 | 1303 | 17 | 10.4 |
| #24 | 1993 | 14 | 12.8 |
| #25 | 2009 | 15 | 12.8 |

### 4.3 Systematic Surface Soil Sampling for Sign Test

Surface soil samples (0 to 15 cm, bgs) were collected in each of the survey units, to provide inputs to the FSS data evaluation. The minimum number of systematic soil sample locations required for this evaluation, in each of the survey units, was established using MARSSIM (NRC 2000) guidance. It was determined that a minimum number of sample locations were required in each of the survey units shown in Table 4-1. No reference area was selected since the natural occurring level of $^{238}U$ in the soil, (the primary constituent of DU) is a small fraction of the ALARA DCGL. For purposes of the FSS data evaluation, it is conservatively

assumed that the reference area $^{238}U$ concentration is zero. Thus the MARSSIM Sign Test is applicable.

Paragon Analytics Laboratory (Paragon) of Ft. Collins, Colorado performed gamma spectroscopy on soil samples. Soil samples were analyzed using gamma spectroscopy (EPA analysis methodology 901.1, Modified). Results are reported in terms of dry weight activity per gram of soil. Appendix C presents the results of the soil samples from the 25 survey units

## 4.4 Gamma Walkover Surveys

A GWS was performed over 100% of the accessible areas in each of the survey units. The surveys were performed following MARSSIM protocol by walking straight parallel lines over an area while moving the detector in a serpentine motion, approximately 10 cm above the ground surface. The walking speed is maintained at approximately 0.5 meters per second. Survey passes were approximately one meter apart

The purpose of the GWSs was to identify areas of elevated surface radioactivity. These surveys provide position-correlated instantaneous gross gamma count rates at a collection rate of one record per second. This was accomplished using a Global Positioning System (GPS) with sub-meter accuracy coupled to a 3-inch by 3-inch NaI detector and ratemeter/scaler. Calculated detection sensitivity described in the Final Status Survey Plan, Appendix C, for the GWS is approximately 38 pCi/gram for surficially deposited (0 to 15 cm) DU in 50-year equilibrium with its radioactive daughter products. The calculation is based on the methodology described by NUREG-1507 (NRC 1997).

# 5.0 RESULTS

## 5.1 Soil Sample Results

As shown in Figure 3 soil survey areas were divided into 25 survey units, all of which were designated as Class 1. A minimum of thirteen soil samples were collected from each SU and sent to Paragon Analytics (a division of Data Chem Laboratories, Inc) for gamma spectroscopy analysis. EPA analysis methodology 901.1 Modified, was utilized for the analysis. Results are reported in terms of dry weight activity per gram of soil. Sample activity for $^{238}U$ is inferred via the direct measurement of Th-234 decay progeny using gamma spectroscopy analysis. Appendix C presents the results of 379 soil samples from the 25 survey units and ravine area. Samples are shown as sample points 6000 through 6386 in Figures 4 through 7.

The results of the soil samples areas show the highest $^{238}U$ soil sample result was 80 pCi/g. All soil sample results are below the ALARA target of 88 pCi/g $^{238}U$ . The soil samples meet FSS release criterion. Statistical results for these 25 survey units are presented below.

### *5.1.1 SU-1 Results*

The results for the 16 samples (Field ID 6000-6015) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}U$. The $^{238}U$ results for this SU average 0.88 pCi/g, with a standard deviation of 1.3 pCi/g, and a maximum of 3.8 pCi/g. See Appendix C for the full list of soil sample results and Figure 5 for the location of each sample.

### *5.1.2 SU-2 Results*

The results for the 15 samples (Field ID 6017-6031) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}U$ . The $^{238}U$ results for this SU average 16.3 pCi/g, with a standard deviation of 25 pCi/g, and a maximum of 80 pCi/g. See Appendix C for the full list of soil sample results and Figure 7 for the location of each sample.

### *5.1.3 SU-3 Results*

The results for the 17 samples (Field ID 6032-6048) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}U$. The $^{238}U$ results for this SU average 0.95 pCi/g, with a standard deviation of 0.93 pCi/g, and a maximum of 2.5 pCi/g. See Appendix C for the full list of soil sample results and Figure 7 for the location of each sample.

### *5.1.4 SU-4 Results*

The results for the 15 samples (Field ID 6050-6064) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}U$. The $^{238}U$ results for this SU average 1.0 pCi/g, with a standard deviation of 1.0 pCi/g, and a maximum of 3.0 pCi/g. See Appendix C for the full list of soil sample results and Figure 7 for the location of each sample.

### *5.1.5 SU-5 Results*

The results for the 14 samples (Field ID 6066-6079) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 2.1 pCi/g, with a standard deviation of 3.5 pCi/g, and a maximum of 12 pCi/g. See Appendix C for the full list of soil sample results and Figure 7 for the location of each sample.

### *5.1.6 SU-6 Results*

The results for the 14 samples (Field ID 6065, 6080-6092) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 5.4 pCi/g, with a standard deviation of 8.2 pCi/g, and a maximum of 26 pCi/g. See Appendix C for the full list of soil sample results and Figure 5 for the location of each sample.

### *5.1.7 SU-7 Results*

The results for the 15 samples (Field ID 6093-6107) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 1.5 pCi/g, with a standard deviation of 1.0 pCi/g, and a maximum of 4.3 pCi/g. See Appendix C for the full list of soil sample results and Figure 5 for the location of each sample.

### *5.1.8 SU-8 Results*

The results for the 15 samples (Field ID 6108-6122) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 1.2 pCi/g, with a standard deviation of 1.4 pCi/g, and a maximum of 3.3 pCi/g. See Appendix C for the full list of soil sample result and Figure 5 for the location of each sample s.

### *5.1.9 SU-9 Results*

The results for the 15 samples (Field ID 6123-6137) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 14 pCi/g, with a standard deviation of 18 pCi/g, and a maximum of 57 pCi/g. See Appendix C for the full list of soil sample results and Figure 7 for the location of each sample.

### *5.1.10 SU-10 Results*

The results for the 16 samples (Field ID 6138-6154) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 11 pCi/g, with a standard deviation of 12 pCi/g, and a maximum of 41 pCi/g. See Appendix C for the full list of soil sample results and Figure 7 for the location of each sample.

### *5.1.11 SU-11 Results*

The results for the 13 samples (Field ID 6155-6167) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 3.6 pCi/g, with a standard deviation of 5.1 pCi/g, and a maximum of 18 pCi/g. See Appendix C for the full list of soil sample results and Figure 6 for the location of each sample.

SU-12 Results

The results for the 15 samples (Field ID 6168-6182) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 6.2 pCi/g, with a standard deviation of 9.3 pCi/g, and a maximum of 37 pCi/g. See Appendix C for the full list of soil sample results and Figure 6 for the location of each sample.

### *5.1.12 SU-13 Results*

The results for the 15 samples (Field ID 6185-6199) collected and analyzed in this Class 1 SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 4.8 pCi/g, with a standard deviation of 7.6 pCi/g, and a maximum of 26 pCi/g. See Appendix C for the full list of soil sample results and Figure 6 for the location of each sample.

### *5.1.13 SU-14 Results*

The results for the 14 samples (Field ID 6200-6213) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 3.3 pCi/g, with a standard deviation of 6.9 pCi/g, and a maximum of 27 pCi/g. See Appendix C for the full list of soil sample results and Figure 6 for the location of each sample.

### *5.1.14 SU-15 Results*

The results for the 15 samples (Field ID 6214-6228) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 0.81 pCi/g, with a standard deviation of 0.63 pCi/g, and a maximum of 1.8 pCi/g. See Appendix C for the full list of soil sample results and Figure 6 for the location of each sample.

### *5.1.15 SU-16 Results*

The results for the 15 samples (Field ID 6229-6248) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 7.8 pCi/g, with a standard deviation of 9.7 pCi/g, and a maximum of 32 pCi/g. See Appendix C for the full list of soil sample results and Figure 4 for the location of each sample.

### *5.1.16 SU-17 Results*

The results for the 15 samples (Field ID 6249-6263) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 1.2 pCi/g, with a standard deviation of 1.5 pCi/g, and a maximum of 4.6 pCi/g. See Appendix C for the full list of soil sample results and Figure 6 for the location of each sample.

### *5.1.17 SU-18 Results*

The results for the 15 samples (Field ID 6264-6278) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 0.93 pCi/g, with a standard deviation of 0.78 pCi/g, and a maximum of 2.3 pCi/g. See Appendix C

for the full list of soil sample results and Figure 6 for the location of each sample.

*SU- 19 Results*

The results for the 15 samples (Field ID 6279-6293) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 3.2 pCi/g, with a standard deviation of 7.0 pCi/g, and a maximum of 28 pCi/g. See Appendix C for the full list of soil sample results and Figure 6 for the location of each sample.

*5.1.19 SU-20 Results*

The results for the 14 samples (Field ID 6294-6307) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 2.3 pCi/g, with a standard deviation of 3.1 pCi/g, and a maximum of 12 pCi/g. See Appendix C for the full list of soil sample results and Figure 4 for the location of each sample.

*5.1.20 SU-21 Results*

The results for the 15 samples (Field ID 6308-6322) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 1.4 pCi/g, with a standard deviation of 1.1 pCi/g, and a maximum of 3.6 pCi/g. See Appendix C for the full list of soil sample results and Figure 4 for the location of each sample.

*5.1.21 SU-22 Results*

The results for the 17 samples (Field ID 6323-6339) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 10 pCi/g, with a standard deviation of 13 pCi/g, and a maximum of 47 pCi/g. See Appendix C for the full list of soil sample results and Figure 4 for the location of each sample.

*5.1.22 SU-23 Results*

The results for the 17 samples (Field ID 6340-6356) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 0.95 pCi/g, with a standard deviation of 1.2 pCi/g, and a maximum of 3.1 pCi/g. See Appendix C for the full list of soil sample results and Figure 6 for the location of each sample.

*5.1.23 SU-24 Results*

The results for the 13 samples (Field ID 6357-6371) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 1.7 pCi/g, with a standard deviation of 1.8 pCi/g, and a maximum of 6.9 pCi/g. See Appendix C for the full list of soil sample results and Figure 5 for the location of each sample.

*5.1.24 SU-25 Results*

The results for the 15 samples (Field ID 6372-6386) collected and analyzed in this SU are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this SU average 1.3 pCi/g,

with a standard deviation of 1.0 pCi/g, and a maximum of 3.3 pCi/g. See Appendix C for the full list of soil sample results and Figure 5 for the location of each sample.

#### *5.1.25 Ravine Results*

The results for the 3 samples (Field ID RAVINE1-RAVINE3) collected and analyzed in this location are below the ALARA target of 88 pCi/g for $^{238}$U. The $^{238}$U results for this location average 1.8 pCi/g, with a standard deviation of 0.95 pCi/g, and a maximum of 2.5 pCi/g. See Appendix C for the full list of soil sample results.

### 5.2 Gamma Walkover Survey Results

Figure 3 shows the FSS gamma walkover survey results for the BTD site. Individual FSS GWS data was contoured in ESRI ArcView™ using an inverse distance weighting technique. All contoured data was less than 35,000 cpm, the action level established in the workplan. The GWS included approximately 143,000 individual data points spread over the 25 survey units. The upper range of the GWS cpm legend shown on Figure 2 is equivalent to 105 pCi/g DU based on sensitivity calculations.

# 6.0 QUALITY ASSURANCE / QUALITY CONTROL

## 6.1 Field Replicate Sample Analyses

CABRERA collected and had the offsite laboratory perform replicate analyses for approximately 10% (39 replicates) of the soil samples. Duplicate analysis entailed repeating the analysis on a split sample and comparing the results statistically. The results are presented in Appendix D. These samples were numbered using a unique identifier to support blind submittal to the laboratory. In accordance with the workplan, field replicate analyses were compared to the initial analytical results by determining a NAD value for each data set by the following equation:

$$\text{NAD} = \frac{|\text{Sample - Duplicate}|}{\sqrt{\sigma^2_{\text{Sample}} + \sigma^2_{\text{Duplicate}}}}$$

Where: Sample = first sample value (original),

Duplicate = second sample value (duplicate),

$\sigma_{\text{Sample}}$ = $2\sigma$ counting uncertainty of the sample, and,

$\sigma_{\text{Duplicate}}$ = $2\sigma$ counting uncertainty of the duplicate

The calculated NAD results are compared to a performance criteria of less than or equal to 1.96. Calculated NAD values less than 1.96 are generally considered acceptable and values greater than 1.96 are 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, $\sigma_{\text{Sample}}$ and $\sigma_{\text{Duplicate}}$, represent the true standard deviation of the measured population.

The results, shown in Appendix D, show one of the replicate samples did not pass the NAD value. This, however, is not unexpected due to the inhomogeneity of the DU contaminant. Much of the DU contamination was observed as small fragments in the field.

## 6.2 Field Instrumentation Quality Control Results

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

### *6.2.1 Calibration Requirements*

Radiological instruments were used to scan equipment, personnel, and clothing for radiological contamination and for performance of the GWS. This equipment included Geiger-Mueller detectors, alpha-beta scintillation probes, NaI scintillation detectors, and smear count rate instrumentation. Many of these instruments were used for health and safety purposes and to guide remediation activities, while NaI detectors and GPS units were used directly to generate FSS data and establish FSS sample locations.

Current calibration/maintenance records were kept on site for review and inspection (included in Appendix E). The records include, at a minimum, the following:

- name of the equipment
- equipment identification (model and serial number)
- manufacturer
- date of 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 National Institute of Standards and Technology (NIST) traceable sources.

### *6.2.2 Sodium Iodide (NaI) Gross Gamma Systems*

Sodium iodide detectors were used directly to generate FSS data. Ludlum 44-20 NaI detectors coupled to count rate meters and GPS were used to perform gamma walk-over surveys. Instruments were calibrated within one year of the FSS at a facility possessing appropriate NRC and/or Agreement State licenses for performing calibrations using NIST-traceable standards.

Instruments were response checked daily for quality control by comparing the instrument response to a designated cesium-137 ($^{137}$Cs) source. Response checks consisted of a one-minute integrated count of the $^{137}$Cs source positioned in a reproducible geometry (i.e., a jig). The acceptance criterion for these instrument response checks is within +/- 20% of the mean response generated using ten initial source checks. Results of daily response checks are provided, along with calibration certificates, as Appendix E to this report.

## 6.3 Digital Global Positioning System Requirements

### *6.3.1 Daily Field Checks*

GPS units were used directly to generate FSS data and locate FSS sample locations. GPS point features was collected at the beginning and end of the day at a fixed location established

at the beginning of the FSS. Results of these feature counts were compared to the mean of a series of sequential initial positions. This data was entered into a spreadsheet and examined to ensure less than one-meter variability. Results of daily field checks are provided as Appendix E to this report.

## 7.0 REFERENCES

(ANL 1999) ANL Environmental Assessment Department Health Risk Report, "*Derived Uranium Guidelines for the Depleted Uranium Study Area of the Transonic Range, Aberdeen Proving Ground, Maryland*", M. Picel and S. Kamboj, Argonne National Laboratory, April 1999

(ARMY 1980) Department of the Army, U.S. Army Corps of Engineers, "*Safety Radiation Protection Manual*", EM-385-1-80, dated 30 May, 1997

(AR 11-9 1999) Army Regulation 11-9, *"The Army Radiation Safety Program"*, 28 May, 1999

(ATG 2000) Allied Technology Group, Inc Report, "*APG – DUSA Decommissioning Plan*", Rev 1, March 24, 2000

(BARG 1995) Specific Manufacturing Capability Program, *Depleted Uranium Constituents and Decay Heating*, Lockheed, Idaho presentation, dated October 3, 1995.

(CABRERA 2000a) CABRERA OP-020, "*Operation of Contamination Survey Meters", Rev 0*

(CABRERA 2000b) CABRERA OP-021, "*Alpha-Beta Counting Instrumentation", Rev 0*

(CABRERA 2000c) CABRERA OP-023, "*Operation of micro-R Meters", Rev 0*

(CABRERA 2003) CABRERA Report, "*U.S. Army Garrison, Aberdeen Proving Ground Derived Uranium Guidelines For Depleted Uranium at the BTD Soil Sample Area"*, Contract DAAA09-00-G-0002/039

(CABRERA 2004) CABRERA Report, "*Final U.S. Army Garrison, Aberdeen Proving Ground Derived Uranium Guidelines For Depleted Uranium at the BTD Soil Sample Area, Addendum"*, Contract DAAA09-00-G-0002/039

(NRC 1997) NUREG-1507, *Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions,* December 1997.

(NRC 1999) *Supplemental Information on the Implementation of the Final Rule on Radiological Criteria for License Termination*, Federal Register, Volume 64, Number 234, Tuesday, December 7, 1999, 68396-68396.

(NRC 2000) NUREG-1575, *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM), Revision 1, August 2000.

**FIGURES 1 THROUGH 7**


| Site Overview | Date: 10-12-04 | Figure 1 |
|---|---|---|
| BTD - APG | Project #: 01-3030.39 | |
| | File Name: | |
| | Prepared By: JTM | |

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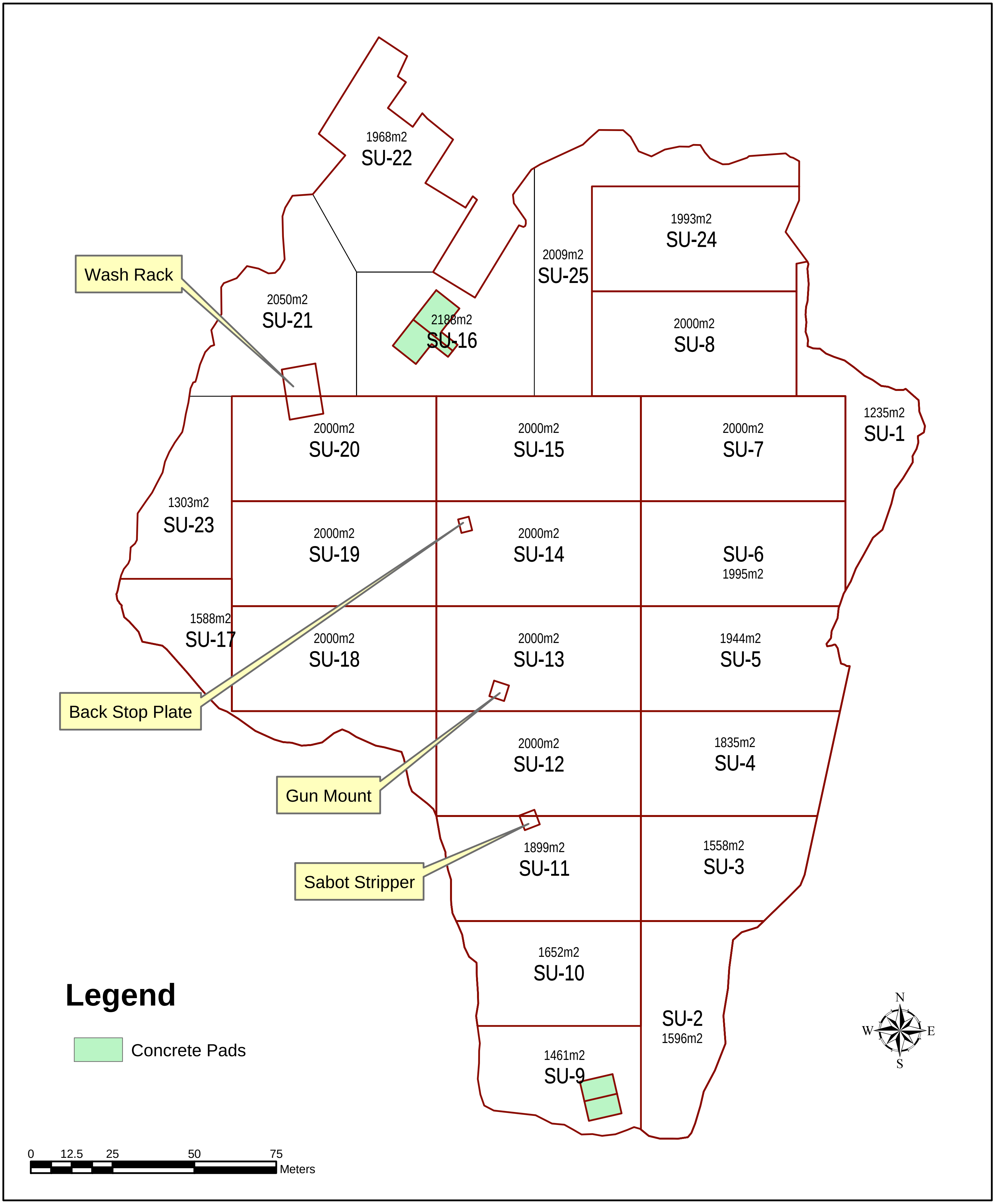


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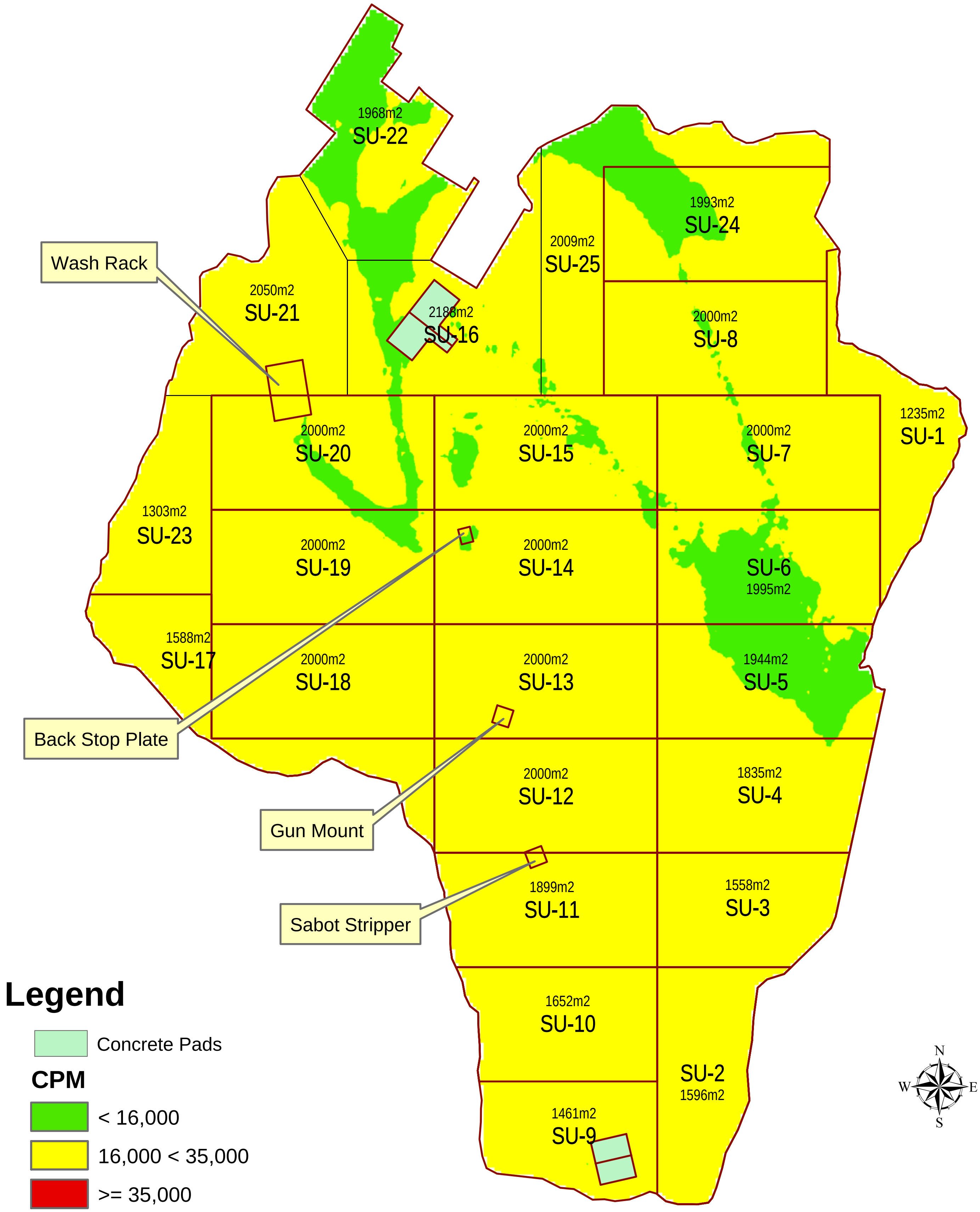
| | | | |
|---|---|---|---|
| Site Survey Units | | Date: 10-31-04<br>Project #: 01-3030-39 | Figure 2 |
| **BTD-APG** | | File Name:<br>Prepared By: JTM | |

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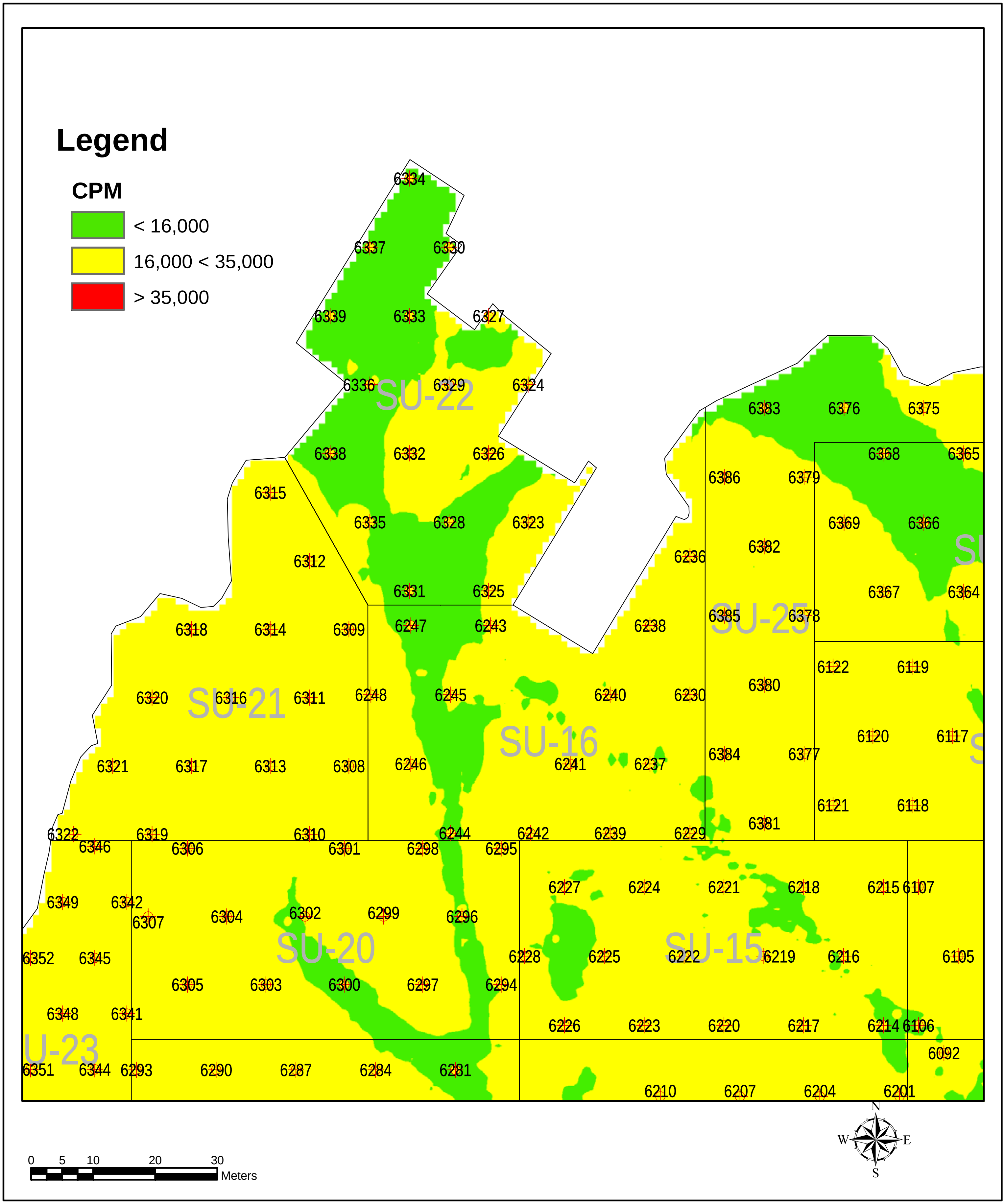
|---|---|---|---|
| CABRERA SERVICES<br>RADIOLOGICAL · ENVIRONMENTAL · REMEDIATION<br>WWW.CABRERASERVICES.COM | Gamma Walkover Survey Results<br>**BTD-APG** | Date: 10-31-04<br>Project #: 01-3030-39<br>File Name:<br>Prepared By: JTM | Figure 3 |

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Soil Sample Locations
North West Areas

**BTD-APG**

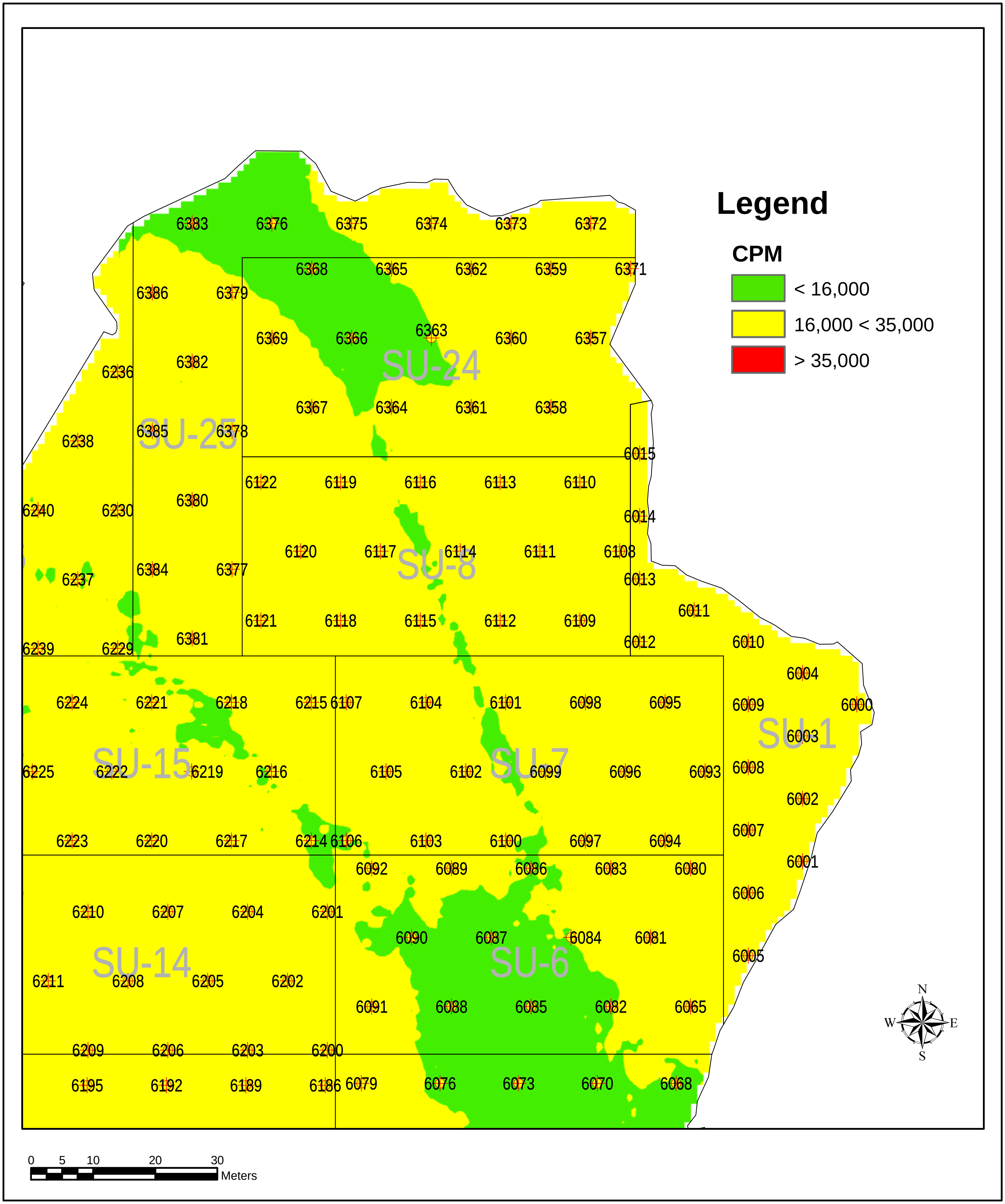
Date: 10-31-04

Project #: 01-3030-39

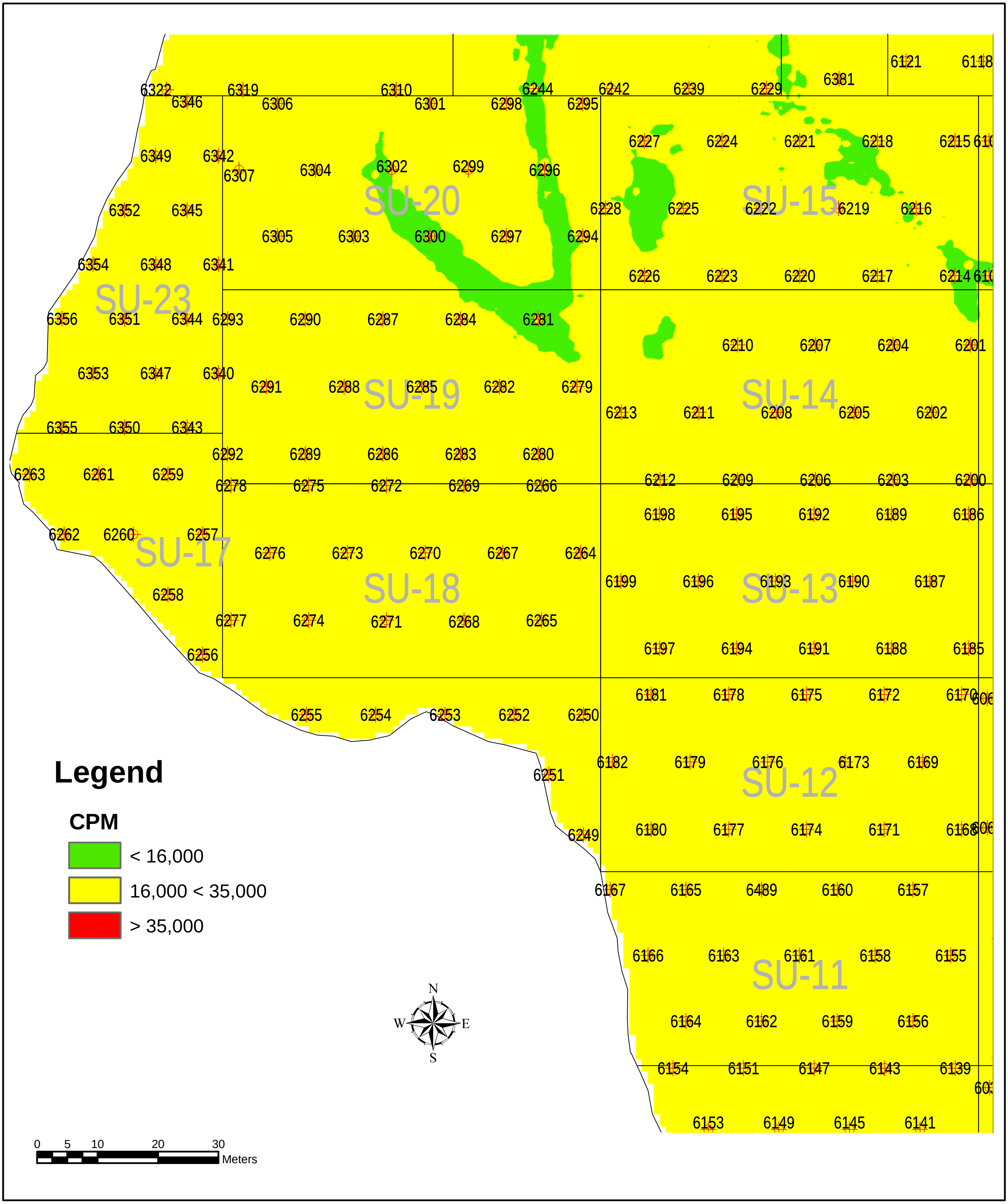
File Name:

Prepared By: JTM

Figure 4




| | | | |
|---|---|---|---|
| CABRERA SERVICES<br>RADIOLOGICAL · ENVIRONMENTAL · REMEDIATION<br>WWW.CABRERASERVICES.COM | Soil Sample Locations<br>North East Areas<br>**BTD-APG** | Date: 10-31-04<br>Project #: 01-3030-39<br>File Name:<br>Prepared By: JTM | Figure<br>5 |

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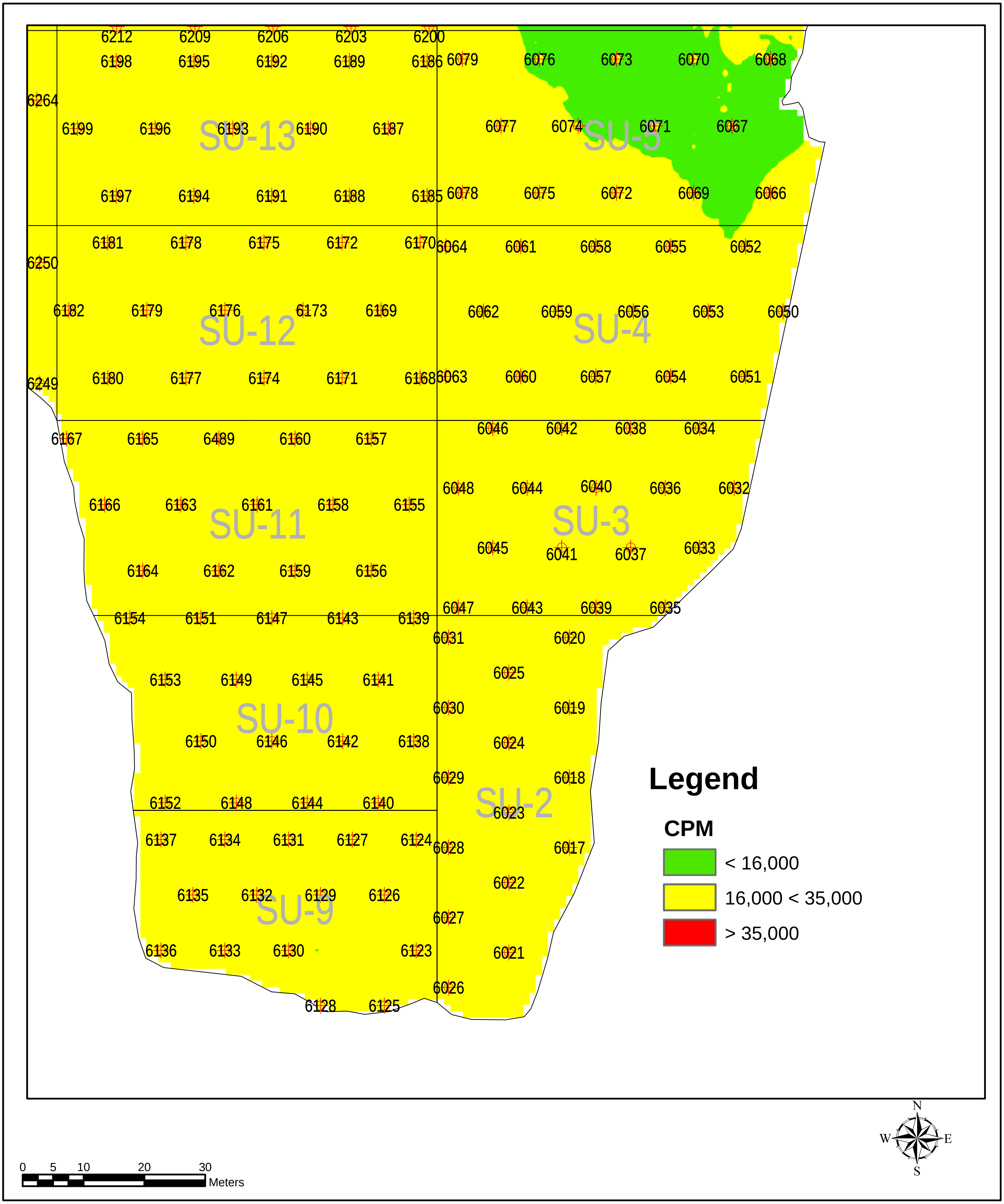
| Soil Sample Locations South West Areas | Date: 10-31-04<br>Project #: 01-3030-39 | Figure 6 |
|---|---|---|
| **BTD-APG** | File Name:<br>Prepared By: JTM | |

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Soil Sample Locations
South East Areas

**BTD-APG**

Date: 10-31-04

Project #: 01-3030-39

File Name:

Prepared By: JTM

Figure
7

# Appendix A: APG DCGL for Depleted Uranium at the BTD Soil Sample Area, Addendum

# FINAL

U. S. ARMY GARRISON, ABERDEEN PROVING GROUND
DERIVED URANIUM GUIDELINES FOR DEPLETED URANIUM
AT THE BTD SOIL SAMPLE AREA
ADDENDUM

**Contract Number**
**DAAA09-00-G-0002 / 039**

**Prepared for:**

**U.S. Army Operations Support Command**
**Rock Island, Illinois**

**Performed By:**


**CABRERA Services Inc.**
**809 Main Street**
**East Hartford, CT 06108**


**Project No. 01-3030.39**

**July 2004**

# EXECUTIVE SUMMARY

The depleted uranium (DU) Derived Concentration Guideline Level (DCGL) previously developed for the Bomb Throwing Device (BTD) Site was developed using data from the Transonic Range located at Aberdeen Proving Ground (APG). This addendum compares the soil DCGL for the BTD site using hydrogeological and other data from the Transonic Range and site-specific data from the BTD Site, to calculate a DCGL for the BTD site. The latest Argonne National Laboratory RESRAD computer code, version 6.22, was utilized.

This evaluation shows that based on the RESRAD version 6.22 computer code output, the proposed BTD Site soil DCGL of 230 pCi/g total DU (resident scenario) is equal to the Transonic Range soil DCGL. The ALARA principle of as-low-as-reasonably-achievable is applied to provide assurance that hypothetical doses are limited. The ALARA action level was previously set at 105 pCi/g.

# U.S. ARMY GARRISON, ABERDEEN PROVING GROUND DERIVED URANIUM GUIDELINES FOR DEPLETED URANIUM AT THE BTD SOIL SAMPLE AREA ADDENDUM

## 1.0 SCOPE/PURPOSE

The purpose of this addendum is to contrast and compare the soil Derived Concentration Guideline Level (DCGL) for the Aberdeen Proving Ground (APG) Bomb Throwing Device (BTD) Site to the Transonic Range. This evaluation compares the soil DCGL derived for the BTD Site to the soil DCGL from the Transonic Range. The Argonne National Laboratory (ANL) computer code RESRAD, version 6.22, was utilized to determine soil DCGLs for the resident and work scenarios.

## 2.0 DCGL EVALUATION

The RESRAD code, version 6.22, was run for the following data sets to calculate the soil DCGL at the BTD Site. RESRAD data files used to calculate the soil DCGL at the Transonic Range were used as the baseline input for the BTD Site because of the vicinity, type of operations, and similar physical factors at both sites. Site-specific inputs were applied as appropriate.

### *2.1.1 APG-RES1*

This is data set assumes natural isotopic uranium activity concentrations of 48.9% $^{234}$U, 2.25% of $^{235}$U, and 48.9% $^{238}$U.

Attachment A lists the RESRAD code data inputs for the BTD Site resident scenario. Highlighted user inputs differing from RESRAD default values and a description of the data source are included.

### *2.1.2 APG-RES2*

This is data set assumes a depleted uranium (DU) activity concentration of 21.1% $^{234}$U, 2.05% of $^{235}$U, and 76.8% $^{238}$U. This isotopic concentration is the same as utilized for the Transonic Range DCGL DU evaluations (ANL 1999) based on measured isotopic data at the Transonic Range.

Attachment A lists the RESRAD code data inputs for the BTD Site resident scenario. Highlighted user inputs differing from RESRAD default values and a description of the data source are included.

### *2.1.3 APG-RES3*

This is data set assumes a DU activity concentration of 13.8% $^{234}U$, 2.34% of $^{235}U$, and 83.9% $^{238}U$. This isotopic concentration is the same as utilized for the Transonic Range DCGL DU evaluations (ANL 1999) based on measured isotopic data at the Transonic Range.

Attachment A lists the RESRAD code data inputs for the BTD Site resident scenario. Highlighted user inputs differing from RESRAD default values and a description of the data source are included.

### *2.1.4 APG-RES4*

This is data set assumes a DU activity concentration of 22.2% $^{234}U$, 1.93% of $^{235}U$, and 75.9% $^{238}U$. This isotopic concentration is the same as utilized for the Transonic Range DCGL DU evaluations (ANL 1999) based on measured isotopic data at the Transonic Site.

Attachment A lists the RESRAD code data inputs for the BTD Site resident scenario. Highlighted user inputs differing from RESRAD default values and a description of the data source are included.

### *2.1.5 APG-WORK*

This is data set assumes a normalized uranium activity corresponding to a soil concentration of 1 pCi/g.

Attachment B lists the RESRAD code data inputs for the BTD Site worker scenario. Highlighted user inputs differing from RESRAD default values and a description of the data source are included.

## 3.0 RESULTS

The RESRAD code output results are shown in Attachments C through G. A summary of these results showing the soil single isotope DCGL is shown in Table 1. It is noted that in all cases the BTD Site soil DCGL is greater than the corresponding Transonic Range value.

Table 2 provides the total uranium concentration resulting in a 25 mrem/year maximum dose based on the sum of the fractions for various uranium isotopic mixture scenarios. The total uranium DCGL concentrations for DU vary from 219.7 to 236.1 with an average of 229.7 pCi/g, rounded to 230 pCi/g for total uranium at the site.

Results for natural uranium resident scenario and the APG worker scenario provide for higher DCGLs than any of the BTD Site DU resident scenarios. The DU resident scenario based on the average isotopic mixture may be used as the limiting soil DCGL.

## TABLE 1

### Single Isotope Uranium DCGL Concentration Comparisons for Transonic and BTD Sites

| RESRAD File | Single Isotope DCGL | | |
|---|---|---|---|
| | $^{234}U$ | $^{235}U$ | $^{238}U$ |
| APG-RES1 (Transonic)[a] | 635.20 | 53.91 | 214.90 |
| APG-RES2 (Transonic)[a] | 635.20 | 53.91 | 214.90 |
| APG-RES3 (Transonic)[a] | 635.20 | 53.91 | 214.90 |
| APG-RES4 (Transonic)[a] | 635.20 | 53.91 | 214.90 |
| APG-WORK (Transonic)[a] | 3733.00 | 159.20 | 730.80 |
| | | | |
| APG-RES1 (BTD)[b] | 636.00 | 53.94 | 215.00 |
| APG-RES2 (BTD)[b] | 636.00 | 53.94 | 215.00 |
| APG-RES3 (BTD)[b] | 636.00 | 53.94 | 215.00 |
| APG-RES4 (BTD)[b] | 636.00 | 53.94 | 215.00 |
| APG-WORK (BTD)[b] | 3745.00 | 159.30 | 731.50 |

Notes:

[a] RESRAD file for Transonic Site run using RESRAD version 6.22; not included in this package.

[b] RESRAD file from Transonic used as template; appropriate Site-Specific factors for BTD Site were utilized for RESRAD run.

## TABLE 2

### Total Uranium DCGL Concentrations for BTD Site with Sum of the Fractions[h]

| BTD Scenario | Combined Individual DCGL Concentrations to Produce 25 mrem/yr Maximum Dose, pCi/g[h] | | | |
|---|---|---|---|---|
| | $^{234}U$ | $^{235}U$ | $^{238}U$ | Total U[a] |
| APG-RES1[b] | 141.3 | 6.5 | 141.3 | 289.1 |
| APG-RES2[c] | 49.3 | 4.8 | 179.3 | 233.4 |
| APG-RES3[d] | 30.3 | 5.1 | 184.3 | 219.7 |
| APG-RES4[e] | 52.4 | 4.6 | 179.1 | 236.1 |
| APG Resident-Average[f] | 44.0 | 4.8 | 180.9 | 229.7 |
| APG-WORK[g] | 103.7 | 17.6 | 630.5 | 751.8 |

Notes:

[a] Total U is the total uranium value based on the summation of $^{234}U$, $^{235}U$, and $^{238}U$

[b] From APG-RES1.RAD file; natural uranium mix with $^{234}U$:$^{235}U$:$^{238}U$ activity proportion of 0.489:0.0225:0.489

[c] From APG-RES2.RAD file; DU mix with $^{234}U$:$^{235}U$:$^{238}U$ activity proportion of 0.211:0.0205:0.768

[d] From APG-RES3.RAD file; DU mix with $^{234}U$:$^{235}U$:$^{238}U$ activity proportion of 0.138:0.0234:0.839

[e] From APG-RES4.RAD file; DU mix with $^{234}U$:$^{235}U$:$^{238}U$ activity proportion of 0.222:0.0193:0.759

[f] Calculated based on DU average mix of APG-RES2, APG-RES3, and APG-RES4

[g] From APG-WORK.RAD file; DU mix with $^{234}U$:$^{235}U$:$^{238}U$ activity limiting proportion of 0.138:0.0234:0.839

[h] Individual uranium isotope concentrations based on 10CFR Part 20 Appendix B Footnote 4

## 4.0 SUMMARY

Since the BTD Site and the Transonic Range are within close proximity of each other, the climate, meteorology, irrigation rates, the type, growth rate, and root depths of vegetation, type of meat and milk producing animals, fish and aquatic organisms, and the geology and soil characteristics are considered to be similar in nature. Additionally, since the type of work activities and the DU isotopic activity fractions at both locations are similar, they result in surface and vertical distributions of DU that are comparable at both the BTD Site and the Transonic Range.

The DCGL developed at the Transonic Range is considered applicable to and adequately protective for the BTD Site on the basis of comparable site-specific RESRAD parameter/pathways, the similarity of both locations, and the equivalence of the radiological isotopic DU mixes.

The most recent version of the RESRAD computer code, version 6.22, was used to verify the BTD Site DCGL. The input data set was based on the Transonic Range with application of appropriate site-specific factors.

Use of the BTD Site DCGL will ensure that the potential dose to a hypothetical individual will not exceed 25 mrem in any one year over a 1,000-year period. The DCGL for the BTD Site soil is 230 pCi/g total DU (resident scenario). The ALARA principle of as-low-as-reasonably-achievable is applied to provide assurance that hypothetical doses are limited. The ALARA action level DCGL has been set at 105 pCi/g total DU.

## 5.0 REFERENCES

1. ANL 1999 *Derived Uranium Guidelines for the Depleted Uranium Study Area of the Transonic Range, Aberdeen Proving Ground, Maryland*, ANL Rad Health Risk Study, M. Picel and S. Kamboj, April 16, 1999

2. CABRERA 2004 *U.S. Army Garrison, Aberdeen Proving Ground Derived Uranium Guidelines for Depleted Uranium at the BTD Soil Sample Area*, Contract DAAA09-00G-0002 / 039, Prepared for U.S. Army Operations Support Command Rock Island, Illinois, Cabrera Services Inc., January 2004

# Appendix B: Final Status Survey Plan, Bomb Throwing Device (BTD) Site

DEPARTMENT OF THE ARMY
U. S. ARMY ABERDEEN TEST CENTER
400 COLLERAN ROAD
ABERDEEN PROVING GROUND, MARYLAND 21005-5059

J-8

REPLY TO
ATTENTION OF

September 18, 2003

Office of the Commander

Sub-834
04007354

Mr. James Schmidt
Nuclear Regulatory Commission, Region I
Division of Nuclear Materials Safety
475 Allendale Road
King of Prussia, Pennsylvania 19406

Dear Mr. Schmidt:

The final Status Survey Plan for the Aberdeen Test Center Bomb Throwing Device Site is provided for your review and approval (Enclosure).

A copy of this letter with the enclosure has been furnished to the Directorate for Installation Management (CSTE-DTC-MS-S/Mr. Robert Aaserude), U.S. Army Developmental Test Command, 314 Longs Corner Road, Aberdeen Proving Ground, Maryland 21005-5055.

My point of contact at the U.S. Army Aberdeen Test Center is Mr. John C. Beckman at 410-278-9618.

Mary K. Brown
Colonel, U.S. Army
Commanding

Enclosure

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*FINAL*

# Final Status Survey Plan
# Bomb Throwing Device (BTD) Site

**Aberdeen Proving Ground, Aberdeen, MD**

Contract Number
DAAA09-00G-0002/0039

***Prepared for:***

U.S.ARMY

*U.S. Army Joint Munitions Command*
*AMSIO-ACE-D Bldg., 350 5th Floor*
*Rock Island, IL 61299-6000*

***Prepared by:***

CABRERA SERVICES
RADIOLOGICAL · ENVIRONMENTAL · REMEDIATION
*809 Main Street*
*East Hartford, Connecticut 06108*

Cabrera Project No
01-3030.39

August 2003

Enclosure

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ALARA | As Low As Reasonably Achievable |
| APG | Aberdeen Proving Ground |
| ATC | Aberdeen Test Center |
| BTD | Bomb Throwing Device |
| CABRERA | Cabrera Services, Inc. |
| cpm | Counts Per Minute |
| DCGL or DCGLw | Derived Concentration Guideline Level |
| DGPS | Differential Global Positioning System |
| dpm | Disintegrations Per Minute |
| DU | Depleted Uranium |
| FSS | Final Status Survey |
| GWS | Gamma Walkover Survey |
| HEPA | High Efficiency Particulate Air |
| LBGR | Lower Bound of the Grey Region |
| MARSSIM | Multi-Agency Radiation Survey And Site Investigation Manual |
| MDC | Minimum Detectable Concentration |
| $MDC_{scan}$ | Minimum Detectable Concentration for gamma Scanning |
| µRem | Microrem |
| mrem | Millirem |
| NAD | Normalized Absolute Difference |
| NIST | National Institute of Standards and Technology |
| NRC | U. S. Nuclear Regulatory Commission |
| PARAGON | Paragon Analytics, Inc. |
| QA | Quality Assurance |
| QC | Quality Control |
| ROPC | Radionuclides of Potential Concern |
| SU | Survey Unit |
| WESTON | Roy F. Weston |

## 1.0 INTRODUCTION

Cabrera Services, Inc. (CABRERA) is under contract to the United States Army Joint Munitions Command (JMC) to provide support to the Aberdeen Test Center (ATC) at the Aberdeen Proving Ground (APG) in Aberdeen, MD. CABRERA will perform radiological surveys of the Bomb Throwing Device (BTD) site to support consideration for unrestricted release. The BTD site consists of approximately 46,000 square meters of land on the APG. There are several support facilities and access roads located on the BTD site that were used for the testing of Depleted Uranium (DU) munitions. This document presents the plan for the BTD site Final Status Survey (FSS) activities, which are designed in accordance with Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) (NRC, 2000) guidance. This final status survey specifically addresses the survey of approximately 46,000 square meters of BTD site soil, two concrete pads, and three steel test structures located within the boundary of the BTD site. Buildings and other enclosed structures located on the BTD site will be addressed under a separate effort.

### 1.1 Site History

Aberdeen Proving Ground, located in Aberdeen, MD, is an active U.S. Army testing and research facility. The Aberdeen Proving Ground (APG) lies along the western shore of the Chesapeake Bay in Harford and Baltimore Counties, MD, approximately 15 miles northeast of Baltimore. The APG covers a total of 72,516 acres (land and water) and consists of two distinct areas: the northern portion of APG, referred to as the Aberdeen Area; and the southern portion of APG, referred to as the Edgewood Area. The Aberdeen Area became a formal military post, designated as the APG, in 1917.

The BTD site was used between 1982 and 1993 for the testing of DU munitions. The site consists of the Building Armor Reclamation Facility (BARF), Building 701 (DU Test Enclosure Building which has been recently removed), Plate Storage Area (PSA), access roads and several support buildings situated on approximately 46,000 square meters of land. During use, munitions were fired at steel plate and other targets placed inside the DU Test Enclosure Building. The ATC tested DU munitions utilizing an enclosure with high efficiency particulate air (HEPA) equipment, used to collect potentially contaminated air exiting the building.

Prior to remediation of the site, approximately 40 tons of DU-contaminated armor plate was located within the building and surrounding grounds. Heavy equipment was used to transport the armor plates between the PSA and the DU Test Enclosure Building. The DU Test Enclosure Building, which was recently demolished, had dimensions of approximately 25 by 50 feet with a height of 20 feet, will be disposed of at an appropriate facility. Associated HEPA equipment including filters and ductwork are also scheduled for removal and appropriate disposition. A HEPA motor may remain on the site.

### 1.2 General Approach to the BTD Site FSS

The FSS investigations are designed using the approach outlined in MARSSIM (NRC, 2000).

- Development of Derived Concentrations Guideline Levels
- Selection of instrumentation and measurement techniques
- Identification of survey units and classify areas by contamination potential

- Estimation of the number of measurement locations
- Collection of Data
- Evaluation of Data

## 2.0 SITE ASSESSEMENT

### 2.1 Area of Investigation

The focus of this FSS is the radiological assessment of the top six inches of surface soil over the entire 46,000 square meters BTD site and the surface activity on unenclosed structures located within the BTD site boundaries. The land area associated with the BTD site consists of open grassy areas with one area of standing trees. Originating near the center of the BTD site is a wetland ravine. The ravine is approximately 140 meters in length and often has water covered surfaces averaging up to several meters in width. Water depths in the ravine range from several centimeters to approximately 15 centimeters.

Roy F. Weston (Weston) provided a radiological characterization for the BTD site in 2001 (Weston, 2001). The Weston characterization encompassed the BTD site and divided the site into Class 1, 2, and 3 areas. Soil samples were taken from each area and compared to the NRC soil screening value of 14 pCi/g for uranium-238. Both surface (0-0.25 ft) and subsurface samples (1-1.5 ft) were taken. All values exceeding the soil action level as described in this report were found to exist in the surface soil (0-0.25 ft). An exception was the presence of several subsurface samples taken in the vicinity of the DU Test Enclosure Building that showed levels of soil contamination in excess of the soil action level. The removal of the DU Test Enclosure building by the CABRERA remediation and subsequent soil remediation activities will ensure that these areas of soil contamination have been addressed. In addition, the Weston characterization classified the majority of the BTD site as Class 3. The CABRERA remediation and FSS conservatively assumes the entire site is a Class 1.

The BTD site structures of interest are two concrete pads and three unenclosed steel structures. A motor associated with the HEPA filtration system is expected to remain onsite at its current location. The northern concrete pad is approximately 230 square meters size while the southern concrete pad is approximately 130 square meters in size. The unenclosed structures consist of a steel gun mount, a "Sabot Stripper", and a "Back Stop Plate". The bases of these structures are approximately 25 square meters each with an additional 20-25 square meters of vertical surface area. The HEPA motor is several square meters in overall area.

The land areas surrounding the facilities and structures where testing and transport of materials was performed are expected to have a greater potential for surface soil contamination than other areas. DU contamination below the top six inches are not expected in soil due to the trajectory and containment of the targets used during ordnance testing. Prior BTD site characterization study (Weston, 2001), confirms the presence of DU contamination in the upper six inches of the soil. DU contamination below the concrete pads and steel test structures are not expected as these structures were in place prior to testing protocols.

### 2.2 Radionuclides of Potential Concern

Site Radionuclides of Potential Concern (ROPC) are limited to DU and short-lived uranium progeny (Appendix A). For brevity, Appendix A does not show the radionuclides from the actinium decay series as parent uranium-235 contributes a vanishingly small fraction of the radioactivity and mass. The uranium ratios are based on isotopic uranium weight ratios used for

shipments of routine DU waste from APG (BARG, 1995). The activity fractions are calculated from the isotopic weight ratios and the specific activity of each uranium isotope. The result is a Uranium-234 ($^{234}U$): Uranium-235 ($^{235}U$): Uranium-238 ($^{238}U$) ratio of 0.084:0.012:0.904. This composition is similar to the 0.190:0.021:0.790 average ratio from three DU soil samples described in the APG report (ANL 1999) entitled "Derived Uranium Guideline for the Depleted Uranium Study Area of the Transonic Range, Aberdeen Proving Ground, Maryland", Argonne National Laboratory Environmental Assessment Department, April 1999.

## 2.3 Residual Radioactivity Limit (DCGL)

As described by MARSSIM, a DCGL is a derived radionuclide activity concentration within a survey unit that corresponds to a dose-based release criterion. For this FSS, separate $DCGL_W$'s were developed for soil and structure surfaces. The release criteria for miscellaneous equipment (e.g. Back Stop Plate, HEPA Motor, etc) are discussed in Section 5.0.

*Soil $DCGL_W$*

A soil DCGL of 230 pCi/g total DU (resident-farmer scenario) developed for the Transonic Range is considered applicable for the BTD site based on a report prepared by CABRERA and included as Appendix B (CABRERA, 2003). The report evaluates site-specific RESRAD parameters/pathways, the similarity of both locations, and the equivalence of the radiological isotopic DU mixes at both locations. Use of the approved BTD soil DCGL will ensure that the potential dose to a hypothetical individual will not exceed 25 mrem in any one year over a 1,000 period consistent with 10 CFR Part 20 Subpart E requirements. For this FSS, a soil $DCGL_W$ of 105 pCi/g total DU in soil will be used based on the ALARA principle of as-low-as-reasonably-achievable to provide assurance that hypothetical doses are limited to a fraction of the 25 mrem/year requirement.

*Structure Based $DCGL_W$*

A release criterion of 25 mrem/yr per year will be used for the unenclosed structures per the requirement of 10CFR20 Subpart E. Doses from residual radioactivity will be kept as low as reasonably achievable (ALARA) whenever possible. Using MARSSIM Section 4.3.4, and the equation below, and knowing that there is one alpha decay per decay of each uranium isotope, a single total uranium $DCGL_W$ of 100 dpm alpha/100cm$^2$ was derived for DU. This $DCGL_W$ was calculated using the values provided by the NRC screening guidelines of 90.6 dpm/100cm$^2$, 97.6 dpm/100cm$^2$, 101 dpm/100cm$^2$ and for $U^{234}$, $U^{235}$, and $U^{238}$, respectively, as presented in Table 5.19 of NUREG/CR-5512, Volume 3, October 1999 and the DU activity fractions as presented in Section 2.2 of this FSS. As noted in the NUREG/CR-5512 document, screening level guidelines are based on the assumption that the fraction of removable surface contamination is ten percent.

$$DCGL_W = \frac{1}{\left(\frac{f_1}{DCGL_1}\right) + \left(\frac{f_2}{DCGL_2}\right) + \left(\frac{f_3}{DCGL_3}\right)}$$

Where: $DCGL_w$= Combined gross activity DCGL (i.e., release limit).

$f$ = Activity fraction of radionuclide

DCGL = DCGL of radionuclide

## 2.4 Action Levels

For soil, the soil ALARA $DCGL_W$ of 105 pCi/g will be used as the action level for scanning measurements. If any scan measurement results in readings above the soil $DCGL_W$ (Section 3.1), the Field Supervisor shall be notified and the detector and survey location shall be evaluated. Following evaluation, the immediate area will be rescanned to verify the initial result. If the verified result is greater than the $DCGL_W$, the location will be marked and remediated to ensure that the soil $DCGL_W$ of 105 pCi/g is not exceeded. Additional scans of the area will be performed to verify that the additional remediation has removed soil above the action level of 105 pCi/g.

For unenclosed non-equipment structures (e.g., concrete pads), the structural $DCGL_W$ of 100 dpm alpha/100 $cm^2$ for total uranium will be used as the action level for both scanning and integrated measurements (Section 3.2 & 3.4). If any survey measurement results in readings above this $DCGL_W$, the Field Supervisor shall be notified and the detector and survey location shall be evaluated. Following evaluation, a follow-up measurement shall be performed at the measurement location to verify the initial result. If the result of the verification measurement is in excess of the $DCGL_W$, a biased smear sample (Section 3.6) will be performed at that location. Follow-up remediation and survey scan and integrated measurements will be provided at the subject location as necessary.

For equipment, the $DCGL_W$ will be based on equipment release criteria of 1,000 dpm alpha/100 $cm^2$ removable contamination and 5,000 dpm alpha/100 $cm^2$ total contamination in accordance with Army Regulation 11-9 (AR11-9, 1999) Table 5-2 (Section 5.0). If any survey measurement results in readings above this $DCGL_W$, the Field Supervisor shall be notified and the detector and survey location shall be evaluated. Following evaluation, a follow-up measurement shall be performed at the measurement location to verify the initial result. If the result of the verification measurement is in excess of the $DCGL_W$, a biased smear sample (Section 3.6) will be performed at that location. In certain cases, the equipment may be removed from the site and the small area beneath the equipment will be resurveyed in accordance with the soil $DCGL_W$.

## 3.0 SURVEY INSTRUMENTATION AND TECHNIQUES

The purpose of this section is to describe radiological survey instruments and techniques that will be used for surveys implemented during site radiological investigations. Specific measurement/sampling frequencies and approaches for the FSS are discussed in later sections.

For the soil FSS, ambient gamma scanning, discrete soil sampling, offsite laboratory analyses of the soil, and dose rate measurements will be performed to measure radioactivity concentrations of total uranium in surface soil. Implements used to collect soil samples will be cleaned and surveyed after each sample is collected to minimize cross-contamination of samples.

For unenclosed structures, scanning and integrated direct measurements will be performed to measure surface radioactivity concentrations of total uranium. These measurements will be based solely on alpha emissions. Beta measurements will be collected in tandem with alpha measurements and presented for qualitative review in an appendix of the FSS report. Prior to the initiation of alpha survey activities on unenclosed structures, surfaces of interest will be cleaned to remove dirt and grime that could shield alpha emissions from detection. The cleaning implements used to clean surfaces will be collected and stored on site and disposed in accordance with the contaminants found.

### 3.1 Gamma Walkover Surveys (GWS)

A GWS will be performed over soil to identify surface soil DU contamination. These surveys will provide position-correlated gross gamma count rate data proportional to the gross gamma fluence rate at the ground surface. The results of these surveys will be used to detect areas of elevated activity and select locations for biased soil sampling.

The GWS will be performed using a Ludlum Model 44-20 3" x 3" NaI gamma scintillation detector (or equivalent) coupled to a Ludlum Model 2221 rate meter (or equivalent). These instruments will be linked with differential global positioning system (DGPS) receiver/dataloggers. The gamma detection systems will be setup to measure gamma interactions in the NaI crystal that are discernable from electronic noise. Specifically, the detection systems will be calibrated with no lower level discriminator and no upper level discriminator (i.e., open window). This system will log the gross gamma reading and position every second in State Plane Coordinates.

Using NUREG-1507 as guidance, a minimum detectable scanning concentration ($MDC_{SCAN}$) and scanning sensitivity was calculated using Microshield®. The results of these calculations are presented in Table 3.1-1. The action level of 6,800 cpm above ambient gamma background was calculated by multiplying the instrument scanning sensitivity by the $DCGL_W$ of 105 pCi/g.

The calculations performed and the assumptions made in the sensitivity estimates are presented in Appendix C. The assumptions include an ambient gamma background of 10uR/hr and a 56 cm diameter soil source term uniformly contaminated to a depth of 15 cm as described by NUREG-1507. The Ludlum Model 44-20 instrument sensitivity and scanning evaluation incorporates 18 energy response groups covering the energy range associated with DU. The sensitivity evaluation also assumes that scanning will be performed in accordance with

MARSSIM protocol by walking straight parallel lines over an area while moving the detector in a serpentine motion, approximately 10 cm above the ground surface. Survey passes will be approximately 1 meter apart and the scan rate will be approximately 0.5 meters per second. The CABRERA General Countrate Meter QC template will be used to assure proper instrument operability prior to daily scanning.

The action level of 6,800 cpm above background, the instrument scanning sensitivity, and the $MDC_{scan}$ values are shown in Table 3.1-1.

*Table 3.1-1: NaI Scanning Sensitivities for Soil*

| **Detector** | **Description** | **$MDC_{SCAN}$** (pCi/g) | **Scanning Sensitivity** (cpm/pCi/g) | **Action Level** (cpm above background) |
|---|---|---|---|---|
| Ludlum 44-20 | NaI 3"x3" | 38 | 65 | 6,800 |

### 3.2 Direct Alpha Radioactivity Scan Surveys

Direct alpha scanning will be performed to identify surface locations on structures where contaminant concentrations may exceed the criterion for unrestricted release. Scanning surveys for alpha activity will also be performed to determine if radiological surface contamination is present on soil sampling equipment. Scanning will be performed using a Ludlum Model 43-93 (100 $cm^2$) active area scintillation detectors, or equivalent. Scanning will be performed with the active area of the detector at a height of 0.5 cm above the surface of interest using the detector specific assumptions listed in Table 3.2-1. Scanning measurements will be performed in accordance with CABRERA procedures OP-020 "*Operation of Contamination Survey Meters,*" *Rev 0* and use CABRERA General Countrate Meter QC template.

Using MARSSIM equation J-5 and the instrument specific assumptions listed in Table 3.1-2, the $MDC_{SCAN}$ is determined to be equal to the structural $DCGL_W$. The chance of detecting a concentration equal to the $DCGL_W$ would be 90% and signified by the incidence of one alpha count occurring within the pause time of that stationary instrument.

$$P(n \geq 1) = 1 - P(n = 0) = 1 - e^{-A} \qquad \text{(MARSSIM J-5)}$$

$$\text{for } A = \frac{GEd}{60v}$$

where,

$P(n \geq 1)$ = probability of getting 1 or more counts during the time interval t
$P(n = 0)$ = probability of not getting any counts during the time interval t
G = source activity (dpm)
E = detector efficiency ($4\pi$)
d = width of the detector in the direction of scan (cm)
v = scan speed (cm/s)
A = detector area ($cm^2$)

Whenever an alpha count is detected during the scan, the detector will be held in place over the location where the count was detected for the duration of the pause time (approximately 7 seconds). If a second alpha count is detected over this location during the pause time, a two minute integrated count will be performed. If the result of the integrated measurement is in excess of the structural $DCGL_W$ (Section 2.3), the area will be marked and further investigated by the Field Supervisor.

The net count rate will be determined as the difference between the measurement count rate and the daily background count rate measured prior to use.

*Table 3.2-1: Alpha Scan Assumptions*

| Model # | Probe Area ($cm^2$) | Probe Width (cm) | α Efficiency (cpm /dpm) | α Bkgrd (cpm) | Scan Speed (cm/sec) | Pause Time (sec) | P(n>=1) | Dwell Time (sec) | P(n>=2) |
|---|---|---|---|---|---|---|---|---|---|
| 43-93 | 100 | 9 | 0.20 | 3 | 1 | 6.9 | 0.95 | NA | NA |

### 3.3 Soil Sampling

Soil samples will be collected to measure surface soil contaminant concentrations at discrete locations. The soil samples will be analyzed for total uranium and the results will be used to facilitate statistical testing. Discrete sampling locations will be identified using the Trimble DGPS system to get the appropriate Easting and Northing coordinates (North American Datum System). Samples will be sent to Paragon Analytics, Inc. (Paragon) for analysis for isotopic uranium and analyzed in accordance with Paragon's standard operating procedure. Volumetric samples will be collected in accordance with CABRERA procedure *OP-005 Volumetric and Material Sampling, rev 0.*

Soil samples will be collected using surface scraping tools such as trowels or spoons. In general, surface soil samples will be collected from the top six inches of soil. The sample will be transferred into a stainless steel bowl, where it will be thoroughly mixed to homogenize the sampled media. Visually identifiable non-soil components such as stones, twigs, and foreign objects will be manually separated in the field and excluded from the laboratory samples to avoid biasing results. Samples will not be preserved in the field, as there are no preservation requirements for the radiological analyses. All sampling equipment, mixing utensils, and homogenizing bowls will be decontaminated using distilled water after each sample to avoid cross contaminating the subsequent sample. A Ludlum 43-93 detector and smear sample will be used to ascertain that no cross-contamination occurs between samples. The presence of less than 1,000 dpm/100 $cm^2$ of DU alpha activity on a smear is sufficient to show non-contamination of volumetric samples from the sampling equipment thus limiting cross-contamination between soil samples.

Soil will be collected in 500 ml sample containers. These containers will hold sufficient sample material as to allow detection of radioactive materials at the MDC values specified (approximately 4 pCi/gram DU). The analysis lab has indicated this amount to be equivalent to

approximately 500 grams of soil. Each filled 500 ml container will hold more than 500 grams of soil.

Samples will be marked to show the sample identification number. Sample identification number, northing and easting coordinates, and other pertinent data will be recorded on appropriate field data recording sheets. Samples will be collected in accordance with the Paragon Laboratories applicable chain of custody procedures.

### 3.4 Integrated Direct Surface Alpha Radioactivity Measurements

Integrated direct measurements (i.e., static measurements) of surface alpha radioactivity will be performed during the FSS to compare contaminant concentrations at discrete sampling locations on construction materials (i.e., concrete pad) to the release criterion and facilitate statistical testing. Model 43-93 hand held (active area 100 $cm^2$) alpha scintillation detector or equivalent. The estimated detector sensitivity and the assumptions used for this detector are presented in Table 3.4-1.

Static measurements will be performed in accordance with CABRERA procedures OP-020 "*Operation of Contamination Survey Meters,*" *Rev 0,* and OP-021 *"Alpha-Beta Counting Instrumentation," Rev 0, and* CABRERA standard radiation instrumentation templates *"Alpha Beta Counting and Smear Worksheet", Rev 2.* Prior to field mobilization, FSS instrumentation will be checked for expected response using a Chi-Square distribution utilizing the CABRERA template *"Equipment Chi-Square Distribution Worksheet", Rev 0.*

The net count rate will be determined as the difference between the measurement count rate and the daily background count rate measured prior to use.

*Table 3.4-1: Detector Sensitivities and Assumptions*

| Model # | Count/Bkg Time (min) | Probe Area ($cm^2$) | $\alpha$[1] Efficiency (cpm /dpm) | $\alpha$ Background (cpm) | $\alpha$ Static MDC (dpm / 100 $cm^2$) |
|---|---|---|---|---|---|
| 43-93 | 2 | 100 | 0.20 | 3 | 36 |
| 2929 | 4 | smear | 0.37 | 0.5 | 6 |

[1] Instrument efficiencies are estimated from vendor literature-based $^{230}$Th and $^{239}$Pu efficiencies.

### 3.5 Gamma Dose Rate Measurements

Gamma dose rate measurements may be qualitatively performed during the FSSs to ensure worker health and safety and to identify unusual dose rate conditions. Measurements will be performed using a Bicron MicroRem tissue-equivalent scintillation detector, or equivalent, and will be performed in accordance with CABRERA Procedure OP-023, *Operation of micro-R Meters, Rev 0.* Measurements will be performed using the "slow" response time constant setting. The detector will be positioned over the area of interest and allowed to stabilize prior to recording the measurement. The technician will use their judgment to determine when the

instrument has stabilized, it is estimated that this will take at least 15 seconds. Such measurements will typically be performed at 30 cm from and/or on contact with the surface being evaluated.

### 3.6 Smear Sample Collection and Analysis

For non-equipment structural smear samples (e.g., concrete pads), gross transferable alpha contamination will be collected and analyzed to determine if transferable activity is less than or equal to 10% of total activity as assumed in the NUREG/CR-5512 document for screening level guidelines.

For equipment smear samples, gross transferable alpha contamination will be collected and analyzed to ensure compliance with equipment release criterion of Army Regulation 11-9 of 1,000 dpm/100 $cm^2$.

Smear samples will be collected over approximately 100 $cm^2$ areas at systematic and biased locations identified during scanning activities. Smear samples will be analyzed for alpha and beta radioactivity using a Ludlum 2929 alpha/beta scintillation counter or equivalent in accordance with CABRERA procedure OP-021 *"Alpha-Beta Counting Instrumentation," Rev 0.* Based on the assumptions listed in Table 3.4-1, an alpha MDC of 6 dpm/100$cm^2$ will be achieved.

# 4.0 FINAL STATUS SURVEY DESIGN

The FSS to be performed at the BTD site is designed in accordance with Final Status Survey guidance from MARSSIM (NRC, 2000). FSS activities will consist of scanning surveys over 100% of the reasonable accessible surface soil and structure surfaces. Discrete soil sampling and integrated direct surface measurements will be performed at frequencies based on MARSSIM guidance. Survey activities will also include biased smear sample collection. The FSS is designed conservatively in that the radiological background present in the soil will be neglected and the measure of total activity will be used for statistical comparisons to the respective $DCGL_W$.

## 4.1 Area Classification Based on Contamination Potential

Using MARSSIM as guidance, the BTD site will be divided into 29 Class 1 survey units (SU). The initial SU classifications are based on sample matrix, area, and contamination potential. Table 4.1-1 lists each SU by matrix type, area, number of samples to be collected in that SU, and the distance between each sample using a triangular grid pattern.

For soil areas, MARSSIM suggests that outdoor Class 1 SUs be not more than 2,000 square meters in size. For unenclosed structures (concrete pads), SU size was limited to approximately 100 square meters that MARSSIM suggests for interior SUs. This more restrictive size was selected for unenclosed structures based on the possibility that enclosures may be built upon existing concrete pads and around test equipment in the future. To accommodate the interior SU size, concrete pads remaining in place were divided into two separate SUs of equal size.

Three pieces of steel test equipment and a HEPA motor are considered equipment and will be released based on Army Regulation 11-9 as described in sections 4.2 and 5.1.

MARSSIM identifies Class 1 areas as having, or had prior to remediation, a potential for radioactive contamination or known contamination. Initially, all survey units will be considered Class 1 survey units based on the process involved (i.e., the testing and firing of DU munitions), the amount of DU present on the BTD site (i.e., approximately 40 tons of contaminated plate armor), the on-site transport of contaminated materials, the length of time the BTD site was used to test munitions. This is a conservative assumption.

*Table 4.1-1: Survey Units*

| SU # | Matrix | Area ($m^2$) | L (m) | No. of Samples | SU # | Matrix | Area ($m^2$) | L (m) | No. of Samples |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Soil | 1235 | 10.1 | 16 | 16 | Soil | 1970 | 12.8 | 15 |
| 2 | Soil | 1600 | 11.5 | 15 | 17 | Soil | 1590 | 11.5 | 15 |
| 3 | Soil | 1560 | 11.3 | 17 | 18 | Soil | 2000 | 12.8 | 15 |
| 4 | Soil | 1840 | 12.3 | 15 | 19 | Soil | 2000 | 12.8 | 15 |
| 5 | Soil | 1945 | 12.7 | 14 | 20 | Soil | 1935 | 12.6 | 14 |
| 6 | Soil | 1995 | 12.8 | 14 | 21 | Soil | 1950 | 12.7 | 15 |
| 7 | Soil | 2000 | 12.8 | 15 | 22 | Soil | 1970 | 12.8 | 17 |
| 8 | Soil | 2000 | 12.8 | 15 | 23 | Soil | 1300 | 10.4 | 17 |
| 9 | Soil | 1335 | 10.5 | 15 | 24 | Soil | 2000 | 12.8 | 14 |
| 10 | Soil | 1650 | 11.7 | 17 | 25 | Soil | 2000 | 12.8 | 15 |
| 11 | Soil | 1900 | 12.5 | 14 | 26 | Concrete | 65 | 1.94 | 20 |
| 12 | Soil | 2000 | 12.8 | 15 | 27 | Concrete | 65 | 1.94 | 20 |
| 13 | Soil | 1980 | 12.8 | 15 | 28 | Concrete | 115 | 2.58 | 20 |
| 14 | Soil | 2000 | 12.8 | 14 | 29 | Concrete | 115 | 2.58 | 20 |
| 15 | Soil | 2000 | 12.8 | 15 | | | | | |

### 4.2 Number of Static Measurements/Soil Samples

MARSSIM provides a method to determine the number of measurement locations required in a given survey unit. A minimum number of measurement locations are required in each survey unit to obtain sufficient statistical confidence that the conclusions drawn from the measurements are correct. The following subsections describe the bases for and derivation of the minimum required measurement locations per survey unit.

*Estimation of Relative Shift*

The minimum number of measurement locations required is dependent on the distribution of site residual radionuclide concentrations relative to the $DCGL_w$ and acceptable decision error limits ($\alpha$ and $\beta$).

The relative shift describes the relationship of site residual radionuclide concentrations to the $DCGL_w$ and is calculated using the guidance found in Section 5.5.2.3 of MARSSIM. The relative shift is calculated as follows:

$$\Delta/\sigma = \frac{DCGL_w - LBGR}{\sigma}$$

Where: $DCGL_w$= Derived Concentration Guideline Level

LBGR = concentration at the lower bound of the gray region. The Lower Bound of the Grey Region (LBGR) is the concentration at which the survey unit has an acceptable probability of passing the statistical tests.

$\sigma$ = an estimate of the standard deviation of the concentration of residual radioactivity in the survey unit (which includes real spatial variability in the concentration as well as the precision of the measurement system).

The $DCGL_w$ for surface soil radioactivity is 105 pCi/g. The LBGR is estimated at 52.5 pCi/g which is half of the $DCGL_w$ as suggested by MARSSIM. Using an estimated coefficient of variation of 30 percent and the LBGR as an estimate of the sample mean, a sigma value of 15.8 pCi/g is calculated. Using the parameters discussed above, the relative shift is calculated as 3.3.

The unenclosed concrete pad $DCGL_w$ for surface alpha radioactivity is 100 dpm/100cm$^2$. The LBGR was conservatively estimated at 70 dpm alpha/100 cm$^2$ based on previous studies with similar instruments on concrete. Without prior survey, it is reasonable to assume a coefficient of variation on the order of 30 percent (MARSSIM Section 5.5.2.2). Using a coefficient of variation of 30 percent and the LBGR as an estimate of the sample mean, a sigma value of 21 dpm/100cm$^2$ is estimated. Using the parameters discussed above, the relative shift is calculated as 1.4.

The unenclosed steel structures and HEPA motor are considered equipment and will be released based on Army Regulation 11-9, submitted as part of the APG ATC NRC License document SUB-834. Table 5-2 of Army Regulation 11-9 provides for surface radioactivity values of up to 1,000 dpm/100 cm$^2$ removable and 5,000 dpm/100 cm$^2$ total activity for $^{235}U$ and $^{238}U$ and associated decay products. These values are the same as provided by Regulatory Guide 1.86.

*Determination of N (Number of Required Measurement Locations)*

For soil SUs, the final number of suggested measurement locations per survey unit is 14 as per MARSSIM (Table 5.5) given a relative shift of 3.7 and an error rate for both Type I and Type II errors of five percent (i.e., $\alpha = \beta = 0.05$). The actual number of measurements to be performed in each survey unit ranges from 14 to 17 samples based on the size and geometry of the SU and are presented in Table 4.1-1.

For unenclosed concrete structures, the final number of direct surface required measurement locations per survey unit is 20 as per MARSSIM (Table 5.5) given a relative shift of 1.4 and an error rate for both Type I and Type II errors of five percent (i.e., $\alpha = \beta = 0.05$). The actual number of measurements to be performed in each concrete survey unit is 20 samples based on the size and geometry of the survey area.

### 4.3 Elevated Measurement Criterion ($DCGL_{EMC}$)

MARSSIM states that, for Class 1 survey units, a dose area factor should be used to evaluate the magnitude by which the concentration within a small area of elevated activity can exceed the $DCGL_w$ while maintaining compliance with the release criterion. For the purpose of ALARA, the $DCGL_w$ will be used as the $DCGL_{EMC}$ for both soil and structures. This corresponds to an area factor of one. Since soil and structure $MDC_{SCAN}$ values are sensitive enough to identify a concentration that is less than half of their respective $DCGL_w$, it is unlikely that small areas of elevated activity exceeding the release criterion would be missed during scanning.

### 4.4 Static Measurement Locations

Measurement locations in Class 1 survey units will be established using a random start point in a systematic triangular grid. The grid spacing for Class 1 survey units will be determined, based on the measured area of the survey unit, using the following equation (Equation 5-7 from MARSSIM).

$$L = \sqrt{\frac{A}{0.866\,N}}$$

Where: L = rectangular grid spacing for survey unit
A = area of survey unit
N = number measurement locations

Measurement spacing results (L) using the equation above are presented in Table 4.1-1. Maps presenting the BTD site SU delineations and the reference coordinate system are presented in Appendix D.

### 4.5 Gamma Walkover Surveys

GWS will be performed as described in Section 3.1 over 100% of reasonably accessible soil SU areas. If a scan measurement exceeds the soil action level, the Field Supervisor shall be notified and the detector and survey location shall be evaluated. Following evaluation, the immediate area will be rescanned to verify the initial result. If the verified result is greater than the action level, the location will be marked for further remediation followed by additional surveying of the location.

As described previously in section 2.1, the ravine area site feature has water covered surfaces that range from several centimeters to approximately 15 centimeters in depth. Scan surveys over soil areas covered by more than 13 cm of water may result in a $MDC_{SCAN}$ sensitivity less than the soil $DCGL_W$ of 105 pCi/g. To compensate for potential reduced instrument sensitivity in these areas, streambed sediment samples will be taken. The GWS for the area will be provided up to the areas of standing water. Sediment samples will be taken in the center of the streambed ravine where GWS measurements stop. Section 4.7 provides additional details associated with the sediment sampling.

### 4.6 Surface Alpha Radioactivity Scan Surveys

Alpha scan surveys will be performed as described in Section 3.2 and will cover 100% of reasonably accessible structure surfaces. Areas of elevated radioactivity identified during scanning will be physically marked and biased integrated measurements will be performed to quantify surface alpha activity concentrations for direct comparison to the $DCGL_W$. Survey areas in excess of the $DCGL_W$ will be investigated by the Field Supervisor and flagged for additional biased sampling (e.g., smear sampling). Beta scans will be performed in tandem with alpha measurements and recorded for qualitative purposes only.

### 4.7 Soil Sampling

Sampling of surface soil will be performed in soil SUs at locations selected for MARSSIM statistical testing and at biased locations identified during the GWS. Such measurements will be performed as described in Section 3.3. Collected samples will be sent to an offsite laboratory for isotopic uranium analysis.

Sediment samples will be taken in the streambed of the ravine to provide additional assurance that the soil action levels are not exceeded for this area. The sediment samples collected may take the place of systematic soil samples that may be co-located in streambed areas covered by water. Sediment samples will be taken in the approximate center of the ravine streambed at a rate of 1 sediment sample for every 7 linear meters of the ravine. This will result in a statistically significant number of samples (20 samples) based on the estimated total length of the ravine of 140 meters. The locations for these samples will be determined in the field due to the transient nature of the water in the ravine area.

### 4.8 Integrated Direct Surface Alpha Radioactivity Measurements

Measurements of surface alpha radioactivity will be performed on structures at locations selected for MARSSIM statistical testing and at biased locations identified prior to and during scanning activities. Such measurements will be performed as described in Section 3.4. Beta measurements will be performed in tandem with alpha measurements and recorded for qualitative purposes.

If any alpha survey measurement results in readings above the structure $DCGL_W$, the Field Supervisor shall be notified and the detector and survey location shall be evaluated. Following evaluation, a follow-up measurement shall be performed at the measurement location to verify the initial result. If the result of the verification measurement is in excess of the $DCGL_W$, remediation of the surface followed by biased sampling will be performed at that location.

### 4.9 Gamma Dose Rate Measurements

Gamma dose rate measurements will be performed at locations selected for MARSSIM statistical testing and at biased locations identified during scanning. At soil locations, dose rate measurements will be prior to soil samples being drawn. Gamma dose rate measurements may be performed to ensure worker safety and to identify unusual dose rate conditions. Gamma dose rate measurements will be performed as described in Section 3.5.

### 4.10 Smear Sample Collection and Analysis

Smear samples will be collected at biased survey locations and at least 10% of systematic survey locations. Smear samples will be collected as described in Section 3.6. Beta measurements will be performed in tandem with alpha measurements and recorded for qualitative purposes. Smear samples will also be collected on soil sampling equipment between sampling.

# 5.0 EQUIPMENT RELEASE

## 5.1 Survey of Equipment for Release Without Restriction

Certain equipment present within the BTD site boundaries may need to be surveyed for consideration of release without restriction. CABRERA will follow the surface release limits of 1,000 dpm/100 $cm^2$ removable DU alpha activity and 5,000 dpm/100 $cm^2$ total DU alpha activity per Army Regulation 11-9, "*The Army Radiation Safety Program*". It is expected that all final release surveys of equipment will be performed by the licensee and these surveys will follow APG procedures. If CABRERA performs these release surveys for APG, then CABRERA will follow the APG procedures.

# 6.0 DATA PROCESSING

This section describes how project events and data will be retained for this FSS.

## 6.1 Project Log Book

All significant events which occur during this FSS be documented and retained for future reference. While many types of project events have specific forms on which they are documented, many events occur on a routine basis during survey field activities that must be documented as they occur. Additionally, project data transactions must also be recorded as they occur. To provide a practical means of capturing this information, a project logbook will be initiated upon project commencement.

Significant project events, including data transactions involving project electronic data, shall be recorded in the Project Logbook. Data transactions are defined as any transfer, download, export, copy, differential correction, sort, or other manipulation performed on project electronic data. Project Logbook records shall be sufficient to allow data transactions to be reconstructed after the project is completed. The Field Supervisor shall be responsible for maintaining the Project Data Logbook and will review the Project Data Logbook at least daily to report significant issues.

The Project Logbook is considered a legal record and will be permanently bound and the pages will be pre-numbered. Pages may not be removed from the logbook under any circumstances. Entries shall be legible, factual, detailed, and complete and shall be signed and dated by the individual(s) making the entries. If a mistake is made, the individual making the entry shall place a single line through the erroneous entry and shall initial and date the deletion. Under no circumstances shall any previously entered information be completely obliterated. Use of whiteout in the Project Logbook is not permitted for any reason. Only one Project Logbook will be maintained. If a Project Logbook is completely filled, another volume shall be initiated. In this case, each volume shall be sequentially numbered.

## 6.2 Project Electronic Data

Much of this FSS will rely on data collected and stored electronically. Electronic data is subject to damage and/or loss if not properly protected. As such, all project electronic data shall be downloaded from its collection device (e.g., laptop computers, data loggers, etc.) on at least a daily basis. At the conclusion of each day's survey activities, the Field Supervisor shall back up all electronic data collected that day to appropriate removable media (e.g., CD, zip disk, or equivalent) and shall ensure the backup is removed from site. Under no circumstances shall the backup be stored in the same building in which the original project electronic data is stored.

Data files shall be named according to a naming protocol designated by the Field Supervisor. No variations from this protocol shall occur without the prior concurrence of the field supervisor. During data download and transfer transactions, the applicable data file name(s) shall be included in project data logbook entries.

## 7.0 INTERPRETATION OF SURVEY RESULTS

The results of individual soil and sediment samples and direct integrated alpha measurements performed for this FSS will be evaluated statistically and compared to the release criteria. This comparison will determine if the BTD site can be considered for release without radiological restriction. If all of the SUs of the BTD site meet the criteria for unrestricted release, the entire BTD site as defined in this FSS will be considered a viable candidate for unrestricted release.

Background in the sampled matrix is not considered during interpretation of individual soil samples, concrete smear samples, or the integrated alpha count measurements associated with soil, sediment, and concrete at the BTD site. This is a conservative approach and is appropriate since the background for these media are small compared to the $DCGL_w$ levels.

In accordance with MARSSIM guidance, a preliminary data review will be performed to identify patterns, relationships, and potential anomalies present in the survey data. In this review, basic statistics including the mean, standard deviation, maximum, and minimum values will be calculated for each SU. A graphical review of the data will be performed consisting of posting plots and histograms. Posting plots will be used to review the spatial independence of measurements within survey units, while histograms will be employed to review the overall symmetry of the data.

Once the data have been reviewed, soil sample or direct integrated alpha measurement results for each SU will be compared to the respective $DCGL_W$. If all of the results for a SU are below the $DCGL_W$, the survey unit meets the release criteria. If the average residual radioactivity in an individual SU is greater than the $DCGL_W$, the SU does not meet the release criteria. If any results in a SU are greater than the $DCGL_W$ and the average residual radioactivity in that survey unit is below the $DCGL_W$, the Sign test will be performed as described in MARSSIM to compare the median concentration of residual radioactivity in individual survey units to the $DCGL_W$. If the results of that survey unit pass the Sign test, that SU meets the release criteria. Finally, a retrospective power curve will be computed to measure the power of the Sign test based on the results of the measurements performed. The results of all of these statistical processes will be provided in the FSS Report.

## 8.0 SURVEY QUALITY ASSURANCE/QUALITY CONTROL

Activities associated with this work plan shall be performed in accordance with written procedures and/or protocols to ensure consistent, repeatable results. Topics covered in project procedures and protocols may include proper use of instrumentation, Quality Control (QC) requirements, equipment limitation, etc. Implementations of Quality Assurance (QA) measures for this work plan are described herein.

### 8.1 Instrumentation Requirements

The Field Supervisor is responsible for selecting the instrumentation required to complete the requirements of this work plan. Only instrumentation approved by the Field Supervisor will be used to collect radiological data. The Field Supervisor is responsible for ensuring individuals are appropriately trained to use project instrumentation and other equipment, and that instrumentation meets the required detection sensitivities. Instrumentation shall be operated in accordance with either a written procedure or manufacturers' manual, as determined by the Field Supervisor. The procedure and/or manual will provide guidance to field personnel on the proper use and limitations of the instrument.

*Calibration Requirements*

Instruments used during the FSS shall have current calibration/maintenance records kept on site for review and inspection. The records will include, at a minimum, the following:

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

Instrumentation shall be maintained and calibrated to manufacturers' specifications to ensure that required traceability, sensitivity, accuracy and precision of the equipment/instruments are maintained. Instruments will be calibrated at a facility possessing appropriate NRC and/or Agreement State licenses for performing calibrations using National Institute of Standards and Technology (NIST) traceable sources.

### 8.2 Instrument QC Source and Background Checks

The following subsections describe the techniques that will be used to evaluate accuracy and precision of measurements obtained with project instrumentation. Daily instrument response check data and calibration certificates for each instrument will be included in an appendix of the FSS.

*Sodium Iodide (NaI) Gross Gamma Systems*

NaI detectors coupled to count rate meters and DGPS systems will be used to perform gamma walk-over surveys and integrated fixed location measurements. Instruments will be calibrated at

least annually at a facility possessing appropriate NRC and/or Agreement State licenses for performing calibrations using NIST-traceable standards.

Instruments will be response checked daily for quality control by comparing the instrument response to a designated $^{137}$Cs source. Response checks will consist of a one-minute integrated count of the $^{137}$Cs source positioned in a reproducible geometry (i.e., a jig). The acceptance criterion for these instrument response checks is within +/- 20% of the mean response generated using ten initial source checks and ten measurements of ambient background. A response check outside these criteria will be cause for evaluation of conditions (e.g., instrument operation, source/detector geometry). The response check will be repeated once prior to field use of that instrument. Instruments that fail the second response check will be removed from service. During daily response checks, instruments will be inspected for physical damage, battery voltage levels, current calibration and erroneous readings.

Background checks will be performed daily for each instrument. These checks will be performed to monitor fluctuations in ambient gamma background that could impact the interpretation of the gross gamma measurements, not to monitor the performance of the instruments. The results of the background measurements will be recorded and presented on a control chart.

*MicroRem Meter*

A MicroRem meter will be to provide gamma dose rate information during performance of area radiation surveys. The instrument was calibrated at least annually by a facility possessing appropriate NRC and/or Agreement State licenses for performing calibrations using NIST-traceable standards.

Instruments will be checked daily for quality control by comparing response to a designated $^{137}$Cs source. Response checks will consist of exposing the instrument to a designated $^{137}$Cs source positioned in a reproducible geometry and location. The acceptance criterion for these instruments is response within a +/- 20% of the mean response generated using ten initial source checks and ten measurements of ambient background. A response check outside these criteria is cause for evaluation of conditions (e.g., instrument operation, source/detector geometry). The response check is repeated once prior to field use of that instrument. Instruments that fail the second response check will be removed from service pending evaluation. During daily response checks, the instrument used to obtain radiological data was also inspected for physical damage, battery voltage levels, current calibration and erroneous readings in accordance with CABRERA procedures.

*Alpha/Beta Detector*

Quality control source checks for the Ludlum 43-93 will consist of a one-minute integrated count with the designated Thorium–230 ($^{230}$Th) and Technetium-99 ($^{99}$Tc) sources. The acceptance criterion for this instrument response is within +/- 20% of the average response generated using ten initial source checks and ten measurements of background performed at the beginning of the project. A response check outside these criteria will be cause for evaluation of conditions (e.g., instrument operation, source/detector geometry), and the response check will be repeated once

prior to field use of that instrument. Instruments that fail the second successive response check will be removed from service and corrective actions will be taken. Only Field Supervisors can return a failed instrument back to service after proper corrective actions are taken and documented.

*Smear Counter*

A Ludlum Model 2929 smear counter will be used for on site analysis of radiological contamination smears in conjunction with project soil sampling. The instrument will be calibrated at least annually at a facility possessing appropriate NRC and/or Agreement State licenses for performing calibrations using NIST-traceable standards.

Instruments will be checked daily for quality control by comparing response to designated $^{230}$Th (Alpha) and $^{99}$Tc (Beta) NIST-traceable sources and to ambient background. Response checks will consist of a one-minute count of the $^{230}$Th and $^{99}$Tc sources positioned in a reproducible geometry and location within the detector system. Background measurements will be performed in an identical fashion for a twenty-minute count, with the source removed. The acceptance criteria for instrument response will be set to two and three-sigma of the mean response generated using ten initial source checks and ten measurements of ambient background. A response check outside the two-sigma, but within the three-sigma criteria will be cause for a recount prior to further evaluation. A response check outside two sigma on the second count or three-sigma on the initial count will be cause for further evaluation prior to continued use. A response check outside these criteria is cause for notification of the Field Supervisor and evaluation of conditions (e.g., instrument operation, source/detector geometry) prior to further counts and/or removal of the instrument from service. Instruments must pass a response check prior to field use. During daily response checks, instruments used to obtain radiological data will also be inspected for physical damage, battery voltage levels, current calibration and erroneous readings in accordance with CABRERA procedures.

*Digital Global Positioning System*

DGPS point features will be collected at the beginning and end of the day at a fixed location established at the beginning of the FSS. Results of these feature counts will be compared to the mean of a series of sequential initial positions. This data will be entered into a spreadsheet and examined to ensure no more than one-meter variability occurs. A feature count outside these criteria is cause for notification of the Site Supervisor and evaluation of conditions prior to further counts and/or removal of the GPS from service. GPS units must pass a feature count prior to field use. During daily feature counts, GPS systems will also be inspected for physical damage, battery voltage levels and erroneous readings in accordance with SOPs.

## 8.3 Duplicate Measurements

Instrumentation will be operated and sampling performed in accordance with standard operating procedures and/or protocols.

*Duplicate Measurements*

Duplicate measurements will be required for 10% of the total soil samples collected from all survey units. Duplicate measurements will be compared to the initial analytical results by determining a Normalized Absolute Difference (NAD) value and comparing it against the performance criteria specified as follows:

Analyses of field and laboratory duplicates will be compared to the initial analytical results by determining a NAD value for each data set by the following equation:

$$NAD = \frac{|\text{Sample - Duplicate}|}{\sqrt{\sigma^2_{\text{Sample}} + \sigma^2_{\text{Duplicate}}}}$$

Where: Sample = first sample value (original),
Duplicate = second sample value (duplicate),
$\sigma_{\text{Sample}}$ = 2σ counting uncertainty of the sample, and,
$\sigma_{\text{Duplicate}}$ = 2σ counting uncertainty of the duplicate

The calculated NAD results will be compared to a performance criteria of less than or equal to 1.96. Calculated NAD values less than 1.96 will be considered acceptable and values greater than 1.96 will be 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, $\sigma_{\text{Sample}}$ and $\sigma_{\text{Duplicate}}$, represent the true standard deviation of the measured population.

## 9.0 REFERENCES

(ANL, 1999) ANL Environmental Assessment Department Health Risk Report, "*Derived Uranium Guidelines for the Depleted Uranium Study Area of the Transonic Range, Aberdeen Proving Ground, Maryland*", M. Picel and S. Kamboj, Argonne National Laboratory, April 1999

(AR11-9, 1999) Army Regulation 11-9, *"The Army Radiation Safety Program"*, 28 May, 1999

(BARG, 1995) Specific Manufacturing Capability Program, *Depleted Uranium Constituents and Decay Heating*, Lockheed, Idaho presentation, dated October 3, 1995.

(CABRERA, 2000a) CABRERA OP-020, "*Operation of Contamination Survey Meters", Rev 0*

(CABRERA, 2000b) CABRERA OP-021, "*Alpha-Beta Counting Instrumentation", Rev 0*

(CABRERA, 2000c) CABRERA OP-023, "*Operation of micro-R Meters", Rev 0*

(CABRERA, 2003) Cabrera Report, "*U.S. Army Garrison, Aberdeen Proving Ground Derived Uranium Guidelines For Depleted Uranium at the BTD Soil Sample Area*", Contract DAAA09-00-G-0002/039

(NRC, 1999) NUREG/CR-5512, Volume 3 *Residual Radioactive Contamination from Decommissioning, Parameter Analysis*, Draft Report for Comment, U.S. Nuclear Regulatory Commission, dated October, 1999.

(NRC, 2000) NUREG-1575, *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM), U.S. Nuclear Regulatory Commission, dated August, 2000.

(Weston, 2001) Weston Report, "*Radiological Characterization for the Bomb Throwing Device Interim Report, Aberdeen Test Center, Aberdeen Proving Ground, MD*", Contract No. DAAD05-97-D-7004, dated September, 2001.

# Appendix A:
# Uranium 238 Decay Series

# Uranium 238 Decay Series

(Excerpted from Radioactive Decay Data Tables, David Kocher, 1981)

| Radionuclide | Half-Life | Emissions | Energy (MeV) | Percent Yield |
|---|---|---|---|---|
| U-238 | 4.5 x 109 y | α | 4.2 | 75 |
| | | α | 4.15 | 25 |
| Th-234 | 24.1 d | β | 0.193 | 79 |
| | | β | 0.1 | 21 |
| | | γ | 0.093 | 4 |
| | | γ | 0.063 | 3.5 |
| Pa-234m | 1.17 min | β | 2.29 | 98 |
| Pa-234 | 6.75 h | β | 0.53 | <1 |
| | | β | 1.13 | <1 |
| U-234 | 2.47 x105 y | α | 4.72 | 28 |
| | | α | 4.77 | 72 |
| Th-230 | 8.0 x 104 y | α | 4.62 | 24 |
| | | α | 4.68 | 76 |
| Ra-226 | 1602 y | α | 4.60 | 6 |
| | | α | 4.78 | 95 |
| | | γ | 0.186 | 4 |
| Rn-222 | 3.82 d | α | 5.49 | 100 |
| Po-218 | 3.05 min | α | 6.0 | 100 |
| Pb-214 | 26.8 min | β | 0.65 | 50 |
| | | β | 0.71 | 40 |
| | | γ | 0.3 | 19 |
| | | γ | 0.35 | 36 |
| Bi-214 | 19.7 min | β | 1.0 | 23 |
| | | β | 1.51 | 40 |
| | | β | 3.26 | 19 |
| | | γ | 0.609 | 47 |

# Appendix B:

# Derived Concentration Guideline Level (DCGL) Determination For U. S. Army Garrison, Aberdeen Proving Grounds (APG) Bomb Throwing Device Site

# U. S. ARMY GARRISON, ABERDEEN PROVING GROUND DERIVED URANIUM GUIDELINES FOR DEPLETED URANIUM AT THE BTD SOIL SAMPLE AREA

**Contract Number**
**DAAA09-00-G-0002 / 039**

**Prepared for:**

**U.S. Army Operations Support Command**
**Rock Island, Illinois**

**Performed By:**

**CABRERA Services Inc.**
**809 Main Street**
**East Hartford, CT 06108**

**Project No. 01-3030.39**

# EXECUTIVE SUMMARY

The depleted uranium (DU) derived concentration guideline level (DCGL) developed for the Transonic Range is considered applicable to and adequately protective for the BTD Site on the basis of comparable site-specific RESRAD parameters/pathways, the similarity of both locations, and the equivalence of the radiological isotopic DU mixes at both locations. Use of the approved Transonic DCGL at the BTD Site will ensure that the potential dose to a hypothetical individual will not exceed 25 mrem in any one year over a 1,000 period consistent with 10 CFR Part 20 Subpart E requirements.

On these bases, the proposed DCGL for the BTD Site in soil is 230 pCi/g total DU (resident-farmer scenario). This evaluation utilizes the more conservative resident-farmer scenario. Additionally, the ALARA principle of as-low-as-reasonably-achievable is applied to provide assurance that hypothetical doses are limited. The ALARA action level has been set at 105 pCi/g.

# DERIVED CONCENTRATION GUIDELINE LEVEL (DCGL) DETERMINATION FOR U. S. ARMY GARRISON, ABERDEEN PROVING GROUNDS (APG) BOMB THROWING DEVICE SITE

## 1.0 BACKGROUND

The Aberdeen Test Center (ATC) Bomb Throwing Device (BTD) site was used between 1982 and 1993 for the testing of Depleted Uranium (DU) munitions. The site consists of the BTD Butt Enclosure, access roads, Plate Storage Area (PSA), and several support buildings situated on approximately 4-5 acres of land. The BTD Butt Enclosure has dimensions of approximately 25 by 50 feet with a height of 20 feet. WESTON previously performed a MARSSIM type characterization at the BTD Site. Data from that characterization has been utilized in this evaluation. The total BTD site land area is approximately 10 acres.

During testing at the site, munitions were fired at either steel plate targets or vehicles placed inside the BTD Butt Enclosure. A HEPA ventilation system associated with the BTD Butt Enclosure was designed to filter potentially contaminated air exiting the building. Heavy equipment was used to transport the armor plates between the PSA and the BTD Butt Enclosure. Currently, approximately 40 tons of DU-contaminated armor plate is located within the BTD Site.

A characterization study was initiated to identify DU and other environmental contaminants currently present in the soil as well as gamma radiation levels at the site. This is in preparation for removal of the BTD Butt Enclosure and decommissioning of the BTD Site currently covered by **NRC LICENSE #**. The WESTON characterization study provided quantitative activity concentration levels of $^{235}U$ and $^{238}U$ in soil and identified MARSSIM class 1, 2, and 3 areas based on comparison of results to NRC screening derived concentration guideline levels (DCGLs).

Results from the WESTON BTD Site characterization are compared in this evaluation to characterization data from the Transonic Range. The Transonic Range Decommissioning Plan (DP) developed by ATG utilized the characterization data and DCGL dose analysis as provided by Argonne National Laboratory. NRC has approved this DP.

## 2.0 SCOPE/PURPOSE

The purpose of this evaluation is to contrast and compare the parameters used to develop the DU-contaminated soil (DCGL) applied at the Transonic Range to the BTD Site. This evaluation will be used to demonstrate that the DCGL used at the Transonic Range may be equally applied at the BTD Site.

## 3.0 DCGL EVALUATION

The DCGL for the DU Study Area of the Transonic Range is based on a site-specific uranium guideline derived on the basis of a 50-year Total Effective Dose Equivalent (TEDE) to a

hypothetical individual not exceeding 25 mrem in any one year and evaluated over a 1,000 year time interval.

## 3.1 DCGL Derivation from Transonic DP

The results of a previous DU DCGL developed for the Transonic Range were submitted to NRC as part of a DP for the Transonic Range and was approved. The computer code, RESRAD, Version 5.82 (ANL 1999) used to develop DCGLs for the Transonic Range. The RESRAD code parameters/pathways used in the Transonic Range evaluation was set up to consider nine exposure pathways:

1) Direct exposure from contaminated soil,
2) Internal dose from inhalation of contaminated dust,
3) Internal radiation from the inhalation of emanating radon-222,
4) Internal radiation from the ingestion of plant foodstuffs grown in contaminated soil and irrigated with groundwater drawn from a well located within the decontaminated area,
5) Internal radiation from the ingestion of meat from livestock fed fodder grown in the decontaminated area and irrigated with groundwater from the decontaminated area,
6) Ingestion of milk from milk animals raised with fodder and irrigation groundwater drawn from the decontaminated area,
7) Internal radiation from ingestion of fish from a pond drawing water from the decontaminated area,
8) Internal dose from the ingestion of on-site soil, and
9) Internal radiation from drinking water drawn from an on-site well.

Two potential exposure scenarios were considered using combinations of the above pathways. These are the industrial-worker scenario and the resident-farmer scenario. The industrial-worker scenario assumes the continued industrial use of the site. The scenario assumes 2,000 hours per year at the site with 6 hours per day spent indoors and 2 hours per day spent outdoors. No plant foodstuffs, meat, milk, fish, or water is consumed from the site. The dose is assumed to arise only from the contaminated soil. This scenario reflects the current use and is a likely future use scenario.

The resident-farmer scenario has a subsistence farmer who lives on the site and consumes foodstuffs grown on the site. This includes on-site groundwater for drinking and irrigation, vegetables, fruits, livestock meat, milk, and 50% of the farmer's fish consumption. At the present time, no agricultural activity occurs on the site. This scenario is plausible but considered an unlikely future use. Table 1 provides a summary of the exposure pathways by scenario.

| **TABLE 1 - Applicable Pathways for Industrial-Worker and Resident-Farmer Scenarios** | | |
|---|---|---|
| | Applicable Pathways | |
| Pathway | Industrial-worker | Resident-Farmer |
| External gamma exposure | Yes | Yes |
| Inhalation of soil | Yes | Yes |
| Inhalation of radon | Yes | Yes |
| Ingestion of soil | Yes | Yes |
| Ingestion of plant foodstuffs | No | Yes |
| Ingestion of meat | No | Yes |
| Ingestion of milk | No | Yes |
| Ingestion of fish | No | Yes |
| Ingestion of water | No | Yes |

## 3.2 Evaluation of Applicability of Transonic Range DCGL to BTD Site

Since the BTD Site and the Transonic Range are within a few miles of each other at APG, the climate, meteorology, irrigation rates, the type, growth rate, and root depths of vegetation, type of meat and milk producing animals, fish and aquatic organisms, and the geology and soil characteristics are considered to be similar in nature for purposes of this evaluation. Additionally, the types of work activities causing the contamination of the soil are similar and result in like soil surface and vertical distributions. Table 2 provides a summary comparison of the parameters.

The DU contaminated soil at the Transonic Range was characterized from the analysis of 100 total soil samples collected from 1-3 inch and 3-6 inch depths. The samples were analyzed for $^{234}U$, $^{235}U$, and $^{238}U$ isotopes by alpha spectroscopy.

| TABLE 2 - RESRAD Parameters for Transonic Range and BTD Site | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Region | Area | Soil Cover | Vegetation | Water | Meat | Milk | Fish Pond | Radon | Direct Soil Irrad. | Soil Inhal | Meteor-ology | Geology/ Soil Char. |
| Transonic Range | 12 acre | none | Site parameters are those indigenous to the eastern shore area of Maryland at APG | | | | | | | | | |
| BTD Site | 10.5 acre | none | Due to geographic proximity of both sites and type of work activities causing soil activity, BTD Site parameters are considered the same | | | | | | | | | |

A soil characterization (WESTON) was completed at the BTD Site in 2001. As with the Transonic Range soil samples, soil was collected from the surface and near surface. At the BTD Site soil was collected from the surface to a depth of 3 inches. Samples were collected in areas designated as class 1, class 2, and class 3 areas following MARSSIM definition and an assumed NRC screening DCGL. A total of 44 samples from the class 1 area had detectable $^{235}U$; 36 samples from the class 2 area had detectable $^{235}U$; and 20 samples from the class 3 area had detectable $^{235}U$ activity concentrations. In addition, 13 samples from a background area had detectable $^{235}U$ activity concentrations.

For the purpose of contaminant magnitude and isotopic mixture evaluation, the BTD Site class 1 and class 2 area characterization results were lumped together as one category because of the significant levels of uranium identified in these areas. The listed class 3 area results were similar in magnitude to that observed in the background area and had $^{235}U/^{238}U$ ratios that are indicative of natural uranium concentrations as opposed to typical DU ratios. These areas are not considered further in this evaluation.

The BTD Site class 1 and class 2 area data was analyzed in the same fashion as the Transonic Range soil samples, namely case 1 included all samples, case 2 included samples greater than 1 pCi/g, and case 3 excluded samples greater than 1,000 pCi/g $^{238}U$. Since the BTD Site analysis was based on gamma spectroscopy, only the $^{235}U$ and $^{238}U$ isotopes are identified. A comparison of the soil concentration activity ranges and $^{235}U/^{238}U$ activity ratios at the Transonic Range and the BTD Site for the 3 cases is shown in Table 3.

The comparison indicates that the $^{235}U/^{238}U$ activity concentration ratio at the BTD Site is similar to that detected at the Transonic Range. This is expected because the DU utilized at both locations has the same $^{235}U$ depletion. At both the Transonic Range and the BTD Site the activity ratio of $^{235}U/^{238}U$ indicates that the uranium is in fact DU since the activity ratio ranges from 0.013 to 0.028 while natural uranium has a $^{235}U/^{238}U$ activity ratio of 0.045.

| TABLE 3 – Transonic Range and BTD Site Soil Data Activity Ratio Comparison | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Transonic Range | | | | BTD Site | | | |
| Case No. | Item | $^{234}U$ | $^{235}U$ | $^{238}U$ | $^{235}U/^{238}U$ | $^{234}U$ | $^{235}U$ | $^{238}U$ | $^{235}U/^{238}U$ |
| 1[a] | Activity Range, pCi/g | 0.19 - 49,000 | 0.001 - 8,300 | 0.19 - 370,000 | - | No results provided | 0.055-31.7 | 0.974-1,470 | - |
| 1[a] | Average Activity Fraction | 0.211 | 0.0205 | 0.768 | 0.027 | - | - | - | 0.027 |
| 2[b] | Activity Range, pCi/g | 6.7 - 49,000 | 1.2 - 8,300 | 45 – 370,000 | - | No results provided | 1.05 – 31.7 | 70.6 – 1470 | - |
| 2[b] | Average Activity Fraction | 0.138 | 0.0234 | 0.839 | 0.028 | - | - | - | 0.013 |
| 3[c] | Activity Range, pCi/g | 0.19 - 46 | 0.001 – 6.3 | 0.19 - 290 | - | No results provided | 0.055-5.99 | 0.974-528 | - |
| 3[c] | Average Activity Fraction | 0.222 | 0.0193 | 0.759 | 0.025 | - | - | - | 0.027 |
| Nat. U | Activity Fraction | 0.489 | 0.022 | 0.489 | 0.045 | 0.489 | 0.022 | 0.489 | 0.045 |

[a] For case 1, all samples were grouped together
[b] For case 2, only samples with $^{235}U$ activity greater than 1 pCi/g were grouped together
[c] For case 3, hot samples were removed, and the remaining samples were grouped together

The $^{234}U$ soil activity concentrations were not determined for the BTD Site since analysis was performed using gamma spectroscopy. However, the dose fraction assigned to a hypothetical individual from the $^{234}U$ isotope is a small fraction of the total dose. Tables 4 and 5 summarize the maximum dose-to-source concentration ratio (dose conversion factor or DCF) as a function of pathway and scenario at Transonic range as derived from ANL 1999. Since the maximum dose occurs immediately after remediation, the dose from the inhalation of radon, water ingestion, and fish ingestion pathways are zero (ANL 1999). Since the BTD Site depth to ground water is deeper than at the Transonic Range, it is logical that the breakthrough time for the BTD area would be longer than at Transonic. The breakthrough time (i.e., time it takes the uranium to reach the water table) does not occur within 1,000 years (ANL 1999).

The $^{234}U$ dose contribution DCF for the industrial-worker and the resident-farmer scenarios immediately following remedial action is small, being on the order of 3.4% and 6.5% of the total uranium DCF respectively. Tables 4 and 5 list the fractional DCF for $^{234}U$ compared to total uranium DCF for the Transonic Range. Based on the information in these two tables, the $^{234}U$ DCF components are expected to be generally smaller or comparable to the $^{235}U$ and $^{238}U$ DCFs. Therefore the $^{234}U$ DCF may be estimated for the BTD Site as being the same as the Transonic Range without incurring any significant calculation differences.

**TABLE 4 – Maximum Dose/Source Concentration Ratios for the Industrial-Worker Scenario at the Depleted Uranium Study Area of the Transonic Range**

| | Maximum Dose/Source Concentration Ratios[a] (mrem/yr)/(pCi/g) | | | |
|---|---|---|---|---|
| Pathway | $^{234}U$ | $^{235}U$ | $^{238}U$ | $^{234}U$/Total U |
| External gamma exposure | 8.3E-5 | 1.5E-1 | 2.6E-2 | 4.7E-4 |
| Inhalation of dust | 4.3E-3 | 4.0E-3 | 3.8E-3 | 3.6E-1 |
| Inhalation of radon | 0 | 0 | 0 | - |
| Ingestion of soil | 2.4E-3 | 2.2E-3 | 2.3E-3 | 3.5E-1 |
| Total | 6.7E-3 | 1.6E-1 | 3.2E-2 | 3.4E-2 |

[a] All values are reported to two significant figures. Maximum dose/source concentration ratios would occur immediately following remedial action for all uranium isotopes. This value is the dose conversion factor, DCF.

**TABLE 5 – Maximum Dose/Source Concentration Ratios for the Resident-Farmer Scenario at the Depleted Uranium Study Area of the Transonic Range**

| | Maximum Dose/Source Concentration Ratios[a] (mrem/yr)/(pCi/g) | | | |
|---|---|---|---|---|
| Pathway | $^{234}U$ | $^{235}U$ | $^{238}U$ | $^{234}U$/Total U |
| External gamma exposure | 2.4E-4 | 4.3E-1 | 7.2E-2 | 4.8E-4 |
| Inhalation of dust | 9.9E-3 | 9.2E-3 | 8.9E-3 | 3.5E-1 |
| Inhalation of radon | 0 | 0 | 0 | - |
| Ingestion of plant foods | 1.0E-2 | 9.7E-3 | 9.8E-3 | 3.4E-1 |
| Ingestion of meat | 3.2E-3 | 3.0E-3 | 3.0E-3 | 3.5E-1 |
| Ingestion of water | 0 | 0 | 0 | - |
| Ingestion of milk | 8.2E-3 | 7.7E-3 | 7.8E-3 | 3.5E-1 |
| Ingestion of fish | 0 | 0 | 0 | - |
| Ingestion of soil | 7.7E-3 | 7.3E-3 | 7.4E-3 | 3.4E-1 |
| Total | 4.0E-2 | 4.7E-1 | 1.1E-1 | 6.5E-2 |

[a] All values are reported to two significant figures. Maximum dose/source concentration ratios would occur immediately following remedial action for all uranium isotopes. This value is the dose conversion factor, DCF.

The residual radioactive material guideline is the concentration of contaminated material that may remain in a decontaminated area and still allow for unrestricted use of the area. The residual radioactive material guideline, or derived concentration guideline level (DCGL) for a given dose limit, DL, to a hypothetical individual derived from the soil data at the Transonic Range may be calculated as

$$DCGL = DL/DCF$$

Where,

DCGL = Derived Concentration Guideline Level, pCi/g in soil

DL = NRC Dose Limit for unrestricted use, 25 mrem/year for both industrial-worker and resident-farmer

DCF = Dose conversion factor to transform volumetric concentration to dose rate, (mrem/year)/(pCi/g)

The DCF ratios listed in Table 6 were used in turn to determine the allowable residual radioactivity for uranium in soil at the Transonic Range using the above relationship. The resulting DCGL for each radionuclide is shown in Table 7. The $^{238}U$ isotope may be used as an indicator radionuclide by multiplying the Table 7 individual depleted uranium DCGL guideline by the appropriate $^{238}U$ activity concentration fraction. This allows for use of the readily identified field indicator, $^{238}U$, to be used as the indicator radionuclide DCGL.

**TABLE 6 – Total Dose/Source Concentration Ratios for Uranium at the Depleted Uranium Study Area of the Transonic Range**

| | Maximum Dose/Source Concentration Ratios[a] (mrem/yr)/(pCi/g) | |
|---|---|---|
| Radionuclide | Industrial-Worker[b] | Resident-Farmer[c] |
| $^{234}U$ | 6.7E-3 | 4.0E-2 |
| $^{235}U$ | 1.6E-1 | 4.7E-1 |
| $^{238}U$ | 3.2E-2 | 1.1E-1 |
| Natural Uranium | 2.2E-2 | 8.3E-2 |
| Depleted Uranium[d] | 2.9E-2 | 1.0E-1 |
| Depleted Uranium[e] | 3.1E-2 | 1.1E-1 |
| Depleted Uranium[f] | 2.9E-2 | 1.0E-1 |

[a] All values are reported to two significant figures. Maximum dose/source concentration ratios would occur immediately following remedial action for all uranium isotopes
[b] Industrial-Worker: no consumption of water or food obtained on the site (current use scenario)
[c] Resident-Farmer : Water used for drinking, household purposes, livestock, watering, and irrigation assumed to be from an on-site well (an unlikely but plausible future use scenario)
[d] The uranium isotopes ($^{238}U$, $^{234}U$, and $^{235}U$) are present in the activity ratio of 0.768:0.211:0.0205
[e] The uranium isotopes ($^{238}U$, $^{234}U$, and $^{235}U$) are present in the activity ratio of 0.839:0.138:0.0234
[f] The uranium isotopes ($^{238}U$, $^{234}U$, and $^{235}U$) are present in the activity ratio of 0.759:0.222:0.0193

| **TABLE 7 – Residual Radioactive material DCGL for Depleted Uranium Study Area of the Transonic Range (25 mrem)** | | |
|---|---|---|
| | DCGL Guideline, pCi/g[a] | |
| Radionuclide | Industrial-Worker[b] | Resident-Farmer[c] |
| $^{234}U$ | 3,700 | 630 |
| $^{235}U$ | 160 | 54 |
| $^{238}U$ | 790 | 230 |
| Natural Uranium | 1,100 | 300 |
| Depleted Uranium[d] | 860; (660)[g] | 250; (190)[g] |
| Depleted Uranium[e] | 800; (670)[g] | 230; (190)[g] |
| Depleted Uranium[f] | 880; (670)[g] | 250; (190)[g] |

[a] All values are reported to two significant figures.
[b] Industrial-Worker: no consumption of water or food obtained on the site (current use scenario, dose constraint 25 mrem/yr)
[c] Resident-Farmer : Water used for drinking, household purposes, livestock, watering, and irrigation assumed to be from an on-site well (an unlikely but plausible future use scenario, dose constraint 25 mrem/yr)
[d] The uranium isotopes ($^{238}U$, $^{234}U$, and $^{235}U$) are present in the activity ratio of 0.768:0.211:0.0205
[e] The uranium isotopes ($^{238}U$, $^{234}U$, and $^{235}U$) are present in the activity ratio of 0.839:0.138:0.0234
[f] The uranium isotopes ($^{238}U$, $^{234}U$, and $^{235}U$) are present in the activity ratio of 0.759:0.222:0.0193
[g] First number is the total DU DCGL; number in parenthesis is the indicator radionuclide $^{238}U$ value

## 4.0 SUMMARY

Since the BTD Site and the Transonic Range are within close proximity of each other, the climate, meteorology, irrigation rates, the type, growth rate, and root depths of vegetation, type of meat and milk producing animals, fish and aquatic organisms, and the geology and soil characteristics are considered to be similar in nature. Additionally, since the type of work activities and the DU isotopic activity fractions at both locations are similar they result in surface and vertical distributions of DU that are comparable at both the Transonic Range and the BTD Site.

The DCGL developed at the Transonic Range is considered applicable to and adequately protective for the BTD Site on the basis of comparable site-specific RESRAD parameter/pathways, the similarity of both locations, and the equivalence of the radiological isotopic DU mixes. Use of the approved Transonic DCGL at the BTD Site will ensure that the potential dose to a hypothetical individual will not exceed 25 mrem in any one year over a 1,000-year period. The DCGL for the BTD Site soil is 230 pCi/g total DU (resident-farmer scenario). Additionally, the ALARA principle of as-low-as-reasonably-achievable is applied to provide

assurance that hypothetical doses are limited. The ALARA action level DCGL has been set at 105 pCi/g total DU.

## 5.0 REFERENCES

1. ANL 1999 — *Derived Uranium Guidelines for the Depleted Uranium Study Area of the Transonic Range, Aberdeen Proving Ground, Maryland,* ANL Rad Health Risk Study, M. Picel and S. Kamboj, April 16, 1999

2. WESTON — *Radiological Characterization for the Bomb Throwing Device Interim Report Aberdeen Test Center Aberdeen Proving Ground, MD,* Addendum to the BEST Contract General Safety and Health Program, Rev. 2 September 1999, Contract No. DAAD05-97-D-7004, Delivery Order No. 191, dated September 2001

# Appendix C:

# Ludlum NaI 3"x3" $MDC_{SCAN}$ and Instrument Sensitivity Results Calculated Using Microshield®

## Bomb Throwing Device Area 3x3 NaI Calibration Factor (DU)

**$MDC_{SCAN}$:** 38 pCi/g
**Sensitivity:** 65 cpm per pCi/g
**Assumed bkg:** 10 uR/hr
**Source Distribution per:** NUREG-1507 (56 cm dia soil uniformly contaminated to a depth of 15 cm)
**DU Activity fractions:** 84.7% U238; 14.2% U234; 1.1% U235

## BTDA 3x3 NaI Scan for DU @ 1pCi/g total Uranium w/ no soil cover at 15 cm thick x 28 cm RADIUS

**Fluence rate to exposure rate (FRER, no units) = ~ (1 uR/h)/(Eγ)($u_{en}/\rho$)air**

| TABLE 1 | | |
|---|---|---|
| Energy$_\gamma$, keV | $(u_{en}/\rho)_{air}$, $cm^2/g$ | FRER |
| 15 | 1.29 | 0.0517 |
| 20 | 0.516 | 0.0969 |
| 30 | 0.147 | 0.2268 |
| 40 | 0.064 | 0.3906 |
| 50 | 0.0384 | 0.5208 |
| 60 | 0.0292 | 0.5708 |
| 80 | 0.0236 | 0.5297 |
| 100 | 0.0231 | 0.4329 |
| 150 | 0.0251 | 0.2656 |
| 200 | 0.0268 | 0.1866 |
| 300 | 0.0288 | 0.1157 |
| 400 | 0.0296 | 0.0845 |
| 500 | 0.0297 | 0.0673 |
| 600 | 0.0296 | 0.0563 |
| 800 | 0.0289 | 0.0433 |
| 1,000 | 0.0280 | 0.0357 |
| 1,500 | 0.0255 | 0.0261 |
| 2,000 | 0.0234 | 0.0214 |

**Probability of interaction (P) through end of detector for given energy is**

Probability = $1-e^{-(\mu/\rho)NaI\,(x)\,(\rho NaI)}$

| TABLE 2 | | |
|---|---|---|
| Energy$_\gamma$, keV | $(\mu/\rho)_{NaI}$, cm$^2$/g | P |
| 15 | 47.4 | 1.00 |
| 20 | 22.3 | 1.00 |
| 30 | 7.45 | 1.00 |
| 40 | 19.3 | 1.00 |
| 50 | 10.7 | 1.00 |
| 60 | 6.62 | 1.00 |
| 80 | 3.12 | 1.00 |
| 100 | 1.72 | 1.00 |
| 150 | 0.625 | 1.00 |
| 200 | 0.334 | 1.00 |
| 300 | 0.167 | 0.99 |
| 400 | 0.117 | 0.96 |
| 500 | 0.0955 | 0.93 |
| 600 | 0.0826 | 0.90 |
| 800 | 0.0676 | 0.85 |
| 1,000 | 0.0586 | 0.80 |
| 1,500 | 0.0469 | 0.73 |
| 2,000 | 0.0413 | 0.68 |

for Ludlum 3x3 Model 44-20 7.6 cm dia x 7.6 cm thick NaI crystal

x = 7.6 cm

$\rho$ = 3.67 g/cm$^3$

aluminum window per Ludlum ~0.05 inch thick

**Relative Detector Response (RDR) = relative fluence-to-exposure rate (FRER) times probability (P) of interaction**

| **TABLE 3** | | | |
|---|---|---|---|
| Energy$_\gamma$, keV | FRER | P | RDR |
| 15 | 0.0517 | 1.00 | 0.0517 |
| 20 | 0.0969 | 1.00 | 0.0969 |
| 30 | 0.2268 | 1.00 | 0.2268 |
| 40 | 0.3906 | 1.00 | 0.3906 |
| 50 | 0.5208 | 1.00 | 0.5208 |
| 60 | 0.5708 | 1.00 | 0.5708 |
| 80 | 0.5297 | 1.00 | 0.5297 |
| 100 | 0.4329 | 1.00 | 0.4329 |
| 150 | 0.2656 | 1.00 | 0.2656 |
| 200 | 0.1866 | 1.00 | 0.1866 |
| 300 | 0.1157 | 0.99 | 0.1146 |
| 400 | 0.0845 | 0.96 | 0.0812 |
| 500 | 0.0673 | 0.93 | 0.0626 |
| 600 | 0.0563 | 0.90 | 0.0507 |
| 800 | 0.0433 | 0.85 | 0.0367 |
| 1,000 | 0.0357 | 0.80 | 0.0287 |
| 1,500 | 0.0261 | 0.73 | 0.0191 |
| 2,000 | 0.0214 | 0.68 | 0.0146 |

Estimated Ludlum 44-20 7.6 cm dia x 7.6 cm thick NaI response for Cs-137 i: 2700 cpm/uR/hr

Use same methodology and interpolating for Cs-137 response have:

| Energy$_\gamma$, keV | $(u_{en}/\rho)_{air}$, $cm^2/g$ | | |
|---|---|---|---|
| 662 | 0.0294 | FRER ~ | 0.0514 |
| Energy$_\gamma$, keV | $(\mu/\rho)_{NaI}$, $cm^2/g$ | | |
| 662 | 0.0780 | Probability = | 0.89 |
| | | RDR = | 0.0455 |

For this detector the response to another energy is based on the ratio of the relative detector response, RDR, to the Cs-137 energy cpm/μR/h, $E_i = (cpm_{cs\text{-}137})^*(RDR_{Ei})/(RDR_{Cs\text{-}137})$

| TABLE 4 | | |
|---|---|---|
| Energy$_\gamma$, keV | $RDR_{Ei}$ | Ludlum 44-20 3x3 NaI Detector, $E_i$, cpm per μR/hr |
| 15 | 0.0517 | 3064 |
| 20 | 0.0969 | 5745 |
| 30 | 0.2268 | 13445 |
| 40 | 0.3906 | 23161 |
| 50 | 0.5208 | 30881 |
| 60 | 0.5708 | 33842 |
| 80 | 0.5297 | 31404 |
| 100 | 0.4329 | 25667 |
| 150 | 0.2656 | 15748 |
| 200 | 0.1866 | 11061 |
| 300 | 0.1146 | 6797 |
| 400 | 0.0812 | 4816 |
| 500 | 0.0626 | 3714 |
| 600 | 0.0507 | 3005 |
| 662 | 0.0455 | 2700 |
| 800 | 0.0367 | 2175 |
| 1,000 | 0.0287 | 1704 |
| 1,500 | 0.0191 | 1131 |
| 2,000 | 0.0146 | 867 |

MDC for Cs-137 energy

Assume 10 μR/hr bkg then have 27,000 cpm

| | | |
|---|---|---|
| $b_i$ = | 450 | counts |
| MDCR = | 1756 | cpm |
| $MDCR_{surveyor}$ = | 2484 | cpm |

minimum detectable exposure rate = 0.92 μR/hr

**Table 5**

| keV | MicroShield Exposure Rate, μR/hr (with buildup ) | cpm/μR/hr | cpm/μR/hr (weighted) | Percent of NaI detector response |
|---|---|---|---|---|
| 15 | 8.274E-09 | 3064 | 0 | 0.0% |
| 20 | 6.657E-11 | 5745 | 0 | 0.0% |
| 30 | 4.852E-06 | 13445 | 9 | 0.1% |
| 40 | 7.972E-09 | 23161 | 0 | 0.0% |
| 50 | 1.133E-06 | 30881 | 5 | 0.1% |
| 60 | 3.234E-04 | 33842 | 1483 | 16.8% |
| 80 | 4.275E-05 | 31404 | 182 | 2.1% |
| 100 | 1.398E-03 | 25667 | 4863 | 55.0% |
| 150 | 1.108E-04 | 15748 | 236 | 2.7% |
| 200 | 5.489E-04 | 11061 | 823 | 9.3% |
| 300 | 1.301E-05 | 6797 | 12 | 0.1% |
| 400 | 1.473E-05 | 4816 | 10 | 0.1% |
| 500 | 2.694E-05 | 3714 | 14 | 0.2% |
| 600 | 1.309E-04 | 3005 | 53 | 0.6% |
| 800 | 9.470E-04 | 2175 | 279 | 3.2% |
| 1000 | 3.690E-03 | 1704 | 852 | 9.6% |
| 1500 | 1.083E-04 | 1131 | 17 | 0.2% |
| 2000 | 1.755E-05 | 867 | 2 | 0.0% |
| Total | 7.378E-03 | | 8840 | 100% |

Minimum Detectable Exposure Rate =

MDCR surveyor/(cpm/μr/hr)
0.281 μr/hr

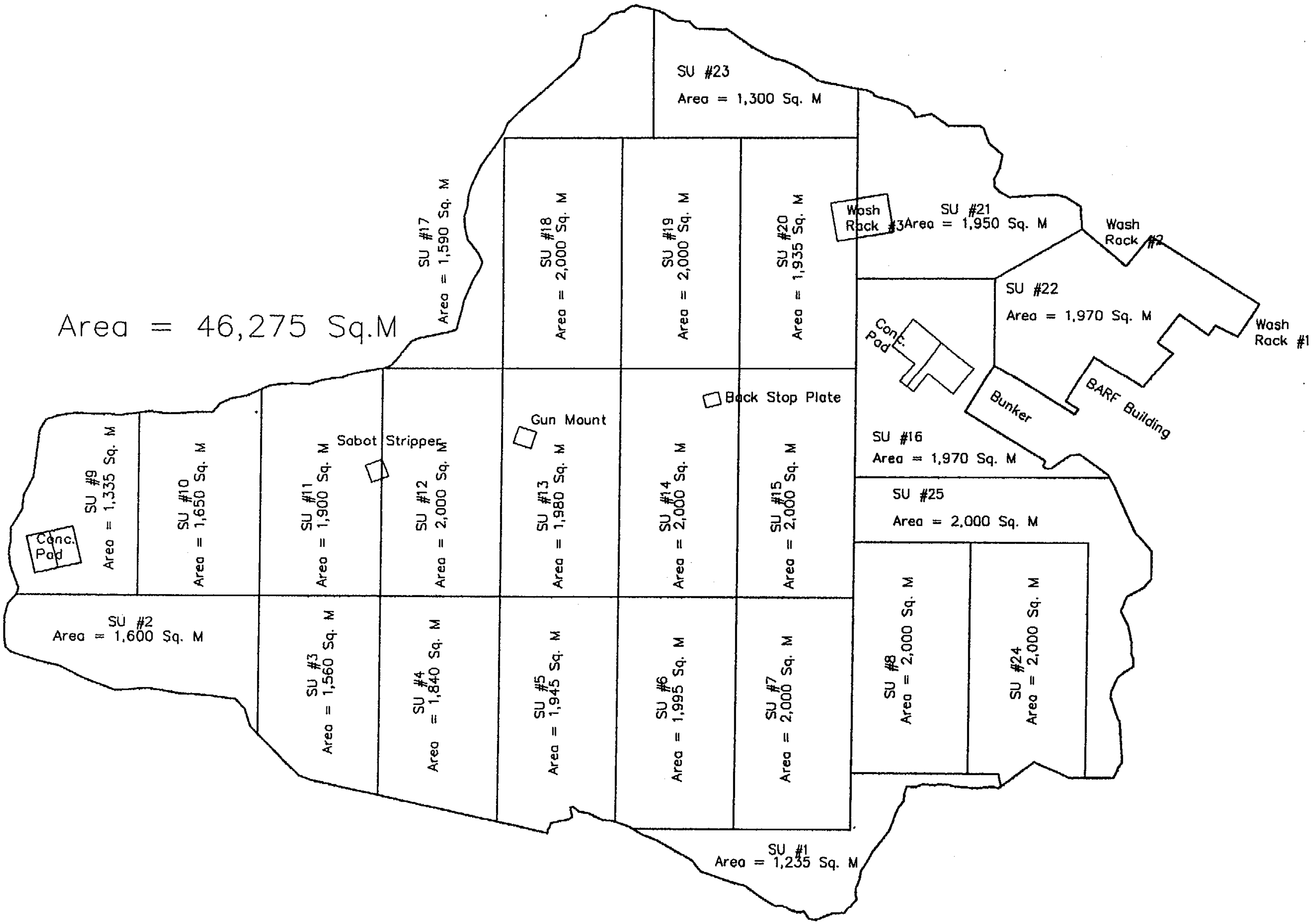
and MDC for DU and 50-year equilibrium progeny based on a normalized 1 pCi/g total uranium

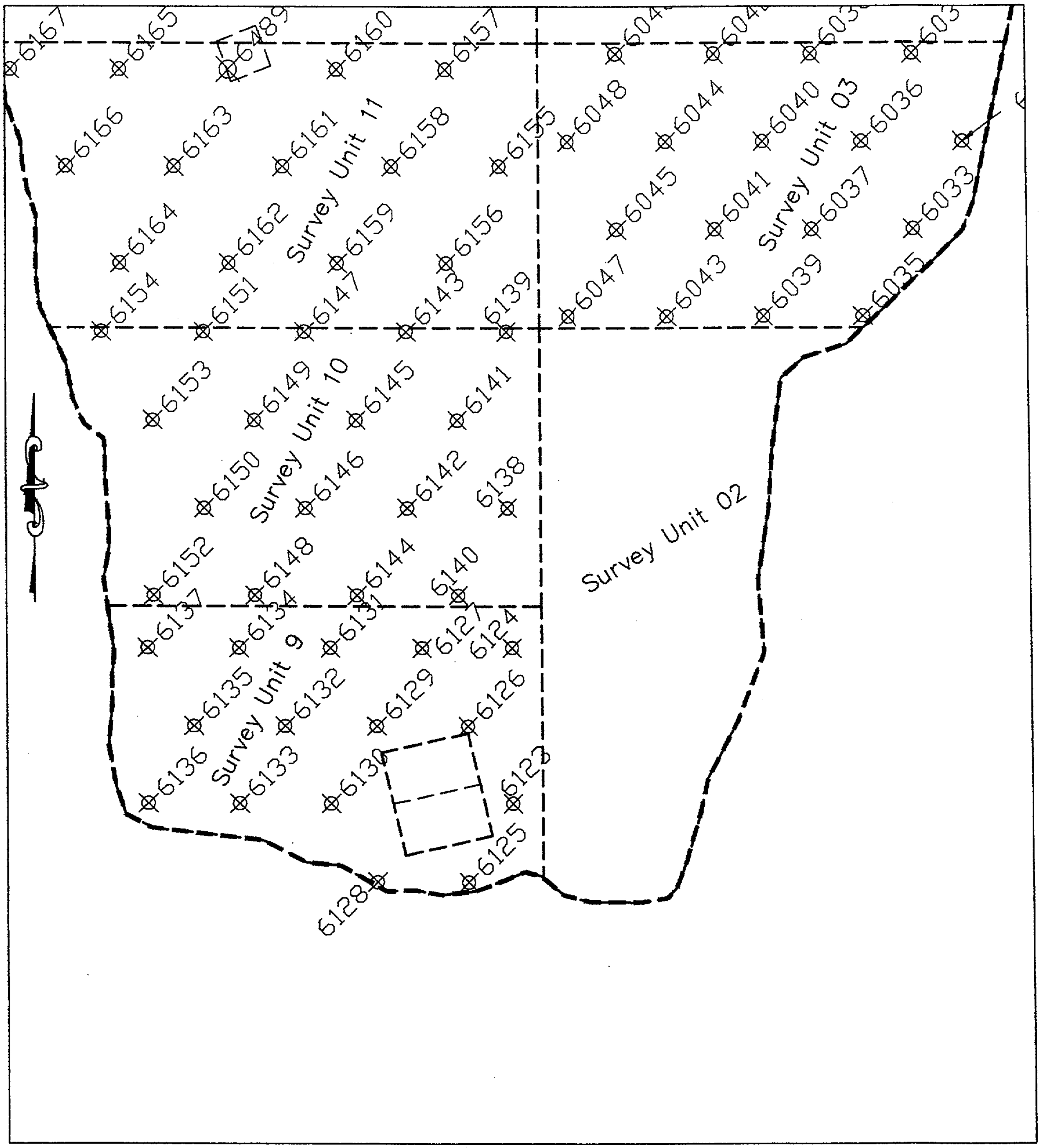
Scan MDC = (Assumed MDC $U_{TOTAL}$Conc) x (Exposure Rate $MDCR_{Surveyor}$)/(Exposure $Rate_{assumed\ U\ Conc}$)

Scan MDC = 38.08 pCi/g

# Appendix D:

# Survey Unit Maps and Sample Locations


Area = 46,275 Sq.M
SU #23 Area = 1,300 Sq. M
SU #17 Area = 1,590 Sq. M
SU #18 Area = 2,000 Sq. M
SU #19 Area = 2,000 Sq. M
SU #20 Area = 1,935 Sq. M
Wash Rack #3
SU #21 Area = 1,950 Sq. M
Wash Rack #2
SU #22 Area = 1,970 Sq. M
Wash Rack #1
Conc. Pad
Bunker
BARF Building
Back Stop Plate
Gun Mount
Sabot Stripper
SU #16 Area = 1,970 Sq. M
SU #25 Area = 2,000 Sq. M
SU #9 Area = 1,335 Sq. M
Conc. Pad
SU #10 Area = 1,650 Sq. M
SU #11 Area = 1,900 Sq. M
SU #12 Area = 2,000 Sq. M
SU #13 Area = 1,980 Sq. M
SU #14 Area = 2,000 Sq. M
SU #15 Area = 2,000 Sq. M
SU #2 Area = 1,600 Sq. M
SU #3 Area = 1,560 Sq. M
SU #4 Area = 1,840 Sq. M
SU #5 Area = 1,945 Sq. M
SU #6 Area = 1,995 Sq. M
SU #7 Area = 2,000 Sq. M
SU #8 Area = 2,000 Sq. M
SU #24 Area = 2,000 Sq. M
SU #1 Area = 1,235 Sq. M



Survey Unit 11
Survey Unit 10
Survey Unit 9
Survey Unit 03
Survey Unit 02
6167
6165
6160
6157
6166
6163
6161
6158
6155
6164
6162
6159
6156
6154
6151
6147
6143
6139
6153
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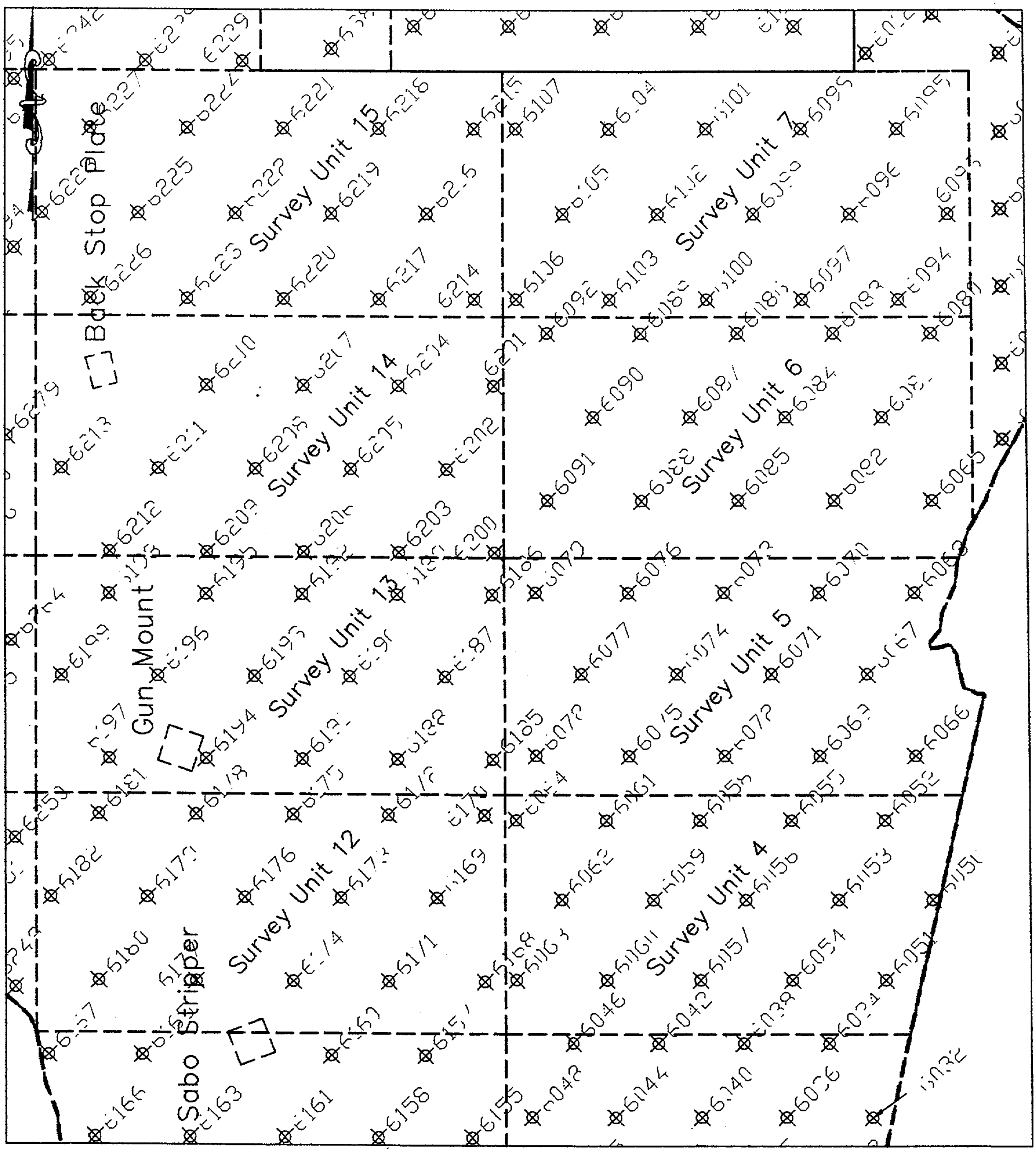
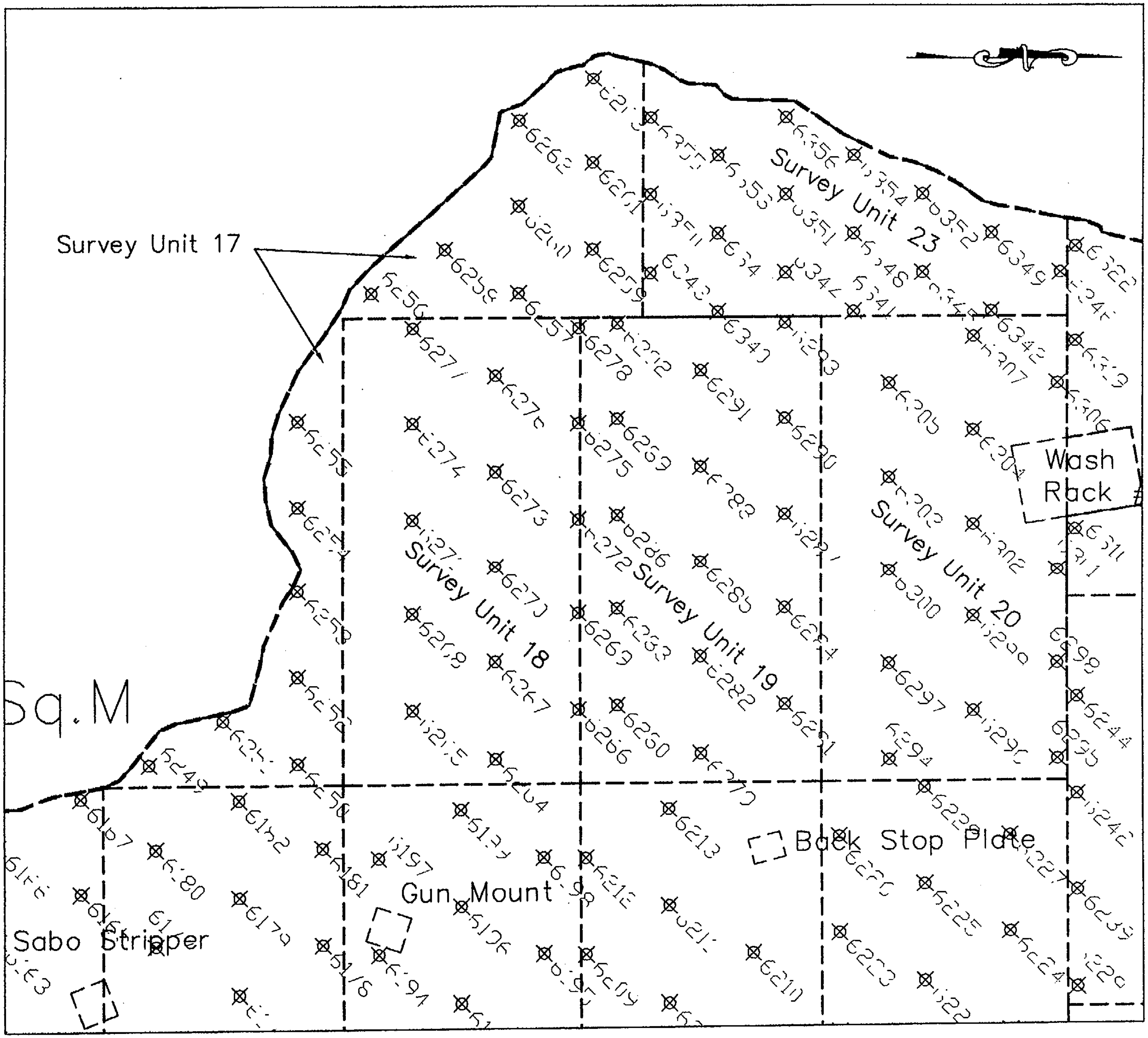
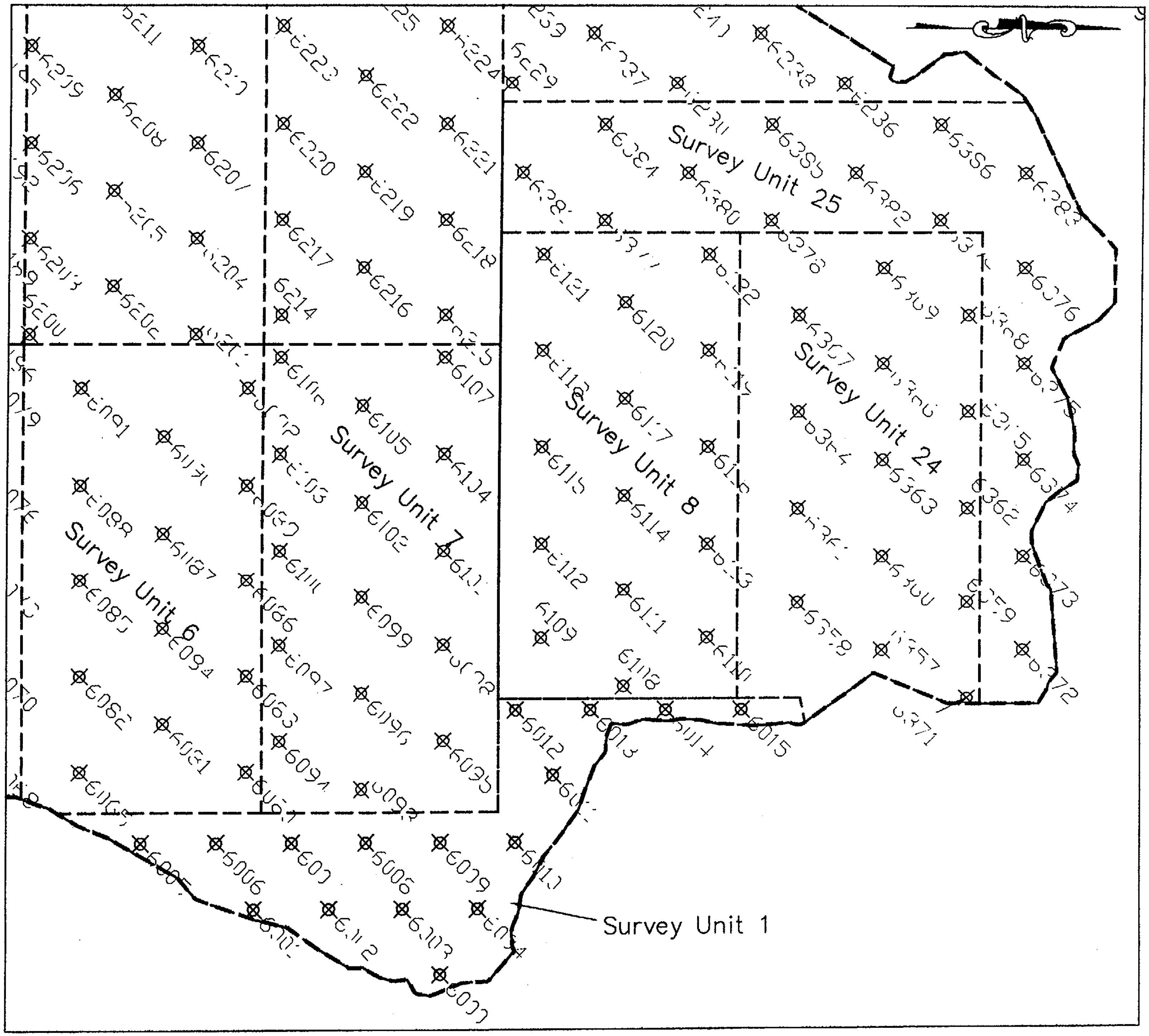
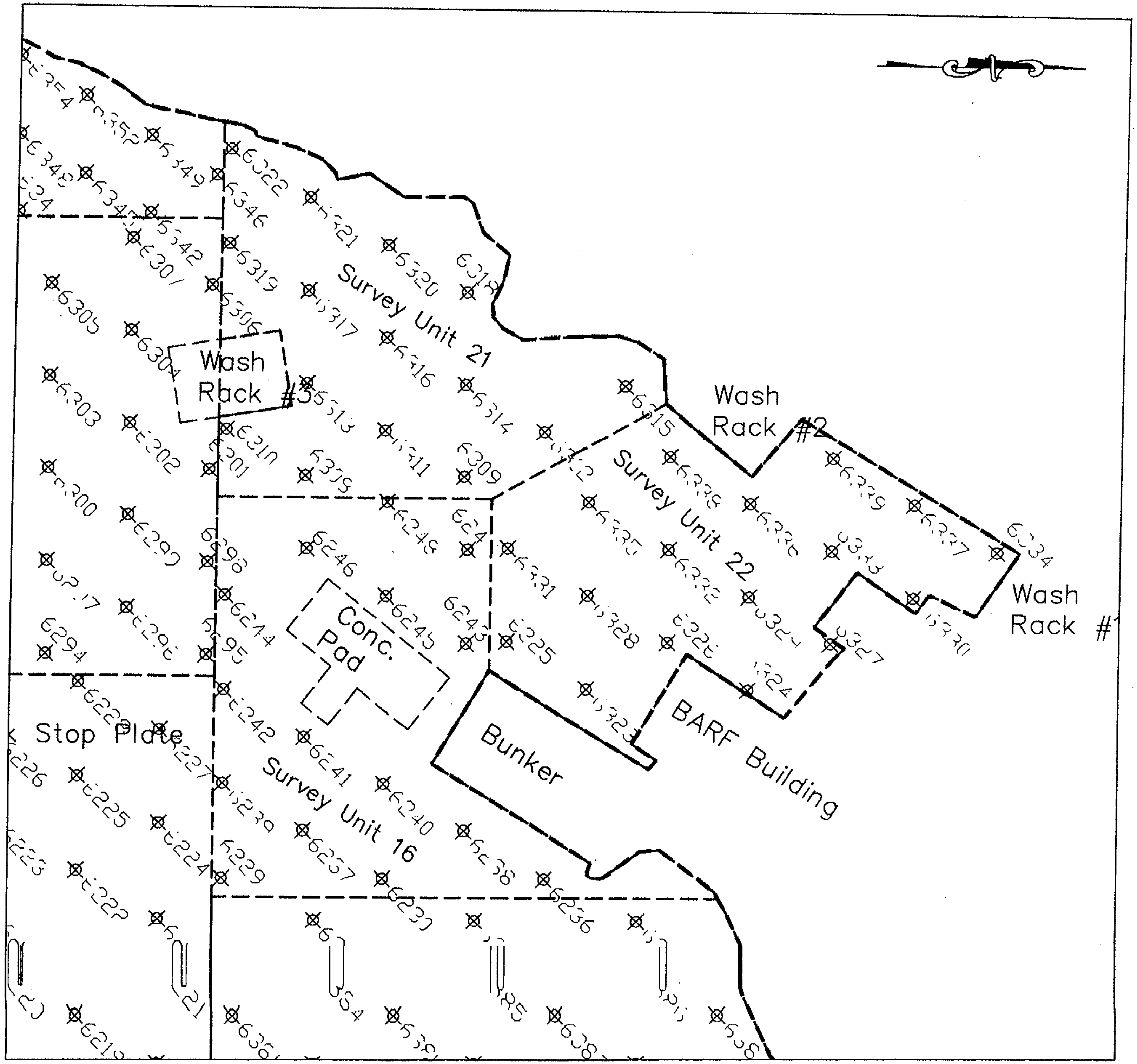
6047
6043
6039
6035


Back Stop Plate
Survey Unit 15
Survey Unit 7
Survey Unit 14
Survey Unit 6
Gun Mount
Survey Unit 13
Survey Unit 5
Survey Unit 12
Survey Unit 4
Sabo Stripper

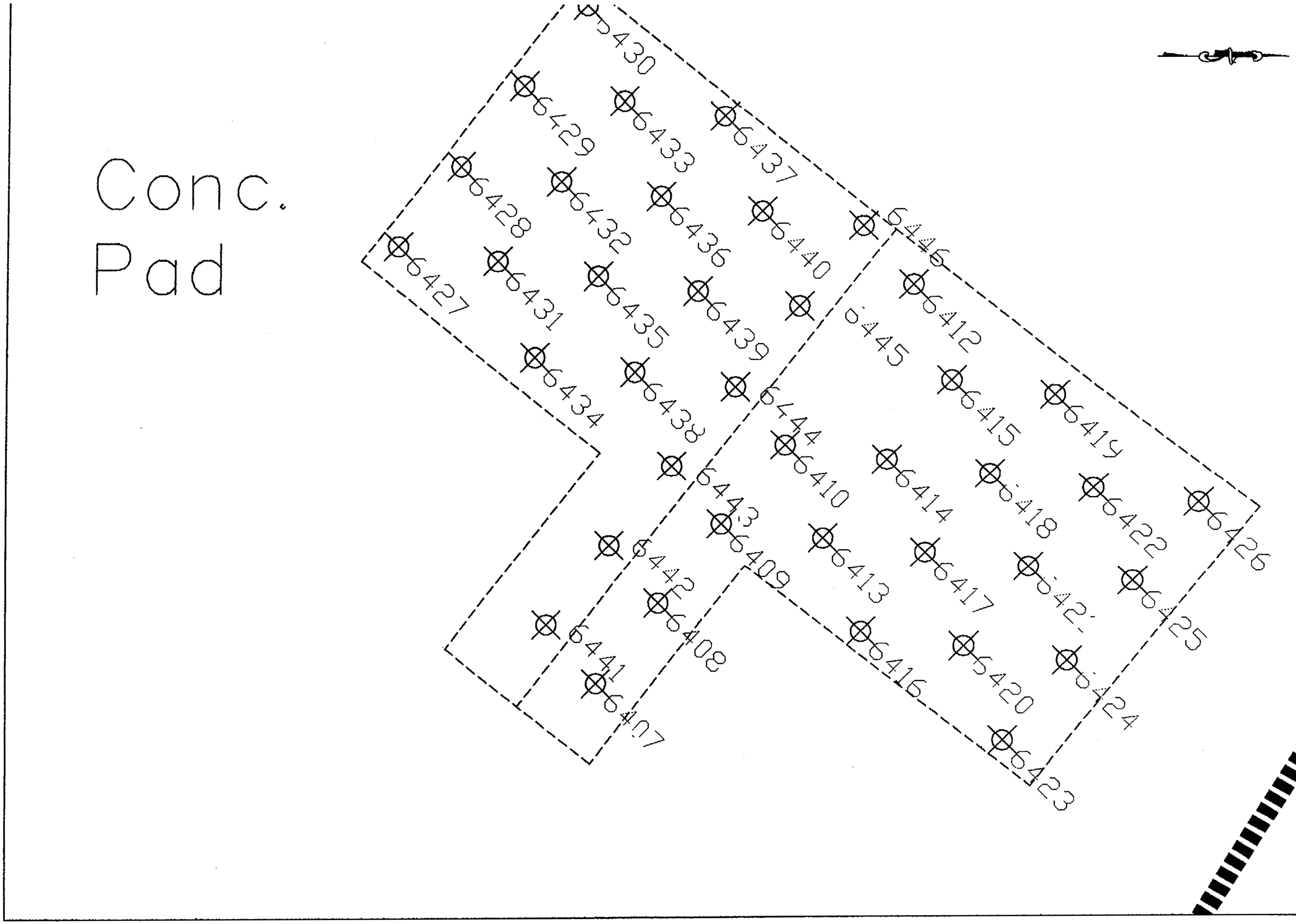


Survey Unit 17
Survey Unit 23
Survey Unit 18
Survey Unit 19
Survey Unit 20
Wash Rack
Back Stop Plate
Gun Mount
Sabo Stripper
Sq.M


Survey Unit 25
Survey Unit 24
Survey Unit 8
Survey Unit 7
Survey Unit 6
Survey Unit 1



Wash Rack #1
Wash Rack #2
Wash Rack #3
Survey Unit 22
Survey Unit 21
Survey Unit 16
BARF Building
Bunker
Conc. Pad
Stop Plate



Conc.
Pad
6429
6433
6437
6428
6432
6436
6440
6446
6427
6431
6435
6439
6445
6412
6434
6438
6444
6415
6419
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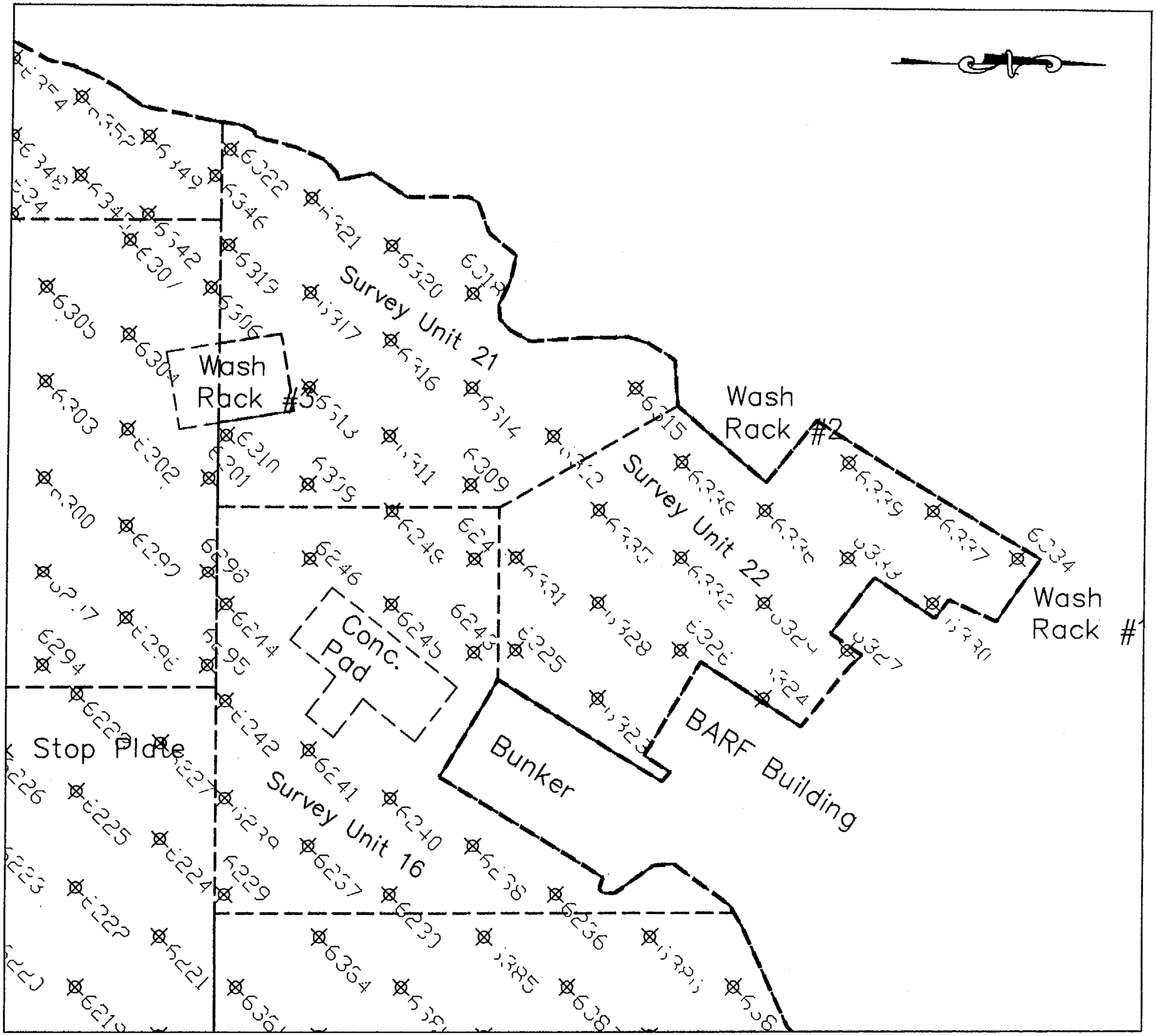
6420
6441
6407
6423


Survey Unit 21
Survey Unit 22
Survey Unit 16
Wash Rack #1
Wash Rack #2
Wash Rack #3
BARF Building
Bunker
Conc. Pad
Stop Plate

```
                                             :          (FOR LFMS USE)
                                             :        INFORMATION FROM LTS
BETWEEN:                                     :        --------------------
                                             :
License Fee Management Branch, ARM           :  Program Code: 11221
           and                               :  Status Code: 0
Regional Licensing Sections                  :  Fee Category: EX 2B 2C
                                             :  Exp. Date: 20080930
                                             :  Fee Comments: SHIELDING AND OTHER
                                             :  Decom Fin Assur Reqd: Y
                                             ::::::::::::::::::::::::::::::::::::::::::::::::
```

LICENSE FEE TRANSMITTAL

A. REGION I

1. APPLICATION ATTACHED
   Applicant/Licensee: ARMY, DEPARTMENT OF THE
   Received Date: 20031117
   Docket No: 4007354
   Control No.: 133995
   License No.: SUB-834
   Action Type: Notifications

2. FEE ATTACHED
   Amount: /
   Check No.: /

3. COMMENTS

Signed M. A. Perkins
Date 11/17/2003

B. LICENSE FEE MANAGEMENT BRANCH (Check when milestone 03 is entered /__/)

1. Fee Category and Amount: ______________________

2. Correct Fee Paid. Application may be processed for:
   Amendment ______________
   Renewal ______________
   License ______________

3. OTHER ______________________
   ______________________

Signed ______________________
Date ______________________

# Appendix C:  Soil Sample Analytical Results

## Appendix C
## BTD Soil Sample Results

| SU | FieldID | *Isotope | Final Result (pCi/g) | Units | Flag[1] | TPU (+/-) | MDC | Summary | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 6000 | U-238 | 1.6 | pCi/g | | 1.1 | 1.6 | Average | 0.88 |
| 1 | 6001 | U-238 | -1.2 | pCi/g | U | 1.9 | 3.4 | Std Dev | 1.3 |
| 1 | 6002 | U-238 | 3.8 | pCi/g | U | 4.6 | 7.5 | Max | 3.8 |
| 1 | 6003 | U-238 | 0.9 | pCi/g | U | 2.8 | 4.8 | Min | -1.6 |
| 1 | 6004 | U-238 | 0.4 | pCi/g | U | 2.4 | 4.2 | # Samples | 16 |
| 1 | 6005 | U-238 | 0.1 | pCi/g | U | 1 | 1.8 | | |
| 1 | 6006 | U-238 | 2.3 | pCi/g | | 1.2 | 1.8 | | |
| 1 | 6007 | U-238 | 0.9 | pCi/g | U | 1.4 | 2.2 | | |
| 1 | 6008 | U-238 | 1.6 | pCi/g | U | 2.9 | 4.9 | | |
| 1 | 6009 | U-238 | 1.7 | pCi/g | U | 1.4 | 2.2 | | |
| 1 | 6010 | U-238 | 0.52 | pCi/g | U | 0.96 | 1.6 | | |
| 1 | 6011 | U-238 | 0.3 | pCi/g | U | 2.7 | 4.6 | | |
| 1 | 6012 | U-238 | -0.1 | pCi/g | U | 2.5 | 4.4 | | |
| 1 | 6013 | U-238 | 1.3 | pCi/g | U | 1.4 | 2.2 | | |
| 1 | 6014 | U-238 | 1.6 | pCi/g | U | 1.2 | 1.8 | | |
| 1 | 6015 | U-238 | -1.6 | pCi/g | U | 2.7 | 5 | | |
| 2 | 6017 | U-238 | 2.4 | pCi/g | U | 3 | 4.9 | Average | 16 |
| 2 | 6018 | U-238 | 0.9 | pCi/g | U | 1.2 | 1.9 | Std Dev | 25 |
| 2 | 6019 | U-238 | 2.6 | pCi/g | | 1.2 | 1.6 | Max | 80 |
| 2 | 6020 | U-238 | 0.75 | pCi/g | U | 0.73 | 1.1 | Min | 0.75 |
| 2 | 6021 | U-238 | 0.8 | pCi/g | U | 2.4 | 4 | # Samples | 15 |
| 2 | 6022 | U-238 | 11.9 | pCi/g | | 3.8 | 4.3 | | |
| 2 | 6023 | U-238 | 13.8 | pCi/g | | 3 | 2.2 | | |
| 2 | 6024 | U-238 | 2.9 | pCi/g | | 1.2 | 1.6 | | |
| 2 | 6025 | U-238 | 1 | pCi/g | U | 2.4 | 4.1 | | |
| 2 | 6026 | U-238 | 31 | pCi/g | | 10 | 13 | | |
| 2 | 6027 | U-238 | 16.9 | pCi/g | | 5.9 | 7.4 | | |
| 2 | 6028 | U-238 | 68 | pCi/g | | 13 | 8.3 | | |
| 2 | 6029 | U-238 | 80 | pCi/g | G | 12 | 8 | | |
| 2 | 6030 | U-238 | 9 | pCi/g | | 3.6 | 4.8 | | |
| 2 | 6031 | U-238 | 1.9 | pCi/g | | 1.2 | 1.9 | | |
| 3 | 6032 | U-238 | 2.2 | pCi/g | U | 2.5 | 4 | Average | 0.95 |
| 3 | 6033 | U-238 | 2.5 | pCi/g | | 1.6 | 2.4 | Std Dev | 0.93 |
| 3 | 6034 | U-238 | 1.1 | pCi/g | U | 1.8 | 3.1 | Max | 2.5 |
| 3 | 6035 | U-238 | 2.2 | pCi/g | U | 2.6 | 4.2 | Min | -0.4 |
| 3 | 6036 | U-238 | -0.4 | pCi/g | U | 3.2 | 5.7 | # Samples | 17 |
| 3 | 6037 | U-238 | 0.6 | pCi/g | U | 2.5 | 4.3 | | |
| 3 | 6038 | U-238 | 0.4 | pCi/g | U | 2.6 | 4.5 | | |
| 3 | 6039 | U-238 | 0.94 | pCi/g | U | 0.78 | 1.2 | | |
| 3 | 6040 | U-238 | 2 | pCi/g | U | 3.2 | 5.4 | | |
| 3 | 6041 | U-238 | -0.4 | pCi/g | U | 2.5 | 4.4 | | |
| 3 | 6042 | U-238 | 1.6 | pCi/g | U | 2.3 | 3.8 | | |
| 3 | 6043 | U-238 | 1 | pCi/g | U | 1.3 | 2.1 | | |
| 3 | 6044 | U-238 | 0.75 | pCi/g | U | 0.82 | 1.3 | | |
| 3 | 6045 | U-238 | 0.9 | pCi/g | U | 1.5 | 2.5 | | |
| 3 | 6046 | U-238 | -0.2 | pCi/g | U | 2.6 | 4.7 | | |
| 3 | 6047 | U-238 | -0.2 | pCi/g | U | 2.6 | 4.6 | | |
| 3 | 6048 | U-238 | 1.1 | pCi/g | U | 1.2 | 1.9 | | |
| 4 | 6050 | U-238 | 0.87 | pCi/g | U | 0.99 | 1.6 | Average | 1.0 |
| 4 | 6051 | U-238 | 1.8 | pCi/g | | 1.2 | 1.8 | Std Dev | 1.0 |
| 4 | 6052 | U-238 | 0.4 | pCi/g | U | 1.5 | 2.5 | Max | 3 |
| 4 | 6053 | U-238 | 3 | pCi/g | U | 2.9 | 4.6 | Min | -1.1 |
| 4 | 6054 | U-238 | 1.2 | pCi/g | U | 2.1 | 3.5 | # Samples | 15 |
| 4 | 6055 | U-238 | 0.6 | pCi/g | U | 1.2 | 2 | | |
| 4 | 6056 | U-238 | 0.8 | pCi/g | U | 1.2 | 2 | | |
| 4 | 6057 | U-238 | 0.83 | pCi/g | U | 0.94 | 1.5 | | |
| 4 | 6058 | U-238 | 1 | pCi/g | U | 1.8 | 3 | | |
| 4 | 6059 | U-238 | 2.8 | pCi/g | U | 2.7 | 4.3 | | |
| 4 | 6060 | U-238 | -1.1 | pCi/g | U | 2.5 | 4.6 | | |
| 4 | 6061 | U-238 | 0.4 | pCi/g | U | 1.1 | 1.9 | | |
| 4 | 6062 | U-238 | 0.3 | pCi/g | U | 1.4 | 2.4 | | |
| 4 | 6063 | U-238 | 0.6 | pCi/g | U | 1.2 | 2.1 | | |
| 4 | 6064 | U-238 | 1.8 | pCi/g | U | 1.8 | 2.8 | | |

# Appendix C
# BTD Soil Sample Results

| SU | FieldID | *Isotope | Final Result (pCi/g) | Units | Flag[1] | TPU (+/-) | MDC | Summary | |
|---|---|---|---|---|---|---|---|---|---|
| 5 | 6066 | U-238 | -1.5 | pCi/g | U | 2 | 3.9 | Average | 2.1 |
| 5 | 6067 | U-238 | 0.1 | pCi/g | U | 0.52 | 0.91 | Std Dev | 3.5 |
| 5 | 6068 | U-238 | 2 | pCi/g | U | 1.8 | 2.8 | Max | 12 |
| 5 | 6069 | U-238 | 0.45 | pCi/g | U | 0.66 | 1.1 | Min | -1.5 |
| 5 | 6070 | U-238 | 4.8 | pCi/g | U | 4.4 | 6.9 | # Samples | 14 |
| 5 | 6071 | U-238 | 0.79 | pCi/g | U | 0.58 | 0.86 | | |
| 5 | 6072 | U-238 | 1.1 | pCi/g | U | 3.9 | 6.7 | | |
| 5 | 6073 | U-238 | 0.7 | pCi/g | U | 2.2 | 3.9 | | |
| 5 | 6074 | U-238 | 7.1 | pCi/g | | 4.2 | 6.1 | | |
| 5 | 6075 | U-238 | 0.5 | pCi/g | U | 1.2 | 2 | | |
| 5 | 6076 | U-238 | 11.6 | pCi/g | | 3.7 | 4 | | |
| 5 | 6077 | U-238 | 1 | pCi/g | U | 2.4 | 4.1 | | |
| 5 | 6078 | U-238 | 1.1 | pCi/g | U | 1.2 | 1.9 | | |
| 5 | 6079 | U-238 | -0.8 | pCi/g | U | 3.4 | 6.3 | | |
| 6 | 6065 | U-238 | 0.42 | pCi/g | U | 0.62 | 1 | Average | 5.4 |
| 6 | 6080 | U-238 | 0.9 | pCi/g | U | 1.1 | 1.8 | Std Dev | 8.2 |
| 6 | 6081 | U-238 | -1.6 | pCi/g | U | 3.5 | 6.4 | Max | 27 |
| 6 | 6082 | U-238 | 4.2 | pCi/g | U | 3.4 | 5.1 | Min | -1.6 |
| 6 | 6083 | U-238 | 0.5 | pCi/g | U | 2.5 | 4.3 | # Samples | 14 |
| 6 | 6084 | U-238 | 0.1 | pCi/g | U | 2.2 | 3.9 | | |
| 6 | 6085 | U-238 | 0.3 | pCi/g | U | 1.8 | 3.2 | | |
| 6 | 6086 | U-238 | 2.7 | pCi/g | U | 1.9 | 2.9 | | |
| 6 | 6087 | U-238 | 26.5 | pCi/g | | 7.3 | 7.4 | | |
| 6 | 6088 | U-238 | 16.6 | pCi/g | | 6 | 6.9 | | |
| 6 | 6089 | U-238 | 1.1 | pCi/g | U | 1.2 | 1.9 | | |
| 6 | 6090 | U-238 | 13.4 | pCi/g | | 5.2 | 6.2 | | |
| 6 | 6091 | U-238 | 9.6 | pCi/g | | 2.8 | 3.3 | | |
| 6 | 6092 | U-238 | 0.4 | pCi/g | U | 3.4 | 6.1 | | |
| 7 | 6093 | U-238 | 1.3 | pCi/g | U | 3 | 5 | Average | 1.5 |
| 7 | 6094 | U-238 | 0.61 | pCi/g | U | 0.81 | 1.3 | Std Dev | 1.0 |
| 7 | 6095 | U-238 | 1.1 | pCi/g | U | 1.2 | 1.9 | Max | 4.3 |
| 7 | 6096 | U-238 | 2.6 | pCi/g | U | 2.6 | 4.1 | Min | 0.6 |
| 7 | 6097 | U-238 | 4.3 | pCi/g | TI | 2.7 | 3.9 | # Samples | 15 |
| 7 | 6098 | U-238 | 0.9 | pCi/g | U | 1.2 | 2 | | |
| 7 | 6099 | U-238 | 1.06 | pCi/g | U | 0.96 | 1.5 | | |
| 7 | 6100 | U-238 | 1.5 | pCi/g | U | 3.3 | 5.7 | | |
| 7 | 6101 | U-238 | 0.6 | pCi/g | U | 2.6 | 4.4 | | |
| 7 | 6102 | U-238 | 1 | pCi/g | U | 1.5 | 2.4 | | |
| 7 | 6103 | U-238 | 0.7 | pCi/g | U | 1.1 | 1.8 | | |
| 7 | 6104 | U-238 | 1.4 | pCi/g | U | 2.9 | 4.8 | | |
| 7 | 6105 | U-238 | 1.1 | pCi/g | U | 1.2 | 1.9 | | |
| 7 | 6106 | U-238 | 2.5 | pCi/g | | 1.4 | 2 | | |
| 7 | 6107 | U-238 | 1.1 | pCi/g | U | 1.7 | 2.7 | | |
| 8 | 6108 | U-238 | -0.6 | pCi/g | U | 3.9 | 7 | Average | 1.2 |
| 8 | 6109 | U-238 | 1.4 | pCi/g | U | 1.1 | 1.6 | Std Dev | 1.4 |
| 8 | 6110 | U-238 | 0.8 | pCi/g | U | 1.5 | 2.5 | Max | 3.3 |
| 8 | 6111 | U-238 | 2 | pCi/g | U | 4.2 | 7.1 | Min | -2.3 |
| 8 | 6112 | U-238 | 1.4 | pCi/g | U | 2.7 | 4.6 | # Samples | 15 |
| 8 | 6113 | U-238 | 1 | pCi/g | U | 1.5 | 2.4 | | |
| 8 | 6114 | U-238 | 1.1 | pCi/g | U | 1.5 | 2.5 | | |
| 8 | 6115 | U-238 | -2.3 | pCi/g | U | 3 | 5.8 | | |
| 8 | 6116 | U-238 | 3 | pCi/g | U | 3.6 | 5.9 | | |
| 8 | 6117 | U-238 | 0.8 | pCi/g | U | 2.6 | 4.4 | | |
| 8 | 6118 | U-238 | 2.6 | pCi/g | U | 2.8 | 4.5 | | |
| 8 | 6119 | U-238 | 1.5 | pCi/g | U | 1.2 | 1.9 | | |
| 8 | 6120 | U-238 | 0.8 | pCi/g | U | 1 | 1.7 | | |
| 8 | 6121 | U-238 | 0.5 | pCi/g | U | 1.7 | 2.9 | | |
| 8 | 6122 | U-238 | 3.3 | pCi/g | U | 3.8 | 6.1 | | |

# Appendix C
## BTD Soil Sample Results

| SU | FieldID | *Isotope | Final Result (pCi/g) | Units | Flag[1] | TPU (+/-) | MDC | Summary | |
|---|---|---|---|---|---|---|---|---|---|
| 9 | 6123 | U-238 | 9.2 | pCi/g | | 5 | 7.1 | Average | 14 |
| 9 | 6124 | U-238 | 8 | pCi/g | | 2.2 | 2.5 | Std Dev | 18 |
| 9 | 6125 | U-238 | 55.5 | pCi/g | | 9.8 | 3.1 | Max | 57 |
| 9 | 6126 | U-238 | 4.3 | pCi/g | U | 3.2 | 4.9 | Min | 0.50 |
| 9 | 6127 | U-238 | 10.2 | pCi/g | | 2.4 | 2 | # Samples | 15 |
| 9 | 6128 | U-238 | 57 | pCi/g | | 10 | 3.2 | | |
| 9 | 6129 | U-238 | 11.3 | pCi/g | | 2.8 | 2.2 | | |
| 9 | 6130 | U-238 | 25.1 | pCi/g | G | 3.7 | 2.3 | | |
| 9 | 6131 | U-238 | 1.7 | pCi/g | U | 1.5 | 2.4 | | |
| 9 | 6132 | U-238 | 19 | pCi/g | | 3.8 | 2.5 | | |
| 9 | 6133 | U-238 | 0.5 | pCi/g | U | 1.2 | 2 | | |
| 9 | 6134 | U-238 | 2.4 | pCi/g | | 1.3 | 1.9 | | |
| 9 | 6135 | U-238 | 0.9 | pCi/g | U | 2.5 | 4.2 | | |
| 9 | 6136 | U-238 | 3.7 | pCi/g | U | 3 | 4.7 | | |
| 9 | 6137 | U-238 | 4.3 | pCi/g | | 1.8 | 2.5 | | |
| 10 | 6138 | U-238 | 28.6 | pCi/g | G | 4.1 | 2.3 | Average | 11 |
| 10 | 6139 | U-238 | 3.5 | pCi/g | U | 3.6 | 5.8 | Std Dev | 12 |
| 10 | 6140 | U-238 | 8.1 | pCi/g | | 2 | 1.8 | Max | 41 |
| 10 | 6141 | U-238 | 5.7 | pCi/g | | 3.1 | 4.5 | Min | 0.40 |
| 10 | 6142 | U-238 | 18.6 | pCi/g | | 4.8 | 4.8 | # Samples | 17 |
| 10 | 6143 | U-238 | 6.7 | pCi/g | | 2 | 2.3 | | |
| 10 | 6144 | U-238 | 30.4 | pCi/g | | 9.9 | 12 | | |
| 10 | 6145 | U-238 | 1.7 | pCi/g | U | 1.8 | 2.9 | | |
| 10 | 6146 | U-238 | 6.2 | pCi/g | U | 5.1 | 7.9 | | |
| 10 | 6147 | U-238 | 17.9 | pCi/g | | 6.1 | 7.2 | | |
| 10 | 6148 | U-238 | 4.8 | pCi/g | | 2.7 | 3.9 | | |
| 10 | 6149 | U-238 | 2.5 | pCi/g | U | 2.6 | 4.2 | | |
| 10 | 6150 | U-238 | 41.2 | pCi/g | | 8.4 | 5.4 | | |
| 10 | 6151 | U-238 | 15.6 | pCi/g | | 3.1 | 1.8 | | |
| 10 | 6152 | U-238 | 1.1 | pCi/g | U | 1.1 | 1.9 | | |
| 10 | 6153 | U-238 | 0.8 | pCi/g | U | 3.3 | 5.6 | | |
| 10 | 6154 | U-238 | 0.4 | pCi/g | U | 2.2 | 3.9 | | |
| 11 | 6155 | U-238 | 0.9 | pCi/g | U | 2.5 | 4.3 | Average | 3.6 |
| 11 | 6156 | U-238 | 0.6 | pCi/g | U | 1.2 | 2.1 | Std Dev | 5.1 |
| 11 | 6157 | U-238 | 0.6 | pCi/g | U | 2.5 | 4.4 | Max | 18 |
| 11 | 6158 | U-238 | -1.2 | pCi/g | U | 2.4 | 4.3 | Min | -1.2 |
| 11 | 6159 | U-238 | 3.1 | pCi/g | | 1.3 | 1.7 | # Samples | 13 |
| 11 | 6160 | U-238 | 1.8 | pCi/g | U | 3.9 | 6.5 | | |
| 11 | 6161 | U-238 | 4.5 | pCi/g | U | 3.1 | 4.8 | | |
| 11 | 6162 | U-238 | 10.7 | pCi/g | | 2.5 | 2.1 | | |
| 11 | 6163 | U-238 | 17.7 | pCi/g | | 5 | 5.1 | | |
| 11 | 6164 | U-238 | 2.8 | pCi/g | U | 2.8 | 4.5 | | |
| 11 | 6165 | U-238 | 3.2 | pCi/g | | 1.6 | 2.2 | | |
| 11 | 6166 | U-238 | 2.4 | pCi/g | U | 3.7 | 6.1 | | |
| 11 | 6167 | U-238 | 0.1 | pCi/g | U | 2.6 | 4.5 | | |
| 12 | 6168 | U-238 | 3 | pCi/g | U | 2.9 | 4.5 | Average | 6.2 |
| 12 | 6169 | U-238 | 1.48 | pCi/g | | 0.97 | 1.4 | Std Dev | 9.3 |
| 12 | 6170 | U-238 | 1.3 | pCi/g | U | 3 | 5.2 | Max | 37 |
| 12 | 6171 | U-238 | 1.5 | pCi/g | U | 1.5 | 2.4 | Min | 0.6 |
| 12 | 6172 | U-238 | 3.1 | pCi/g | U | 3.8 | 6.2 | # Samples | 15 |
| 12 | 6173 | U-238 | 1.6 | pCi/g | U | 1.2 | 1.9 | | |
| 12 | 6174 | U-238 | 5.4 | pCi/g | | 3.3 | 4.8 | | |
| 12 | 6175 | U-238 | 0.6 | pCi/g | U | 1.3 | 2.2 | | |
| 12 | 6176 | U-238 | 8 | pCi/g | | 2.1 | 2 | | |
| 12 | 6177 | U-238 | 14.6 | pCi/g | | 5.3 | 6.3 | | |
| 12 | 6178 | U-238 | 36.6 | pCi/g | | 8.2 | 6.7 | | |
| 12 | 6179 | U-238 | 11.2 | pCi/g | | 2.8 | 2.5 | | |
| 12 | 6180 | U-238 | 2 | pCi/g | | 1.3 | 1.9 | | |
| 12 | 6181 | U-238 | 1.8 | pCi/g | U | 1.6 | 2.5 | | |
| 12 | 6182 | U-238 | 1.5 | pCi/g | U | 3.8 | 6.5 | | |

**Appendix C**
**BTD Soil Sample Results**

| SU | FieldID | *Isotope | Final Result (pCi/g) | Units | Flag[1] | TPU (+/-) | MDC | Summary | |
|---|---|---|---|---|---|---|---|---|---|
| 13 | 6185 | U-238 | -0.9 | pCi/g | U | 3.8 | 6.9 | Average | 4.8 |
| 13 | 6186 | U-238 | 0.9 | pCi/g | U | 2.8 | 4.8 | Std Dev | 7.6 |
| 13 | 6187 | U-238 | 1.3 | pCi/g | U | 1.6 | 2.6 | Max | 26 |
| 13 | 6188 | U-238 | 0.39 | pCi/g | U | 0.89 | 1.5 | Min | -0.9 |
| 13 | 6189 | U-238 | 1.3 | pCi/g | U | 1.1 | 1.8 | # Samples | 15 |
| 13 | 6190 | U-238 | 1.1 | pCi/g | U | 1.5 | 2.5 | | |
| 13 | 6191 | U-238 | -0.4 | pCi/g | U | 3.9 | 7 | | |
| 13 | 6192 | U-238 | 1.5 | pCi/g | U | 2.6 | 4.4 | | |
| 13 | 6193 | U-238 | 1.6 | pCi/g | | 1.1 | 1.6 | | |
| 13 | 6194 | U-238 | 3.4 | pCi/g | | 1.4 | 1.9 | | |
| 13 | 6195 | U-238 | 0.7 | pCi/g | U | 1.1 | 1.9 | | |
| 13 | 6196 | U-238 | 12.7 | pCi/g | | 4.2 | 4.9 | | |
| 13 | 6197 | U-238 | 25.9 | pCi/g | | 6.5 | 5.8 | | |
| 13 | 6198 | U-238 | 5.6 | pCi/g | | 1.9 | 2.3 | | |
| 13 | 6199 | U-238 | 16.3 | pCi/g | | 3.4 | 2.2 | | |
| 14 | 6200 | U-238 | 1.8 | pCi/g | U | 1.3 | 1.9 | Average | 3.3 |
| 14 | 6201 | U-238 | 1.4 | pCi/g | U | 1.6 | 2.5 | Std Dev | 6.9 |
| 14 | 6202 | U-238 | 1.1 | pCi/g | U | 2.5 | 4.3 | Max | 27 |
| 14 | 6203 | U-238 | 1.2 | pCi/g | U | 2.2 | 3.6 | Min | 0.5 |
| 14 | 6204 | U-238 | 0.82 | pCi/g | U | 0.93 | 1.5 | # Samples | 14 |
| 14 | 6205 | U-238 | 1 | pCi/g | U | 1.4 | 2.2 | | |
| 14 | 6206 | U-238 | 0.6 | pCi/g | U | 1.4 | 2.3 | | |
| 14 | 6207 | U-238 | 0.5 | pCi/g | U | 4.2 | 7.3 | | |
| 14 | 6208 | U-238 | 0.9 | pCi/g | U | 2.8 | 4.8 | | |
| 14 | 6209 | U-238 | 0.6 | pCi/g | U | 2.5 | 4.2 | | |
| 14 | 6210 | U-238 | 1.3 | pCi/g | U | 1.2 | 1.8 | | |
| 14 | 6211 | U-238 | 1.2 | pCi/g | U | 1.1 | 1.8 | | |
| 14 | 6212 | U-238 | 26.6 | pCi/g | | 5.3 | 3.8 | | |
| 14 | 6213 | U-238 | 7.1 | pCi/g | | 3.7 | 5.3 | | |
| 15 | 6214 | U-238 | 0.5 | pCi/g | U | 2.4 | 4.1 | Average | 0.81 |
| 15 | 6215 | U-238 | 1.1 | pCi/g | U | 1.1 | 1.7 | Std Dev | 0.63 |
| 15 | 6216 | U-238 | 1.7 | pCi/g | U | 2.3 | 3.7 | Max | 1.8 |
| 15 | 6217 | U-238 | 0.2 | pCi/g | U | 1.1 | 1.9 | Min | -0.10 |
| 15 | 6218 | U-238 | -0.1 | pCi/g | U | 2.7 | 4.8 | # Samples | 15 |
| 15 | 6219 | U-238 | 0.87 | pCi/g | U | 0.84 | 1.3 | | |
| 15 | 6220 | U-238 | 1.4 | pCi/g | U | 2.5 | 4.2 | | |
| 15 | 6221 | U-238 | -0.1 | pCi/g | U | 3.5 | 6.3 | | |
| 15 | 6222 | U-238 | 1 | pCi/g | U | 1.1 | 1.8 | | |
| 15 | 6223 | U-238 | 0.78 | pCi/g | U | 0.99 | 1.6 | | |
| 15 | 6224 | U-238 | 1.6 | pCi/g | U | 2.3 | 3.8 | | |
| 15 | 6225 | U-238 | 0.7 | pCi/g | U | 1 | 1.7 | | |
| 15 | 6226 | U-238 | 0.58 | pCi/g | U | 0.86 | 1.4 | | |
| 15 | 6227 | U-238 | 0.12 | pCi/g | U | 0.74 | 1.3 | | |
| 15 | 6228 | U-238 | 1.8 | pCi/g | U | 2.4 | 3.9 | | |
| 16 | 6229 | U-238 | 17.90 | pCi/g | G | 4.1 | 5 | Average | 8.3 |
| 16 | 6230 | U-238 | 1.40 | pCi/g | U,G | 3.8 | 6.3 | Std Dev | 10 |
| 16 | 6236 | U-238 | 1.20 | pCi/g | U,G | 2.9 | 4.8 | Max | 32 |
| 16 | 6237 | U-238 | 28.00 | pCi/g | G | 5.2 | 5.6 | Min | -1.7 |
| 16 | 6238 | U-238 | 0.50 | pCi/g | U,G | 3.3 | 5.6 | # Samples | 15 |
| 16 | 6239 | U-238 | 13.70 | pCi/g | G | 5.1 | 7.4 | | |
| 16 | 6240 | U-238 | 6.80 | pCi/g | LT,G | 2.6 | 3.8 | | |
| 16 | 6241 | U-238 | 32.10 | pCi/g | G | 4.6 | 2.4 | | |
| 16 | 6242 | U-238 | 4.30 | pCi/g | U,G | 3.3 | 5.3 | | |
| 16 | 6243 | U-238 | 2.10 | pCi/g | U,G | 2.2 | 3.6 | | |
| 16 | 6244 | U-238 | 5.30 | pCi/g | LT,G | 2.4 | 3.7 | | |
| 16 | 6245 | U-238 | 3.10 | pCi/g | U | 2 | 3.2 | | |
| 16 | 6246 | U-238 | 5.50 | pCi/g | U,G | 3.7 | 5.8 | | |
| 16 | 6247 | U-238 | 4.60 | pCi/g | U,G | 3.1 | 4.9 | | |
| 16 | 6248 | U-238 | -1.7 | pCi/g | U,G | 3.3 | 5.7 | | |

# Appendix C
# BTD Soil Sample Results

| SU | FieldID | *Isotope | Final Result (pCi/g) | Units | Flag[1] | TPU (+/-) | MDC | Summary | |
|---|---|---|---|---|---|---|---|---|---|
| 17 | 6249 | U-238 | -0.4 | pCi/g | U | 3.9 | 6.9 | Average | 1.2 |
| 17 | 6250 | U-238 | 4.6 | pCi/g | U | 3.6 | 5.6 | Std Dev | 1.5 |
| 17 | 6251 | U-238 | 3.4 | pCi/g | U | 3.3 | 5.2 | Max | 4.6 |
| 17 | 6252 | U-238 | 1.1 | pCi/g | U | 2.4 | 4.1 | Min | -1.0 |
| 17 | 6253 | U-238 | 0.28 | pCi/g | U | 0.83 | 1.4 | # Samples | 15 |
| 17 | 6254 | U-238 | 1.2 | pCi/g | U | 1.1 | 1.7 | | |
| 17 | 6255 | U-238 | 1.1 | pCi/g | U | 1.7 | 2.8 | | |
| 17 | 6256 | U-238 | 0.6 | pCi/g | U | 3.7 | 6.5 | | |
| 17 | 6257 | U-238 | 1.1 | pCi/g | U | 2.5 | 4.3 | | |
| 17 | 6258 | U-238 | 2.9 | pCi/g | U | 2.6 | 4 | | |
| 17 | 6259 | U-238 | 2 | pCi/g | | 1 | 1.4 | | |
| 17 | 6260 | U-238 | 1.2 | pCi/g | U | 1.5 | 2.4 | | |
| 17 | 6261 | U-238 | -1 | pCi/g | U | 1.7 | 3 | | |
| 17 | 6262 | U-238 | 0.2 | pCi/g | U | 3.4 | 5.8 | | |
| 17 | 6263 | U-238 | -0.5 | pCi/g | U | 2.8 | 5 | | |
| 18 | 6264 | U-238 | 1.6 | pCi/g | U | 1.4 | 2.1 | Average | 0.9 |
| 18 | 6265 | U-238 | 2.3 | pCi/g | | 1.5 | 2.2 | Std Dev | 0.8 |
| 18 | 6266 | U-238 | 0.6 | pCi/g | U | 1.2 | 2 | Max | 2.3 |
| 18 | 6267 | U-238 | 0.3 | pCi/g | U | 2.7 | 4.7 | Min | -0.70 |
| 18 | 6268 | U-238 | 0.8 | pCi/g | U | 1 | 1.7 | # Samples | 15 |
| 18 | 6269 | U-238 | 0.9 | pCi/g | U | 1.2 | 2 | | |
| 18 | 6270 | U-238 | 1.4 | pCi/g | U | 2.5 | 4.1 | | |
| 18 | 6271 | U-238 | 2.1 | pCi/g | U | 1.5 | 2.2 | | |
| 18 | 6272 | U-238 | -0.7 | pCi/g | U | 3.8 | 6.8 | | |
| 18 | 6273 | U-238 | -0.1 | pCi/g | U | 1.7 | 2.9 | | |
| 18 | 6274 | U-238 | 0.62 | pCi/g | U | 0.81 | 1.3 | | |
| 18 | 6275 | U-238 | 0.8 | pCi/g | U | 1 | 1.7 | | |
| 18 | 6276 | U-238 | 1.1 | pCi/g | U | 2.9 | 4.9 | | |
| 18 | 6277 | U-238 | 1.27 | pCi/g | U | 1 | 1.5 | | |
| 18 | 6278 | U-238 | 0.9 | pCi/g | U | 1.1 | 1.9 | | |
| 19 | 6279 | U-238 | 28.3 | pCi/g | | 5.8 | 3.1 | Average | 3.1 |
| 19 | 6280 | U-238 | -0.7 | pCi/g | U | 3.7 | 6.6 | Std Dev | 7.0 |
| 19 | 6281 | U-238 | 1.5 | pCi/g | U | 3.2 | 5.4 | Max | 28 |
| 19 | 6282 | U-238 | 2.9 | pCi/g | U | 3.4 | 5.5 | Min | -0.7 |
| 19 | 6283 | U-238 | 1.2 | pCi/g | U | 4 | 6.9 | # Samples | 15 |
| 19 | 6284 | U-238 | 3.7 | pCi/g | U | 3.2 | 4.9 | | |
| 19 | 6285 | U-238 | 1.3 | pCi/g | U | 1.5 | 2.4 | | |
| 19 | 6286 | U-238 | 1 | pCi/g | U | 3 | 5 | | |
| 19 | 6287 | U-238 | 1.9 | pCi/g | U | 2.6 | 4.2 | | |
| 19 | 6288 | U-238 | 0.4 | pCi/g | U | 1.1 | 1.9 | | |
| 19 | 6289 | U-238 | 1 | pCi/g | U | 2.7 | 4.7 | | |
| 19 | 6290 | U-238 | 1.8 | pCi/g | U | 1.5 | 2.3 | | |
| 19 | 6291 | U-238 | 1.1 | pCi/g | U | 1.1 | 1.8 | | |
| 19 | 6292 | U-238 | 0 | pCi/g | U | 2.7 | 4.7 | | |
| 19 | 6293 | U-238 | 1.7 | pCi/g | U | 1.6 | 2.6 | | |
| 20 | 6294 | U-238 | 0.1 | pCi/g | U | 3.8 | 6.7 | Average | 2.3 |
| 20 | 6295 | U-238 | 1.3 | pCi/g | U | 2.9 | 4.9 | Std Dev | 3.1 |
| 20 | 6296 | U-238 | 11.9 | pCi/g | | 4.7 | 6.2 | Max | 12 |
| 20 | 6297 | U-238 | 1.2 | pCi/g | U | 4.2 | 7.1 | Min | 0.10 |
| 20 | 6298 | U-238 | 6 | pCi/g | | 2 | 2.4 | # Samples | 14 |
| 20 | 6299 | U-238 | 1.8 | pCi/g | U | 4.1 | 7 | | |
| 20 | 6300 | U-238 | 3.2 | pCi/g | U | 2.8 | 4.4 | | |
| 20 | 6301 | U-238 | 1.5 | pCi/g | U | 3.9 | 6.7 | | |
| 20 | 6302 | U-238 | 0.4 | pCi/g | U | 4.2 | 7.4 | | |
| 20 | 6303 | U-238 | 0.8 | pCi/g | U | 2.7 | 4.7 | | |
| 20 | 6304 | U-238 | 1 | pCi/g | U | 2.9 | 5 | | |
| 20 | 6305 | U-238 | 1 | pCi/g | U | 1 | 1.6 | | |
| 20 | 6306 | U-238 | 0.3 | pCi/g | U | 2.5 | 4.4 | | |
| 20 | 6307 | U-238 | 1.9 | pCi/g | U | 3.1 | 5.2 | | |

**Appendix C**
**BTD Soil Sample Results**

| SU | FieldID | *Isotope | Final Result (pCi/g) | Units | Flag[1] | TPU (+/-) | MDC | Summary |
|---|---|---|---|---|---|---|---|---|
| 21 | 6308 | U-238 | 3.6 | pCi/g | U | 2.8 | 4.3 | Average 1.4 |
| 21 | 6309 | U-238 | 1.4 | pCi/g | U | 2.9 | 4.9 | Std Dev 1.1 |
| 21 | 6310 | U-238 | 1.1 | pCi/g | U | 1.1 | 1.8 | Max 3.6 |
| 21 | 6311 | U-238 | 3.3 | pCi/g | U | 4.6 | 7.6 | Min -0.2 |
| 21 | 6312 | U-238 | 0 | pCi/g | U | 2.7 | 4.7 | # Samples 15 |
| 21 | 6313 | U-238 | 1.9 | pCi/g | U | 1.6 | 2.4 | |
| 21 | 6314 | U-238 | 2 | pCi/g | U | 1.7 | 2.7 | |
| 21 | 6315 | U-238 | 2.1 | pCi/g | | 1.4 | 2 | |
| 21 | 6316 | U-238 | 1.2 | pCi/g | U | 1.2 | 1.9 | |
| 21 | 6317 | U-238 | 0.9 | pCi/g | U | 1 | 1.7 | |
| 21 | 6318 | U-238 | 1.1 | pCi/g | U | 2.4 | 3.9 | |
| 21 | 6319 | U-238 | 1.5 | pCi/g | U | 4.2 | 7.1 | |
| 21 | 6320 | U-238 | -0.2 | pCi/g | U | 2.6 | 4.7 | |
| 21 | 6321 | U-238 | 0.7 | pCi/g | U | 1.4 | 2.4 | |
| 21 | 6322 | U-238 | 0.4 | pCi/g | U | 1.4 | 2.4 | |
| 22 | 6323 | U-238 | 0.4 | pCi/g | U,G | 2.4 | 4 | Average 11 |
| 22 | 6324 | U-238 | 2 | pCi/g | U,G | 3.6 | 5.9 | Std Dev 13 |
| 22 | 6325 | U-238 | 46.9 | pCi/g | G | 7.4 | 6.5 | Max 47 |
| 22 | 6326 | U-238 | 9.4 | pCi/g | G | 4.7 | 7.1 | Min -0.15 |
| 22 | 6327 | U-238 | 27 | pCi/g | G | 5.5 | 6.2 | # Samples 17 |
| 22 | 6328 | U-238 | 11.6 | pCi/g | G | 3.4 | 4.7 | |
| 22 | 6329 | U-238 | 19.9 | pCi/g | G | 5.8 | 7.9 | |
| 22 | 6330 | U-238 | 2.2 | pCi/g | U,G | 2.2 | 3.6 | |
| 22 | 6331 | U-238 | 4.6 | pCi/g | LT,G | 1.3 | 1.6 | |
| 22 | 6332 | U-238 | 6.7 | pCi/g | LT,G | 3.8 | 5.9 | |
| 22 | 6333 | U-238 | 6.3 | pCi/g | LT | 2.3 | 3.4 | |
| 22 | 6334 | U-238 | 0.02 | pCi/g | U,G | 0.79 | 1.38 | |
| 22 | 6335 | U-238 | 28.9 | pCi/g | G | 4.3 | 2.6 | |
| 22 | 6336 | U-238 | 7 | pCi/g | LT,G | 3.9 | 6.1 | |
| 22 | 6337 | U-238 | -0.15 | pCi/g | U,G | 0.54 | 1.03 | |
| 22 | 6338 | U-238 | 5.6 | pCi/g | LT,G | 2.9 | 4.4 | |
| 22 | 6339 | U-238 | 2.8 | pCi/g | U,G | 2.9 | 4.6 | |
| 23 | 6340 | U-238 | -1.9 | pCi/g | U | 2.6 | 4.9 | Average 1.0 |
| 23 | 6341 | U-238 | 2.1 | pCi/g | U | 2.7 | 4.4 | Std Dev 1.2 |
| 23 | 6342 | U-238 | 1.46 | pCi/g | | 0.95 | 1.4 | Max 3.1 |
| 23 | 6343 | U-238 | 1.2 | pCi/g | U | 2.4 | 4 | Min -1.9 |
| 23 | 6344 | U-238 | -1 | pCi/g | U | 2.7 | 4.9 | # Samples 17 |
| 23 | 6345 | U-238 | 1.9 | pCi/g | U | 1.6 | 2.5 | |
| 23 | 6346 | U-238 | -0.1 | pCi/g | U | 3 | 5.2 | |
| 23 | 6347 | U-238 | 0.4 | pCi/g | U | 3.7 | 6.5 | |
| 23 | 6348 | U-238 | 1.4 | pCi/g | U | 2.8 | 4.6 | |
| 23 | 6349 | U-238 | -0.1 | pCi/g | U | 2.8 | 4.9 | |
| 23 | 6350 | U-238 | 1.2 | pCi/g | U | 1.3 | 2.2 | |
| 23 | 6351 | U-238 | 0.8 | pCi/g | U | 1.1 | 1.9 | |
| 23 | 6352 | U-238 | 0.9 | pCi/g | U | 1.3 | 2.1 | |
| 23 | 6353 | U-238 | 1.1 | pCi/g | U | 3.1 | 5.2 | |
| 23 | 6354 | U-238 | 3.1 | pCi/g | U | 3.3 | 5.3 | |
| 23 | 6355 | U-238 | 1.2 | pCi/g | U | 1.2 | 1.9 | |
| 23 | 6356 | U-238 | 2.5 | pCi/g | U | 3.3 | 5.3 | |
| 24 | 6357 | U-238 | 1.5 | pCi/g | U | 3.9 | 6.7 | Average 1.7 |
| 24 | 6358 | U-238 | 2 | pCi/g | U | 3.4 | 5.7 | Std Dev 1.8 |
| 24 | 6359 | U-238 | 2.3 | pCi/g | U | 2.7 | 4.3 | Max 6.9 |
| 24 | 6360 | U-238 | 1.1 | pCi/g | U | 3.6 | 6.2 | Min -1.2 |
| 24 | 6361 | U-238 | 1.9 | pCi/g | U | 2.8 | 4.6 | # Samples 14 |
| 24 | 6362 | U-238 | 1.3 | pCi/g | U | 4 | 6.9 | |
| 24 | 6363 | U-238 | -1.2 | pCi/g | U | 3.2 | 5.8 | |
| 24 | 6364 | U-238 | 0.6 | pCi/g | U | 2.9 | 5.1 | |
| 24 | 6365 | U-238 | 1.5 | pCi/g | U | 4.1 | 7 | |
| 24 | 6366 | U-238 | 6.9 | pCi/g | TI | 4.8 | 6.8 | |
| 24 | 6367 | U-238 | 2.7 | pCi/g | U | 2.4 | 3.7 | |
| 24 | 6368 | U-238 | 0.8 | pCi/g | U | 1.8 | 3 | |
| 24 | 6369 | U-238 | 0.8 | pCi/g | U | 1 | 1.7 | |
| 24 | 6371 | U-238 | 3.8 | pCi/g | LT,G | 1.6 | 2.2 | |

## Appendix C
## BTD Soil Sample Results

| SU | FieldID | *Isotope | Final Result (pCi/g) | Units | Flag[1] | TPU (+/-) | MDC | Summary | |
|---|---|---|---|---|---|---|---|---|---|
| 25 | 6372 | U-238 | 3.3 | pCi/g | U,G | 3.5 | 5.6 | Average | 1.4 |
| 25 | 6373 | U-238 | 2.4 | pCi/g | U,G | 4 | 6.7 | Std Dev | 1.0 |
| 25 | 6374 | U-238 | 1.4 | pCi/g | U,G | 2.8 | 4.7 | Max | 3.3 |
| 25 | 6375 | U-238 | 0.9 | pCi/g | U,G | 0.9 | 1.43 | Min | 0 |
| 25 | 6376 | U-238 | 0.15 | pCi/g | U,G | 0.65 | 1.14 | # Samples | 15 |
| 25 | 6377 | U-238 | 2.8 | pCi/g | U,G | 3.1 | 5.1 | | |
| 25 | 6378 | U-238 | 0.9 | pCi/g | U,G | 1.1 | 1.9 | | |
| 25 | 6379 | U-238 | 1.1 | pCi/g | U,G | 3.2 | 5.5 | | |
| 25 | 6380 | U-238 | 1 | pCi/g | U,G | 1.3 | 2.2 | | |
| 25 | 6381 | U-238 | 1.4 | pCi/g | U,G | 1.6 | 2.6 | | |
| 25 | 6382 | U-238 | 0 | pCi/g | U,G | 3 | 5.4 | | |
| 25 | 6383 | U-238 | 0.63 | pCi/g | U | 0.64 | 1.03 | | |
| 25 | 6384 | U-238 | 0 | pCi/g | U,G | 3.4 | 6.1 | | |
| 25 | 6385 | U-238 | 2.4 | pCi/g | LT,G | 1.5 | 2.3 | | |
| 25 | 6386 | U-238 | 2.2 | pCi/g | U,G | 3.3 | 5.5 | | |
| | RAVINE 1 | U-238 | 2.1 | pCi/g | U | 4.2 | 7 | Average | 1.8 |
| | RAVINE 2 | U-238 | 0.7 | pCi/g | U | 2.6 | 4.6 | Std Dev | 0.95 |
| | RAVINE 3 | U-238 | 2.5 | pCi/g | U | 3.1 | 5.1 | Max | 2.5 |
| | | | | | | | | Min | 0.70 |

Average 4.25
Maximum 80

*U-238 value is inferred using Th-234 progeny value assuming secular equillibrium.
[1] U - Result is less than the sample specific MDC or less than the associated TPU
LT - Result is less than the requested MDC, greater than sample specific MDC
G - Sample density differs by more than 15% of the Lab Control Sample
TI - Nuclide identification is tentative
MDC - Minimun detectable concentration
TPU - Total propagated uncertainty

| | | | | | |
|---|---|---|---|---|---|
| APG-BTD-WAC-1 | U-238 | 402 | pCi/g | 69 | 17 |
| APG-BTD-WAC-2 | U-238 | 223 | pCi/g | 37 | 5.9 |

# Appendix D: Field Replicate Normalized Absolute Difference Results

## Appendix D
## Field Replicate Normalized Absolute Difference Results

| Sample ID | Paragon Initial Sample Value $^{234}Th$, pCi/g | Two σ Error of Sample | Paragon Duplicate[1,2] Sample Value $^{234}Th$, pCi/g | Two σ Error of Duplicate | NAD | Fail if NAD > 1.96 |
|---|---|---|---|---|---|---|
| 6005 | 1.00E-01 | 1.00E+00 | 9.00E-01 | 1.30E+00 | 0.49 | Pass |
| 6020 | 7.50E-01 | 7.30E-01 | 6.00E-01 | 3.00E+00 | 0.05 | Pass |
| 6025 | 1.00E+00 | 2.40E+00 | 6.20E-01 | 9.00E-01 | 0.15 | Pass |
| 6035 | 2.20E+00 | 2.60E+00 | 4.20E-01 | 7.40E-01 | 0.66 | Pass |
| 6060 | -1.10E+00 | 2.50E+00 | 8.40E-01 | 9.70E-01 | 0.72 | Pass |
| 6065 | 4.20E-01 | 6.20E-01 | -4.00E-01 | 1.20E+00 | 0.61 | Pass |
| 6070 | 4.80E+00 | 4.40E+00 | 2.70E+00 | 1.30E+00 | 0.46 | Pass |
| 6075 | 5.00E-01 | 1.20E+00 | 2.60E+00 | 3.80E+00 | 0.53 | Pass |
| 6105 | 1.10E+00 | 1.20E+00 | 1.20E+00 | 1.80E+00 | 0.05 | Pass |
| 6115 | -2.30E+00 | 3.00E+00 | 0.00E+00 | 2.40E+00 | 0.60 | Pass |
| 6120 | 8.00E-01 | 1.00E+00 | 1.10E+00 | 1.80E+00 | 0.15 | Pass |
| 6125 | 5.55E+01 | 9.80E+00 | 6.00E+01 | 1.10E+01 | 0.31 | Pass |
| 6130 | 1.17E+02 | 2.00E+01 | 1.27E+02 | 2.20E+01 | 0.34 | Pass |
| 6140 | 8.10E+00 | 2.00E+00 | 1.97E+01 | 5.00E+00 | 2.15 | Fail |
| 6150 | 4.12E+01 | 8.40E+00 | 6.10E+01 | 1.20E+01 | 1.35 | Pass |
| 6160 | 1.80E+00 | 3.90E+00 | 4.10E+00 | 2.10E+00 | 0.52 | Pass |
| 6170 | 1.30E+00 | 3.00E+00 | 2.20E+00 | 2.50E+00 | 0.23 | Pass |
| 6185 | -9.00E-01 | 3.80E+00 | -2.10E+00 | 3.50E+00 | 0.23 | Pass |
| 6190 | 1.10E+00 | 1.50E+00 | 4.00E-01 | 3.50E+00 | 0.18 | Pass |
| 6200 | 1.80E+00 | 1.30E+00 | 5.00E-01 | 1.20E+00 | 0.73 | Pass |
| 6215 | 1.10E+00 | 1.10E+00 | -1.00E-01 | 2.50E+00 | 0.44 | Pass |
| 6220 | 1.40E+00 | 2.50E+00 | -4.00E-01 | 9.60E-01 | 0.67 | Pass |
| 6250 | 4.60E+00 | 3.60E+00 | 1.40E+00 | 2.60E+00 | 0.72 | Pass |
| 6252 | 1.10E+00 | 2.40E+00 | 1.00E-01 | 1.00E+00 | 0.38 | Pass |
| 6270 | 1.40E+00 | 2.50E+00 | -1.60E+00 | 4.00E+00 | 0.64 | Pass |
| 6275 | 8.00E-01 | 1.00E+00 | 1.40E+00 | 1.40E+00 | 0.35 | Pass |
| 6280 | -7.00E-01 | 3.70E+00 | 3.00E+00 | 4.70E+00 | 0.62 | Pass |
| 6290 | 1.80E+00 | 1.50E+00 | -1.10E+00 | 2.80E+00 | 0.91 | Pass |
| 6300 | 3.20E+00 | 2.80E+00 | 1.70E+00 | 1.10E+00 | 0.50 | Pass |
| 6310 | 1.10E+00 | 1.10E+00 | 8.00E-01 | 1.70E+00 | 0.15 | Pass |
| 6315 | 2.10E+00 | 1.40E+00 | 3.60E+00 | 3.20E+00 | 0.43 | Pass |
| 6345 | 1.90E+00 | 1.60E+00 | 5.00E-01 | 1.10E+00 | 0.72 | Pass |
| 6355 | 1.20E+00 | 1.20E+00 | 6.20E-01 | 8.40E-01 | 0.40 | Pass |
| 6359 | 2.30E+00 | 2.70E+00 | 2.60E+00 | 3.20E+00 | 0.07 | Pass |
| 6365 | 1.50E+00 | 4.10E+00 | -1.20E+00 | 2.70E+00 | 0.55 | Pass |
| 6230 | 1.40E+00 | 3.80E+00 | -1.20E+00 | 3.80E+00 | 0.48 | Pass |
| 6238 | 5.00E-01 | 3.30E+00 | 4.50E+00 | 3.30E+00 | 0.86 | Pass |
| 6326 | 9.40E+00 | 4.70E+00 | 6.10E+00 | 4.70E+00 | 0.50 | Pass |
| 6386 | 2.20E+00 | 3.30E+00 | 1.00E+00 | 3.30E+00 | 0.26 | Pass |

[1] Duplicates used for NAD analysis were those split samples obtained in the field.

[2] The duplicate samples generated via second counts of the same samples at Paragon Labs were not used here, as those apply only to the lab's QAPP.

# Appendix E: Instrumentation Calibration Certificates and QC Tables

Designer and Manufacturer of Scientific and Industrial Instruments

# CERTIFICATE OF CALIBRATION

**LUDLUM MEASUREMENTS, INC.**
POST OFFICE BOX 810 PH. 325-235-5494
501 OAK STREET FAX NO. 325-235-4672
SWEETWATER, TEXAS 79556, U.S.A.

CUSTOMER CABRERA SERVICES ORDER NO. 210994/279195

Mfg. Ludlum Measurements, Inc. Model 2221 Serial No. 97841
Mfg. Ludlum Measurements, Inc. Model 44-20 Serial No. PR183405

Cal. Date 12-Feb-04 Cal Due Date 12-Feb-05 Cal. Interval 1 Year Meterface 202-159

Check mark ☑ applies to applicable instr. and/or detector IAW mfg. spec. T. 73 °F RH 20 % Alt 710.8 mm Hg

☐ New Instrument Instrument Received ☑ Within Toler. +-10% ☐ 10-20% ☐ Out of Tol. ☐ Requiring Repair ☐ Other-See comments

☑ Mechanical ck. ☑ Meter Zeroed ☐ Background Subtract ☑ Input Sens. Linearity
☑ F/S Resp. ck ☑ Reset ck. ☑ Window Operation ☑ Geotropism
☑ Audio ck. ☐ Alarm Setting ck. ☑ Batt. ck. (Min. Volt) 4.4 VDC
☑ Calibrated in accordance with LMI SOP 14.8 rev 12/05/89. ☐ Calibrated in accordance with LMI SOP 14.9 rev 02/07/97.

Instrument Volt Set 1000 V Input Sens. 10 mV Det. Oper. 1000 V at 10 mV Threshold Dial Ratio 100 = 10 mV

☑ HV Readout (2 points) Ref./Inst. 500 / 500 V Ref./Inst. 2000 / 2003 V

## COMMENTS:

| | Peak settings | Gross Counts |
|---|---|---|
| High Voltage: | 681 V | 1000V |
| Threshold dial: | 642 | 100(10mv) |
| Window dial: | 40 | n/a |
| Window Position: | "IN" | "OUT" |
| Resolution for Cs137: | ≈9.52 % | n/a |

Model 2221 currently set for gross counts.
High voltage set with detector connected.

Firmware: 261027

Cal'd with a 6' cable.

Gamma Calibration: GM detectors positioned perpendicular to source except for M 44-9 in which the front of probe faces source.

| RANGE/MULTIPLIER | REFERENCE CAL. POINT | INSTRUMENT REC'D "AS FOUND READING" | INSTRUMENT METER READING* |
|---|---|---|---|
| X 1K | 400 Kcpm | 400 | 400 |
| X 1K | 100 Kcpm | 100 | 100 |
| X 100 | 40 Kcpm | 400 | 400 |
| X 100 | 10 Kcpm | 100 | 100 |
| X 10 | 4 Kcpm | 400 | 400 |
| X 10 | 1 Kcpm | 100 | 100 |
| X 1 | 400 cpm | 400 | 400 |
| X 1 | 100 cpm | 100 | 100 |

*Uncertainty within ± 10% C.F. within ± 20%

**Range(s) Calibrated Electronically**

| Digital Readout | REFERENCE CAL. POINT | INSTRUMENT RECEIVED | INSTRUMENT METER READING* |
|---|---|---|---|
| | 400 Kcpm | 40045(0) | 40045(0) |
| | 40 Kcpm | 4005 | 4005 |
| | 4 Kcpm | 400 | 400 |
| | 400 cpm | 40 | 40 |
| | 40 cpm | 4 | 4 |

| Log Scale | REFERENCE CAL. POINT | INSTRUMENT RECEIVED | INSTRUMENT METER READING* |
|---|---|---|---|
| | 500 Kcpm | 500K | 500K |
| | 50 Kcpm | 50K | 50K |
| | 5 Kcpm | 5K | 5K |
| | 500 cpm | 500 | 500 |
| | 50 cpm | 50 | 50 |

Ludlum Measurements, Inc. certifies that the above instrument has been calibrated by standards traceable to the National Institute of Standards and Technology, or to the calibration facilities of other International Standards Organization members, or have been derived from accepted values of natural physical constants or have been derived by the ratio type of calibration techniques. The calibration system conforms to the requirements of ANSI/NCSL Z540-1-1994 and ANSI N323-1978

State of Texas Calibration License No. LO-1963

**Reference Instruments and/or Sources:**

Cs-137 Gamma S/N ☐ 1162 ☐ G112 ☐ M565 ☐ 5105 ☐ T1008 ☐ T879 ☐ E552 ☐ E551 ☐ 720 ☐ 734 ☐ 1616 ☐ Neutron Am-241 Be S/N T-304

☐ Alpha S/N ☐ Beta S/N ☑ Other Am-241 @ ≈0.92μCi

☑ m 500 S/N 132899 ☐ Oscilloscope S/N ☑ Multimeter S/N 82080087

Calibrated By: Josh Boston Date 12 Feb 04

Reviewed By: LW Robison Date 13 FEB 04


FORM C22A 11/26/2003

AC Inst. Only ☐ Passed Dielectric (Hi-Pot) and Continuity Test ☐ Failed:

Designer and Manufacturer
of
Scientific and Industrial
Instruments

**LUDLUM MEASUREMENTS, INC.**
POST OFFICE BOX 810 PH. 325-235-5494
501 OAK STREET FAX NO. 325-235-4672
SWEETWATER, TEXAS 79556, U.S.A.

*Bench Test Data For Detector*

Detector 44-20 Serial No. PR183405

Customer CABRERA SERVICES Order #. 210994/279195

Counter 2221 Serial No. 97841 Counter Input Sensitivity 10 mV

Count Time 6 seconds Distance Source to Detector Surface

Other

| High Voltage | Background | Isotope Am-241 Size ≈0.92μCi | Isotope Size | Isotope Size | Isotope Size |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| 800 | 1563 | 16754 | | | |
| 850 | 1614 | 19450 | | | |
| 900 | 1576 | 21442 | | | |
| 950 | 1547 | 22414 | | | |
| → 1000 | 1544 | 22714 | | | |
| 1050 | 1519 | 23078 | | | |
| 1100 | 1674 | 23118 | | | |
| 1150 | 1517 | 22798 | | | |
| 1200 | 1566 | 22977 | | | |
| 1250 | 1597 | 22939 | | | |
| 1300 | 2120 | 23322 | | | |
| 1350 | 2687 | 23922 | | | |
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Signature Josh Boston Date 12 Feb 04

FORM C4A 04/09/2003

Designer and Manufacturer of Scientific and Industrial Instruments

# CERTIFICATE OF CALIBRATION

**LUDLUM MEASUREMENTS, INC.**
POST OFFICE BOX 810 PH. 325-235-5494
501 OAK STREET FAX NO. 325-235-4672
SWEETWATER, TEXAS 79556, U.S.A.

CUSTOMER CABRERA SERVICES ORDER NO. 297073/272297

Mfg. Ludlum Measurements, Inc. Model 2221 Serial No. 161581

Mfg. Ludlum Measurements, Inc. Model 44-20 Serial No. PR182743

Cal. Date 15-May-03 Cal Due Date 15-May-04 Cal. Interval 1 Year Meterface 202-159

Check mark ☑ applies to applicable instr. and/or detector IAW mfg. spec. T. 71 °F RH 46 % Alt 699.8 mm Hg

☐ New Instrument Instrument Received ☑ Within Toler. +-10% ☐ 10-20% ☐ Out of Tol. ☐ Requiring Repair ☐ Other-See comments

☑ Mechanical ck. ☑ Meter Zeroed ☐ Background Subtract ☑ Input Sens. Linearity
☑ F/S Resp. ck ☑ Reset ck. ☑ Window Operation ☑ Geotropism
☑ Audio ck. ☐ Alarm Setting ck. ☑ Batt. ck. (Min. Volt) 5.0 VDC

☑ Calibrated in accordance with LMI SOP 14.8 rev 12/05/89. ☐ Calibrated in accordance with LMI SOP 14.9 rev 02/07/97.

Instrument Volt Set Comments V Input Sens Comments mV Det. Oper Comments V at Comments mV Threshold Dial Ratio ____ = ____ mV

☑ HV Readout (2 points) Ref./Inst. 500 / 500 V Ref./Inst. 2000 / 2000 V

## COMMENTS:

| | Peak settings | Gross Counts |
|---|---|---|
| High Voltage: | 796 | 1100 |
| Threshold dial: | 642 | 100(10mv) |
| Window dial: | 40 | n/a |
| Window Position: | "IN" | "OUT" |
| Resolution for Cs137: | ≈ 9.8 % | n/a |

Model 2221 currently set for Gross counts
High voltage set with detector connected.

Firmware: 26 10 27

Gamma Calibration: GM detectors positioned perpendicular to source except for M 44-9 in which the front of probe faces source.

| RANGE/MULTIPLIER | REFERENCE CAL. POINT | INSTRUMENT REC'D "AS FOUND READING" | INSTRUMENT METER READING* |
|---|---|---|---|
| X 1000 | 400 Kcpm | 400 | 400 |
| X 1000 | 100 Kcpm | 100 | 100 |
| X 100 | 40 Kcpm | 400 | 400 |
| X 100 | 10 Kcpm | 100 | 100 |
| X 10 | 4 Kcpm | 400 | 400 |
| X 10 | 1 Kcpm | 100 | 100 |
| X 1 | 400 cpm | 400 | 400 |
| X 1 | 100 cpm | 100 | 100 |
| | | | |
| | | | |

*Uncertainty within ± 10% C.F. within ± 20% ALL **Range(s) Calibrated Electronically**

| Digital Readout: REFERENCE CAL. POINT | INSTRUMENT RECEIVED | INSTRUMENT METER READING* | Log Scale: REFERENCE CAL. POINT | INSTRUMENT RECEIVED | INSTRUMENT METER READING* |
|---|---|---|---|---|---|
| 400 K cpm | 39911(0) | 39911(0) | 500 K cpm | 450 k | 450K |
| 40 K cpm | 3965(0) | 3965(0) | 50 K cpm | 50 K | 50K |
| 4 K cpm | 394(0) | 394(0) | 5 K cpm | 5 K | 5 K |
| 400 cpm | 40(0) | 40(0) | 500 cpm | 500 | 500 |
| 40 cpm | 4(0) | 4(0) | 50 cpm | 55 | 55 |

Ludlum Measurements, Inc. certifies that the above instrument has been calibrated by standards traceable to the National Institute of Standards and Technology, or to the calibration facilities of other International Standards Organization members, or have been derived from accepted values of natural physical constants or have been derived by the ratio type of calibration techniques. The calibration system conforms to the requirements of ANSI/NCSL Z540-1-1994 and ANSI N323-1978 State of Texas Calibration License No. LO-1963

**Reference Instruments and/or Sources:**

Cs-137 Gamma S/N ☐ 1162 ☐ G112 ☐ M565 ☐ 5105 ☐ T1008 ☐ T879 ☐ E552 ☐ E551 ☐ Neutron Am-241 Be S/N T-304

☐ Alpha S/N ☐ Beta S/N ☐ Other

☑ m 500 S/N 81084 ☐ Oscilloscope S/N ☑ Multimeter S/N 80040300

Calibrated By: Michael J Thomas Date 15-May-03

Reviewed By: [signature] Date 21 MAY 03


FORM C22A 04/09/2003

AC Inst. Only ☐ Passed Dielectric (Hi-Pot) and Continuity Test ☐ Failed:

Designer and Manufacturer of Scientific and Industrial Instruments

LUDLUM MEASUREMENTS, INC.
POST OFFICE BOX 810 PH. 325-235-5494
501 OAK STREET FAX NO. 325-235-4672
SWEETWATER, TEXAS 79556, U.S.A.

# *Bench Test Data For Detector*

Detector 44-20 Serial No. PR 182743

Customer CABRERA SERVICES Order #. 297073/272297

Counter 2221 Serial No. 161581 Counter Input Sensitivity 10 mV

Count Time 6sec Distance Source to Detector Surface

Other

| High Voltage | Background | Isotope Am 241 Size ≈0.77uCi | Isotope Size | Isotope Size | Isotope Size |
|---|---|---|---|---|---|
| 800 | 1427 | 2132 | | | |
| 850 | 1796 | 14901 | | | |
| 900 | 1751 | 15884 | | | |
| 950 | 1879 | 18263 | | | |
| 1000 | 1908 | 19085 | | | |
| 1050 | 1891 | 19353 | | | |
| → 1100 | 1843 | 19162 | | | |
| 1150 | 1859 | 19243 | | | |
| 1200 | 2026 | 19299 | | | |
| 1250 | 2324 | 19522 | | | |
| 1300 | 2667 | 19935 | | | |
| 1350 | 3084 | 21121 | | | |

Signature Michael I Thomas Date 15-May-03

FORM C4A 04/09/2003

• *Serving The Nuclear Industry Since 1962* •

Designer and Manufacturer of Scientific and Industrial Instruments

LUDLUM MEASUREMENTS, INC.
POST OFFICE BOX 810 PH. 325-235-5494
501 OAK STREET FAX NO. 325-235-4672
SWEETWATER, TEXAS 79556, U.S.A.

Revised June 6 2003 By MTT

# CERTIFICATE OF CALIBRATION

CUSTOMER CABRERA SERVICES ORDER NO. 297073/272297

Mfg. Ludlum Measurements, Inc. Model 2221 Serial No. 174945

Mfg. Ludlum Measurements, Inc. Model 44-20 Serial No. PR183404

Cal. Date 15-May-03 Cal Due Date 15-May-04 Cal. Interval 1 Year Meterface 202-159

Check mark ☑ applies to applicable instr. and/or detector IAW mfg. spec. T. 71 °F RH 46 % Alt 699.8 mm Hg

☐ New Instrument Instrument Received ☑ Within Toler. +-10% ☐ 10-20% ☐ Out of Tol. ☐ Requiring Repair ☐ Other-See comments

☑ Mechanical ck. ☑ Meter Zeroed ☐ Background Subtract ☑ Input Sens. Linearity

☑ F/S Resp. ck ☑ Reset ck. ☑ Window Operation ☑ Geotropism

☑ Audio ck. ☐ Alarm Setting ck. ☑ Batt. ck. (Min. Volt) 5.0 VDC

☑ Calibrated in accordance with LMI SOP 14.8 rev 12/05/89. ☐ Calibrated in accordance with LMI SOP 14.9 rev 02/07/97.

Instrument Volt Set Comments V Input Sens. Comments mV Det. Oper. Comments V at Comments mV Threshold Dial Ratio ____ = ____ mV

☑ HV Readout (2 points) Ref./Inst. 500 / 499 V Ref./Inst. 2000 / 1998 V

## COMMENTS:

| | Peak settings | Gross Counts |
|---|---|---|
| High Voltage: | 793V | 1100V |
| Threshold dial: | 642 | 100(10mv) |
| Window dial: | 40 | n/a |
| Window Position: | "IN" | "OUT" |
| Resolution for Cs137: | ≈ 11 % | n/a |

Model 2221 currently set for Gross Counts
High voltage set with detector connected.

Firmware: 261027

Calibrated w/ 39" cable

Gamma Calibration: GM detectors positioned perpendicular to source except for M 44-9 in which the front of probe faces source.

| RANGE/MULTIPLIER | REFERENCE CAL. POINT | INSTRUMENT REC'D "AS FOUND READING" | INSTRUMENT METER READING* |
|---|---|---|---|
| X 1000 | 400 Kcpm | 400 | 400 |
| X 1000 | 100 Kcpm | 100 | 100 |
| X 100 | 40 Kcpm | 400 | 400 |
| X 100 | 10 Kcpm | 100 | 100 |
| X 10 | 4 Kcpm | 400 | 400 |
| X 10 | 1 Kcpm | 100 | 100 |
| X 1 | 400 cpm | 400 | 400 |
| X 1 | 100 cpm | 100 | 100 |

*Uncertainty within ± 10% C.F. within ± 20% ALL Range(s) Calibrated Electronically

| Digital Readout: REFERENCE CAL. POINT | INSTRUMENT RECEIVED | INSTRUMENT METER READING* | Log Scale: REFERENCE CAL. POINT | INSTRUMENT RECEIVED | INSTRUMENT METER READING* |
|---|---|---|---|---|---|
| 400 K cpm | 39912(0) | 39912(0) | 500 K cpm | 450 K | 450k |
| 40 K cpm | 3985(0) | 3985(0) | 50 K cpm | 50 K | 50k |
| 4 K cpm | 399(0) | 399(0) | 5 K cpm | 5 K | 5K |
| 400 cpm | 40(0) | 40(0) | 500 cpm | 500c/m | 500 |
| 40 cpm | 4(0) | 4(0) | 50 cpm | 55 | 55 |

Ludlum Measurements, Inc. certifies that the above instrument has been calibrated by standards traceable to the National Institute of Standards and Technology, or to the calibration facilities of other International Standards Organization members, or have been derived from accepted values of natural physical constants or have been derived by the ratio type of calibration techniques. The calibration system conforms to the requirements of ANSI/NCSL Z540-1-1994 and ANSI N323-1978

State of Texas Calibration License No. LO-1963

**Reference Instruments and/or Sources:**

Cs-137 Gamma S/N ☐ 1162 ☐ G112 ☐ M565 ☐ 5105 ☐ T1008 ☐ T879 ☐ E552 ☐ E551 ☐ Neutron Am-241 Be S/N T-304

☐ Alpha S/N ____ ☐ Beta S/N ____ ☐ Other ____

☑ m 500 S/N 81084 ☐ Oscilloscope S/N ____ ☑ Multimeter S/N 80040300

Calibrated By: Michael T Thomas Date 15-May-03

Reviewed By: [signature] Date 21 MAY 03


FORM C22A 04/09/2003

AC Inst. Only ☐ Passed Dielectric (Hi-Pot) and Continuity Test ☐ Failed: ____

Designer and Manufacturer
of
Scientific and Industrial
Instruments

**LUDLUM MEASUREMENTS, INC.**
POST OFFICE BOX 810 PH. 325-235-5494
501 OAK STREET FAX NO. 325-235-4672
SWEETWATER, TEXAS 79556, U.S.A.

*Bench Test Data For Detector*

Detector 44-20 Serial No. PR 44-20 183404

Customer CABRERA SERVICES Order #. 297073/272297

Counter 2221 Serial No. 174945 Counter Input Sensitivity 10 mV

Count Time 6 sec Distance Source to Detector Surface

Other

| High Voltage | Background | Isotope Am-241 Size ≈ 0.77 uCi | Isotope Size | Isotope Size | Isotope Size |
|---|---|---|---|---|---|
| 800 | 1826 | 2242 | | | |
| 850 | 2113 | 8708 | | | |
| 900 | 2238 | 12570 | | | |
| 950 | 2297 | 14052 | | | |
| 1000 | 2148 | 15941 | | | |
| 1050 | 2156 | 16246 | | | |
| → 1100 | 2231 | 16438 | | | |
| 1150 | 2219 | 16332 | | | |
| 1200 | 2206 | 16435 | | | |
| 1250 | 2162 | 16574 | | | |
| 1300 | 3275 | 17805 | | | |
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Signature Michael J Thomas Date 15-May-03

FORM C4A 04/09/2003

Designer and Manufacturer of Scientific and Industrial Instruments

# CERTIFICATE OF CALIBRATION

**LUDLUM MEASUREMENTS, INC.**
POST OFFICE BOX 810 PH. 325-235-5494
501 OAK STREET FAX NO. 325-235-4672
SWEETWATER, TEXAS 79556, U.S.A.

CUSTOMER CABRERA SERVICES ORDER NO. 213333/280342

Mfg. Ludlum Measurements, Inc. Model 2221 Serial No. 176941

Mfg. Ludlum Measurements, Inc. Model 44-20 Serial No. Pr 172518

Cal. Date 26-Mar-04 Cal Due Date 26-Mar-05 Cal. Interval 1 Year Meterface 202-159

Check mark ☑ applies to applicable instr. and/or detector IAW mfg. spec. T. 75 °F RH 34 % Alt 705.8 mm Hg

☐ New Instrument Instrument Received ☑ Within Toler. +-10% ☐ 10-20% ☐ Out of Tol. ☐ Requiring Repair ☐ Other-See comments

☑ Mechanical ck. ☑ Meter Zeroed ☐ Background Subtract ☑ Input Sens. Linearity
☑ F/S Resp. ck ☑ Reset ck. ☑ Window Operation ☑ Geotropism
☑ Audio ck. ☐ Alarm Setting ck. ☑ Batt. ck. (Min. Volt) 4.4 VDC

☑ Calibrated in accordance with LMI SOP 14.8 rev 12/05/89. ☐ Calibrated in accordance with LMI SOP 14.9 rev 02/07/97.

Instrument Volt Set Comm V Input Sens. Comm mV Det. Oper. Comm V at Comm mV Threshold Dial Ratio 100 = 10 mV

☑ HV Readout (2 points) Ref./Inst. 500 / 492 V Ref./Inst. 2000 / 1972 V

**COMMENTS:**

Peak settings:
Peak Voltage: 704 V.
Win: 40
Win. Pos. "IN"
Thshld: 642
Resolution for Cs 137 is 9%

Gross Settings:
HV: 1000 V.
Win. Pos: "Out"
Thshld 100 (10 mV)
Instrument Currently Set for Gross Settings.
Calib using 5' c/c Cable.

Gamma Calibration: GM detectors positioned perpendicular to source except for M 44-9 in which the front of probe faces source.

| RANGE/MULTIPLIER | REFERENCE CAL. POINT | INSTRUMENT REC'D "AS FOUND READING" | INSTRUMENT METER READING* |
|---|---|---|---|
| X 1K | 400 Kcpm | 400 | 400 |
| X 1K | 100 Kcpm | 100 | 100 |
| X 100 | 40 Kcpm | 400 | 400 |
| X 100 | 10 Kcpm | 100 | 100 |
| X 10 | 4 Kcpm | 400 | 400 |
| X 10 | 1 Kcpm | 100 | 100 |
| X 1 | 400 cpm | 400 | 400 |
| X 1 | 100 cpm | 100 | 100 |
| | | | |
| | | | |

*Uncertainty within ± 10% C.F. within ± 20%

**Range(s) Calibrated Electronically**

| | REFERENCE CAL. POINT | INSTRUMENT RECEIVED | INSTRUMENT METER READING* | | REFERENCE CAL. POINT | INSTRUMENT RECEIVED | INSTRUMENT METER READING* |
|---|---|---|---|---|---|---|---|
| Digital Readout | 400 Kcpm | 400493 Kcpm | 400493 Kcpm | Log Scale | 500 Kcpm | 500 Kcpm | 500 Kcpm |
| | 40 Kcpm | 40036 " | 40036 " | | 50 Kcpm | 50 " | 50 " |
| | 4 Kcpm | 4003 " | 4003 " | | 5 Kcpm | 5 " | 5 " |
| | 400 cpm | 400 cpm | 400 cpm | | 500 cpm | 500 cpm | 500 cpm |
| | 40 cpm | 40 " | 40 " | | 50 cpm | 50 " | 50 " |

Ludlum Measurements, Inc. certifies that the above instrument has been calibrated by standards traceable to the National Institute of Standards and Technology, or to the calibration facilities of other International Standards Organization members, or have been derived from accepted values of natural physical constants or have been derived by the ratio type of calibration techniques. The calibration system conforms to the requirements of ANSI/NCSL Z540-1-1994 and ANSI N323-1978 State of Texas Calibration License No. LO-1963

**Reference Instruments and/or Sources:**

Cs-137 Gamma S/N ☐ 1162 ☐ G112 ☐ M565 ☐ 5105 ☐ T1008 ☐ T879 ☐ E552 ☐ E551 ☐ 720 ☐ 734 ☐ 1616 ☐ Neutron Am-241 Be S/N T-304

☐ Alpha S/N ☐ Beta S/N ☑ Other Am 241 @ 0.77 uCi

☑ m 500 S/N 54680 ☐ Oscilloscope S/N ☑ Multimeter S/N 69101832

Calibrated By: [signature] Date 26-Mar-04

Reviewed By: [signature] Date 27 Mar 04


FORM C22A 11/26/2003

AC Inst. Only ☐ Passed Dielectric (Hi-Pot) and Continuity Test ☐ Failed:

Designer and Manufacturer of Scientific and Industrial Instruments

**LUDLUM MEASUREMENTS, INC.**
POST OFFICE BOX 810 PH. 325-235-5494
501 OAK STREET FAX NO. 325-235-4672
SWEETWATER, TEXAS 79556, U.S.A.

## *Bench Test Data For Detector*

Detector 44-20 Serial No. PR 172518

Customer CABRERA SERVICES Order #. 213333/280342

Counter 2221 Serial No. 176941 Counter Input Sensitivity 10 mV

Count Time 1min. Source + Background Distance Source to Detector Surface

Other

| High Voltage | Background | Isotope Am 241 Size 0.77 uCi | Isotope Size | Isotope Size | Isotope Size |
|---|---|---|---|---|---|
| 800 | 18117 | 143863 | | | |
| 850 | 18115 | 159552 | | | |
| 900 | 17954 | 178391 | | | |
| 950 | 18030 | 186309 | | | |
| 1000 | 17859 | 188523 | | | |
| 1050 | 18354 | 189121 | | | |
| 1100 | 18909 | 190208 | | | |
| 1150 | 19056 | 191706 | | | |
| 1200 | 20608 | 189017 | | | |
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Signature [signature] Date 26-Mar-04

FORM C4A 04/09/2003

Designer and Manufacturer of Scientific and Industrial Instruments

# CERTIFICATE OF CALIBRATION

**LUDLUM MEASUREMENTS, INC.**
POST OFFICE BOX 810 PH. 325-235-5494
501 OAK STREET FAX NO. 325-235-4672
SWEETWATER, TEXAS 79556, U.S.A.

CUSTOMER CABRERA SERVICES ORDER NO. 297073/272297

Mfg. Ludlum Measurements, Inc. Model 2221 Serial No. 176952

Mfg. Ludlum Measurements, Inc. Model 44-20 Serial No. PR 183465

Cal. Date 20-May-03 Cal Due Date 20-May-04 Cal. Interval 1 Year Meterface 202-159

Check mark ☑ applies to applicable instr. and/or detector IAW mfg. spec. T. 71 °F RH 46 % Alt 699.8 mm Hg

☐ New Instrument Instrument Received ☑ Within Toler. +-10% ☐ 10-20% ☐ Out of Tol. ☐ Requiring Repair ☐ Other-See comments

☑ Mechanical ck. ☑ Meter Zeroed ☐ Background Subtract ☑ Input Sens. Linearity
☑ F/S Resp. ck ☑ Reset ck. ☑ Window Operation ☑ Geotropism
☑ Audio ck. ☐ Alarm Setting ck. ☑ Batt. ck. (Min. Volt) 5.0 VDC

☑ Calibrated in accordance with LMI SOP 14.8 rev 12/05/89. ☐ Calibrated in accordance with LMI SOP 14.9 rev 02/07/97.

Instrument Volt Set Comments V Input Sens. Comments mV Det. Oper Comments V at Comments mV Threshold Dial Ratio 100 = 10 mV

☑ HV Readout (2 points) Ref./Inst. 500 / 501 V Ref./Inst. 2000 / ____ V

## COMMENTS:

| | Peak settings | Gross Counts |
|---|---|---|
| High Voltage: | 808V | 1150V |
| Threshold dial: | 642 | 100(10mv) |
| Window dial: | 40 | n/a |
| Window Position: | "IN" | "OUT" |
| Resolution for Cs137: | ≈ 9.4 % | n/a |

Model 2221 currently set for Gross Counts
High voltage set with detector connected.

Firmware: 261027

Gamma Calibration: GM detectors positioned perpendicular to source except for M 44-9 in which the front of probe faces source.

| RANGE/MULTIPLIER | REFERENCE CAL. POINT | INSTRUMENT REC'D "AS FOUND READING" | INSTRUMENT METER READING* |
|---|---|---|---|
| X 1000 | 400 Kcpm | 400 | 400 |
| X 1000 | 100 Kcpm | 100 | 100 |
| X 100 | 40 Kcpm | 400 | 400 |
| X 100 | 10 Kcpm | 100 | 100 |
| X 10 | 4 Kcpm | 400 | 400 |
| X 10 | 1 Kcpm | 100 | 100 |
| X 1 | 400 cpm | 400 | 400 |
| X 1 | 100 cpm | 100 | 100 |

*Uncertainty within ± 10% C.F. within ± 20% ALL **Range(s) Calibrated Electronically**

Digital Readout

| REFERENCE CAL. POINT | INSTRUMENT RECEIVED | INSTRUMENT METER READING* |
|---|---|---|
| 400 K cpm | 39842(0) | 39842(0) |
| 40 K cpm | 3985(0) | 3985(0) |
| 4 K cpm | 398(0) | 398(0) |
| 400 cpm | 39(0) | 39(0) |
| 40 cpm | 4(0) | 4(0) |

Log Scale

| REFERENCE CAL. POINT | INSTRUMENT RECEIVED | INSTRUMENT METER READING* |
|---|---|---|
| 500 K cpm | 450k | 450k |
| 50 K cpm | 50k | 50k |
| 5 K cpm | 5k | 5k |
| 500 cpm | 500 | 500 |
| 50 cpm | 55 | 55 |

Ludlum Measurements, Inc. certifies that the above instrument has been calibrated by standards traceable to the National Institute of Standards and Technology, or to the calibration facilities of other International Standards Organization members, or have been derived from accepted values of natural physical constants or have been derived by the ratio type of calibration techniques. The calibration system conforms to the requirements of ANSI/NCSL Z540-1-1994 and ANSI N323-1978 State of Texas Calibration License No. LO-1963

**Reference Instruments and/or Sources:**

Cs-137 Gamma S/N ☐ 1162 ☐ G112 ☐ M565 ☐ 5105 ☐ T1008 ☐ T879 ☐ E552 ☐ E551 ☐ Neutron Am-241 Be S/N T-304

☐ Alpha S/N ____ ☐ Beta S/N ____ ☐ Other ____

☑ m 500 S/N 81084 ☐ Oscilloscope S/N ____ ☑ Multimeter S/N 80040300

Calibrated By: Michael J Thomas Date 20-May-03

Reviewed By: [signature] Date 21 May 03


FORM C22A 04/09/2003

AC Inst. Only ☐ Passed Dielectric (Hi-Pot) and Continuity Test ☐ Failed: ____

Designer and Manufacturer
of
Scientific and Industrial
Instruments

LUDLUM MEASUREMENTS, INC.
POST OFFICE BOX 810 PH. 325-235-5494
501 OAK STREET FAX NO. 325-235-4672
SWEETWATER, TEXAS 79556, U.S.A.

*Bench Test Data For Detector*

Detector 44-20 Serial No. PR183465

Customer CABRERA SERVICES Order #. 297073/272297

Counter 2221 Serial No. 176952 Counter Input Sensitivity 10 mV

Count Time 6 sec Distance Source to Detector Surface

Other

| High Voltage | Background | Isotope Am-241 Size ≈0.77uCi | Isotope Size | Isotope Size | Isotope Size |
|---|---|---|---|---|---|
| 850 | 1687 | 5320 | | | |
| 900 | 1834 | 14734 | | | |
| 950 | 1875 | 16697 | | | |
| 1000 | 1838 | 18297 | | | |
| 1050 | 1866 | 18544 | | | |
| 1100 | 1958 | 19760 | | | |
| → 1150 | 1925 | 18898 | | | |
| 1200 | 1906 | 18404 | | | |
| 1250 | 1978 | 18731 | | | |
| 1300 | 2189 | 19263 | | | |
| 1350 | 2497 | 19307 | | | |
| 1400 | 2653 | 19628 | | | |
| 1450 | 3443 | 20643 | | | |
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Signature Michael J Thomas Date 20-May-03

FORM C4A 04/09/2003

## Appendix E

## NaI 3 x 3 Daily QC
## $^{137}Cs$

| Inst.#97841 | | |
|---|---|---|
| QC Daily Source | | |
| Date | Result (cpm) | P/F |
| 6/2/2004 | 102600 | Pass |
| 6/3/2004 | 101508 | Pass |
| 6/4/2004 | 98130 | Pass |
| 6/6/2004 | 101417 | Pass |
| 6/7/2004 | 102538 | Pass |
| 6/8/2004 | 99,689 | Pass |
| 6/9/2004 | 101618 | Pass |
| 6/10/2004 | 99987 | Pass |
| 6/11/2004 | 101345 | Pass |
| 6/14/2004 | 102129 | Pass |
| 6/15/2004 | 99,870 | Pass |
| | | |

| Inst.#97841 | | Source Ser. # | 1134 |
|---|---|---|---|
| Initial Source Readings | | Nuclide | Cs137 |
| Date | Result (cpm) | | |
| 6/2/2004 | 101881 | | |
| 6/2/2004 | 105647 | | |
| 6/2/2004 | 105033 | | |
| 6/2/2004 | 105319 | | |
| 6/2/2004 | 103080 | | |
| 6/2/2004 | 98471 | | |
| 6/2/2004 | 99281 | | |
| 6/2/2004 | 101530 | | |
| 6/2/2004 | 101991 | | |
| 6/2/2004 | 102746 | | |
| | Average | | |
| | 102498 | | |

## Appendix E

## NaI 3 x 3 Daily QC
## $^{137}$Cs

| Inst.#161581 | | |
|---|---|---|
| QC Daily Source | | |
| Date | Result (cpm) | P/F |
| 5/29/2003 | 52107 | Pass |
| 5/29/2003 | 52218 | Pass |
| 5/30/2003 | 52715 | Pass |
| 5/30/2003 | 52610 | Pass |
| 7/14/2003 | 56432 | Pass |
| 7/14/2003 | 56589 | Pass |
| 7/15/2003 | 56369 | Pass |
| 7/15/2003 | 55989 | Pass |
| 7/16/2003 | 56502 | Pass |
| 7/16/2003 | 56308 | Pass |
| 7/17/2003 | 56183 | Pass |
| 7/17/2003 | 56346 | Pass |
| 7/18/2003 | 56535 | Pass |
| 7/18/2003 | 56134 | Pass |
| 7/21/2003 | 56991 | Pass |
| 7/21/2003 | 56374 | Pass |
| 7/22/2003 | 57173 | Pass |
| 7/22/2003 | 56989 | Pass |
| 7/23/2003 | 56674 | Pass |
| 7/23/2003 | 55758 | Pass |
| 7/24/2003 | 56336 | Pass |
| 7/24/2003 | 56682 | Pass |
| 7/29/2003 | 56888 | Pass |
| 7/29/2003 | 55867 | Pass |
| 7/30/2003 | 56536 | Pass |
| 7/30/2003 | 56124 | Pass |
| 7/31/2003 | 56704 | Pass |
| 7/31/2003 | 55769 | Pass |
| 8/7/2003 | 56569 | Pass |
| 8/7/2003 | 57219 | Pass |
| 8/8/2003 | 55714 | Pass |
| 8/8/2003 | 56421 | Pass |
| 8/11/2003 | 56184 | Pass |
| 8/11/2003 | 56579 | Pass |
| 8/12/2003 | 56701 | Pass |
| 8/12/2003 | 56467 | Pass |
| 8/13/2003 | 56795 | Pass |
| 8/13/2003 | 56352 | Pass |
| 8/14/2003 | 56725 | Pass |
| 8/14/2003 | 55763 | Pass |

| Inst.#161581 | | Source Ser. # | 1127 |
|---|---|---|---|
| Initial Source Readings | | Nuclide | Cs-137 |
| Date | Result (cpm) | | |
| 5/29/2003 | 51998 | | |
| 5/29/2003 | 51972 | | |
| 5/29/2003 | 51622 | | |
| 5/29/2003 | 51816 | | |
| 5/29/2003 | 51914 | | |
| 5/29/2003 | 51573 | | |
| 5/29/2003 | 51773 | | |
| 5/29/2003 | 51565 | | |
| 5/29/2003 | 51530 | | |
| 5/29/2003 | 52168 | | |
| | Average | | |
| | 51793 | | |

## Appendix E

## NaI 3 x 3 Daily QC
## $^{57}Co$

| Inst.#174945(c) | | |
|---|---|---|
| QC Daily Source | | |
| Date | Result (cpm) | P/F |
| 8/14/2003 | 53889 | Pass |
| 8/14/2003 | 53805 | Pass |
| 8/15/2003 | 53683 | Pass |
| 8/15/2003 | 54004 | Pass |
| 8/18/2003 | 54415 | Pass |
| 8/18/2003 | 49909 | Pass |
| 8/19/2003 | 49504 | Pass |
| 8/19/2003 | 51204 | Pass |
| 8/20/2003 | 53895 | Pass |
| 8/20/2003 | 53729 | Pass |
| 8/21/2003 | 53788 | Pass |
| 8/21/2003 | 53896 | Pass |
| 8/22/2003 | 54034 | Pass |
| 8/22/2003 | 53689 | Pass |
| 8/25/2003 | 53367 | Pass |
| 8/25/2003 | 54021 | Pass |
| 8/26/2003 | 53922 | Pass |
| 8/26/2003 | 53749 | Pass |
| 8/27/2003 | 54029 | Pass |
| 8/27/2003 | 53872 | Pass |

| Inst.#174945(c) | | Source Ser. # | 1127 |
|---|---|---|---|
| Initial Source Readings | | Nuclide | 137Cs |
| Date | Result (cpm) | | |
| 8/14/2003 | 53257 | | |
| 8/14/2003 | 53690 | | |
| 8/14/2003 | 53872 | | |
| 8/14/2003 | 53483 | | |
| 8/14/2003 | 53849 | | |
| 8/14/2003 | 53625 | | |
| 8/14/2003 | 53771 | | |
| 8/14/2003 | 53778 | | |
| 8/14/2003 | 54023 | | |
| 8/14/2003 | 53714 | | |
| | Average | | |
| | 53706 | | |

## Appendix E

## NaI 3 X 3 Daily QC
## $^{137}Cs$

| Inst.#176941 | | |
|---|---|---|
| QC Daily Source | | |
| Date | Result (cpm) | P/F |
| 6/2/2004 | 99684 | Pass |
| 6/3/2004 | 99421 | Pass |
| 6/4/2004 | 100200 | Pass |
| 6/6/2004 | 96903 | Pass |
| 6/7/2004 | 98567 | Pass |
| 6/8/2004 | 100195 | Pass |
| 6/9/2004 | 101318 | Pass |
| 6/10/2004 | 96,543 | Pass |
| 6/11/2004 | 99,145 | Pass |
| 6/14/2004 | 100,487 | Pass |
| 6/15/2004 | 101213 | Pass |
| | | |

| Inst.#176941 | | Source Ser. # | 1134 |
|---|---|---|---|
| Initial Source Readings | | Nuclide | Cs137 |
| Date | Result (cpm) | | |
| 6/2/2004 | 101072 | | |
| 6/2/2004 | 101141 | | |
| 6/2/2004 | 100498 | | |
| 6/2/2004 | 101092 | | |
| 6/2/2004 | 101254 | | |
| 6/2/2004 | 103880 | | |
| 6/2/2004 | 101204 | | |
| 6/2/2004 | 101281 | | |
| 6/2/2004 | 101332 | | |
| 6/2/2004 | 102313 | | |
| | Average | | |
| | 101507 | | |

## Appendix E

## NaI 3 x 3 Daily QC
## $^{137}Cs$

| Inst.#176952 | | |
|---|---|---|
| QC Daily Source | | |
| Date | Result (cpm) | P/F |
| 5/29/2003 | 51776 | Pass |
| 5/29/2003 | 52653 | Pass |
| 5/30/2003 | 51893 | Pass |
| 5/30/2003 | 51759 | Pass |
| 7/14/2003 | 55906 | Pass |
| 7/14/2003 | 56387 | Pass |
| 7/15/2003 | 56256 | Pass |
| 7/15/2003 | 56108 | Pass |
| 7/16/2003 | 55958 | Pass |
| 7/16/2003 | 56327 | Pass |
| 8/12/2003 | 57703 | Pass |
| 8/12/2003 | 56289 | Pass |
| 8/13/2003 | 57003 | Pass |
| 8/13/2003 | 57426 | Pass |
| 8/14/2003 | 56102 | Pass |
| 8/14/2003 | 56727 | Pass |
| 8/15/2003 | 56092 | Pass |
| 8/15/2003 | 56847 | Pass |
| 8/18/2003 | 52803 | Pass |
| 8/18/2003 | 52559 | Pass |
| 8/19/2003 | 52554 | Pass |
| 8/19/2003 | 52786 | Pass |
| 8/20/2003 | 55999 | Pass |
| 8/20/2003 | 56358 | Pass |
| 8/25/2003 | 56723 | Pass |
| 8/27/2003 | 52998 | Pass |
| 8/27/2003 | 54784 | Pass |

| Inst.#176952 | | Source Ser. # | 1127 |
|---|---|---|---|
| Initial Source Readings | | Nuclide | Cs-137 |
| Date | Result (cpm) | | |
| 5/29/2003 | 51994 | | |
| 5/29/2003 | 51435 | | |
| 5/29/2003 | 52117 | | |
| 5/29/2003 | 52172 | | |
| 5/29/2003 | 51774 | | |
| 5/29/2003 | 51834 | | |
| 5/29/2003 | 51587 | | |
| 5/29/2003 | 51760 | | |
| 5/29/2003 | 51529 | | |
| 5/29/2003 | 51909 | | |
| | Average | | |
| | 51811 | | |

# Appendix E

## GPS Daily QC

| Trimble #0224022532, Antenna # 0220161434, Handset # 0220159474 | | | | | |
|---|---|---|---|---|---|
| **QC Daily GPS (Meters)** | | | | | |
| **Date** | **AM/PM** | **Northing (meters)** | **Easting (meters)** | **Offset (Meters)** | **P/F** |
| 7/16/2003 | AM | 197000.7 | 472402.7 | 0.34 | PASS |
| 7/16/2003 | PM | 197000.5 | 472402.5 | 0.58 | PASS |
| 8/13/2003 | AM | 197001.1 | 472402.3 | 0.59 | PASS |
| 8/13/2003 | PM | 197001.4 | 472402.5 | 0.57 | PASS |
| 8/14/2003 | AM | 197001.153 | 472403.009 | 0.21 | PASS |
| 8/14/2003 | PM | 197000.909 | 472403.037 | 0.17 | PASS |
| 8/15/2003 | AM | 197000.771 | 472402.300 | 0.63 | PASS |
| 8/15/2003 | PM | 197000.900 | 472403.100 | 0.23 | PASS |
| 8/18/2003 | AM | 197000.200 | 472402.999 | 0.79 | PASS |
| 8/18/2003 | PM | 197001.609 | 472403.010 | 0.64 | PASS |
| 8/19/2003 | AM | 197001.477 | 472402.686 | 0.53 | PASS |
| 8/19/2003 | PM | 197000.500 | 472402.437 | 0.66 | PASS |
| 8/27/2003 | AM | 197001.790 | 472402.300 | 1.00 | PASS |
| 8/27/2003 | PM | 197001.323 | 472403.156 | 0.43 | PASS |
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| Trimble #0224022532, Antenna # 0220161434, Handset # 0220159474 | | |
|---|---|---|
| **Initial GPS Readings (meters)** | | |
| **Date** | **Northing** | **Easting** |
| 5/21/2003 | 197001.2 | 472402.8 |
| 5/21/2003 | 197001.1 | 472402.9 |
| 5/21/2003 | 197000.9 | 472402.9 |
| 5/21/2003 | 197000.8 | 472402.9 |
| 5/21/2003 | 197000.9 | 472403.0 |
| 5/21/2003 | 197001.0 | 472403.0 |
| 5/21/2003 | 197001.1 | 472403.0 |
| 5/21/2003 | 197001.0 | 472402.9 |
| 5/21/2003 | 197001.0 | 472402.8 |
| 5/21/2003 | 197000.9 | 472402.8 |
| | Average | |
| | 197000.985 | 472402.891 |

| | | |
|---|---|---|
| max | 197001.2 | 472403.0 |
| Min | 197000.8 | 472402.8 |
| Delta | 0.38900 | 0.22400 |
| Stdev | 0.119791667 | 0.083658221 |
| Max offset (meters) | 0.448884172 | |

## Appendix E

## GPS Daily QC

| Trimble #0224022532, Handset # 0220207988 | | | | | |
|---|---|---|---|---|---|
| **QC Daily GPS (Meters)** | | | | | |
| **Date** | **AM/PM** | **Northing (meters)** | **Easting (meters)** | **Offset (Meters)** | **P/F** |
| | | | | | |
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| | | | | | |
| | | | | | |
| | | | | | |
| 7/16/2003 | AM | 197000.853 | 472402.537 | 0.77 | PASS |
| 7/16/2003 | PM | 197001.385 | 472402.577 | 0.42 | PASS |
| 7/17/2003 | AM | 197001.215 | 472402.557 | 0.50 | PASS |
| 7/17/2003 | PM | 197000.910 | 472402.620 | 0.68 | PASS |
| 7/18/2003 | AM | 197000.610 | 472402.506 | 0.99 | PASS |
| 7/18/2003 | PM | 197000.826 | 472402.753 | 0.69 | PASS |
| 7/21/2003 | AM | 197001.373 | 472402.699 | 0.31 | PASS |
| 7/21/2003 | PM | 197000.546 | 472402.940 | 0.93 | PASS |
| 7/22/2003 | AM | 197000.523 | 472402.961 | 0.96 | PASS |
| 7/24/2003 | AM | 197001.204 | 472403.002 | 0.28 | PASS |
| 7/29/2003 | AM | 197001.375 | 472402.722 | 0.28 | PASS |
| 7/29/2003 | PM | 197000.168 | 472402.657 | 1.35 | FAIL |
| 7/29/2003 | PM | 197001.473 | 472402.238 | 0.75 | PASS |
| 7/30/2003 | AM | 197000.324 | 472402.857 | 1.16 | FAIL |
| 7/30/2003 | PM | 197000.790 | 472402.567 | 0.81 | PASS |
| 7/31/2003 | AM | 197000.579 | 472402.559 | 1.00 | PASS |
| 8/7/2003 | AM | 197000.602 | 472402.666 | 0.93 | PASS |
| 8/7/2003 | PM | 197000.903 | 472402.876 | 0.59 | PASS |
| 8/8/2003 | AM | 197000.927 | 472402.671 | 0.64 | PASS |
| 8/8/2003 | PM | 197000.889 | 472402.782 | 0.62 | PASS |
| 8/11/2003 | AM | 197000.947 | 472402.904 | 0.54 | PASS |
| 8/11/2003 | PM | 197001.014 | 472402.419 | 0.73 | PASS |
| 8/12/2003 | AM | 197001.042 | 472402.536 | 0.63 | PASS |

| Trimble #0224022532, Handset # 0220207988 | | |
|---|---|---|
| **Initial GPS Readings (meters)** | | |
| **Date** | **Northing** | **Easting** |
| 5/21/2003 | 197002.1 | 472403.1 |
| 5/21/2003 | 197002.1 | 472403.1 |
| 5/21/2003 | 197001.8 | 472403.0 |
| 5/21/2003 | 197001.4 | 472402.9 |
| 5/21/2003 | 197001.6 | 472403.0 |
| 5/21/2003 | 197001.3 | 472402.8 |
| 5/21/2003 | 197001.3 | 472402.8 |
| 5/21/2003 | 197001.2 | 472403.1 |
| 5/21/2003 | 197001.1 | 472403.2 |
| 5/21/2003 | 197000.8 | 472403.2 |
| | Average | |
| | 197001.480 | 472402.986 |

| | | |
|---|---|---|
| max | 197002.1 | 472403.2 |
| Min | 197000.8 | 472402.8 |
| Delta | 1.30300 | 0.39300 |
| Stdev | 0.416975797 | 0.132697561 |
| Max offset (meters) | 1.360976855 | |

# Appendix E

## GPS Daily QC

| Trimble #0224015316 Antenna # 0220161434, Handset # 0220159474 | | | | | |
|---|---|---|---|---|---|
| **QC Daily GPS (Meters)** | | | | | |
| **Date** | **AM/PM** | **Northing (meters)** | **Easting (meters)** | **Offset (Meters)** | **P/F** |
| 7/16/2003 | AM | 197000.853 | 472402.537 | 0.78 | PASS |
| 7/16/2003 | PM | 197001.385 | 472402.577 | 0.44 | PASS |
| 7/17/2003 | AM | 197001.215 | 472402.557 | 0.52 | PASS |
| 7/17/2003 | PM | 197000.910 | 472402.620 | 0.69 | PASS |
| 7/18/2003 | AM | 197000.610 | 472402.506 | 1.00 | FAIL |
| 7/18/2003 | PM | 197000.826 | 472402.753 | 0.70 | PASS |
| 7/21/2003 | AM | 197001.373 | 472402.699 | 0.32 | PASS |
| 7/21/2003 | PM | 197000.546 | 472402.940 | 0.94 | PASS |
| 7/22/2003 | AM | 197000.523 | 472402.961 | 0.96 | PASS |
| 7/24/2003 | AM | 197001.204 | 472403.002 | 0.28 | PASS |
| 7/29/2003 | AM | 197001.375 | 472402.722 | 0.30 | PASS |
| 7/29/2003 | PM | 197000.168 | 472402.657 | 1.36 | FAIL |
| 7/29/2003 | PM | 197001.473 | 472402.238 | 0.77 | PASS |
| 7/30/2003 | AM | 197000.324 | 472402.857 | 1.16 | FAIL |
| 7/30/2003 | PM | 197000.790 | 472402.567 | 0.82 | PASS |
| 7/31/2003 | AM | 197000.579 | 472402.559 | 1.00 | FAIL |
| 8/7/2003 | AM | 197000.602 | 472402.666 | 0.94 | PASS |
| 8/7/2003 | PM | 197000.903 | 472402.876 | 0.59 | PASS |
| 8/8/2003 | AM | 197000.927 | 472402.671 | 0.65 | PASS |
| 8/8/2003 | PM | 197000.889 | 472402.782 | 0.63 | PASS |
| 8/11/2003 | AM | 197000.947 | 472402.904 | 0.54 | PASS |
| 8/11/2003 | PM | 197001.014 | 472402.419 | 0.75 | PASS |
| 8/12/2003 | AM | 197001.042 | 472402.536 | 0.64 | PASS |
| 8/12/2003 | PM | 197000.884 | 472402.880 | 0.61 | PASS |
| 8/13/2003 | AM | 197000.719 | 472402.815 | 0.78 | PASS |
| 8/13/2003 | PM | 197001.229 | 472402.700 | 0.39 | PASS |
| 8/14/2003 | AM | 197000.960 | 472403.193 | 0.55 | PASS |
| 8/14/2003 | PM | 197000.743 | 472403.031 | 0.74 | PASS |
| 8/15/2003 | AM | 197000.882 | 472402.889 | 0.61 | PASS |
| 8/15/2003 | PM | 197001.168 | 472402.657 | 0.47 | PASS |
| 8/18/2003 | AM | 197001.579 | 472402.559 | 0.46 | PASS |
| 8/18/2003 | PM | 197001.014 | 472402.419 | 0.75 | PASS |
| 8/19/2003 | AM | 197001.324 | 472402.857 | 0.21 | PASS |
| 8/19/2003 | PM | 197000.889 | 472402.782 | 0.63 | PASS |
| 8/20/2003 | AM | 197000.764 | 472402.533 | 0.86 | PASS |
| 8/20/2003 | PM | 197000.899 | 472402.561 | 0.73 | PASS |
| 8/25/2003 | AM | 197001.144 | 472402.351 | 0.73 | PASS |
| 8/25/2003 | PM | 197001.719 | 472402.340 | 0.71 | PASS |
| 8/26/2003 | AM | 197000.537 | 472402.809 | 0.96 | PASS |
| 8/26/2003 | PM | 197001.825 | 472402.505 | 0.61 | PASS |
| 8/27/2003 | AM | 197000.724 | 472403.100 | 0.76 | PASS |
| 8/27/2003 | PM | 197001.825 | 472403.000 | 0.35 | PASS |
| | | | | | |
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| Trimble #0224015316 Antenna # 0220161434, Handset # 0220159474 | | |
|---|---|---|
| **Initial GPS Readings (meters)** | | |
| **Date** | **Northing** | **Easting** |
| 5/21/2003 | 197002.1 | 472403.1 |
| 5/21/2003 | 197002.1 | 472403.1 |
| 5/21/2003 | 197001.8 | 472403.0 |
| 5/21/2003 | 197001.4 | 472402.9 |
| 5/21/2003 | 197001.6 | 472403.0 |
| 5/21/2003 | 197001.3 | 472402.8 |
| 5/21/2003 | 197001.3 | 472402.8 |
| 5/21/2003 | 197001.2 | 472403.1 |
| 5/21/2003 | 197001.1 | 472403.2 |
| 5/21/2003 | 197000.8 | 472403.2 |
| | Average | |
| | 197001.480 | 472403.004 |

| | | |
|---|---|---|
| max | 197002.1 | 472403.2 |
| Min | 197000.8 | 472402.8 |
| Delta | 1.30300 | 0.39900 |
| Stdev | 0.416975797 | 0.137207707 |
| Max offset (meters) | 1.362721542 | |

# Appendix E

## GPS Daily QC

| Trimble #0224048724, Antenna # 0220280009, Handset # 0220151861 | | | | | |
|---|---|---|---|---|---|
| **QC Daily GPS (Meters)** | | | | | |
| **Date** | **AM/PM** | **Northing (meters)** | **Easting (meters)** | **Offset (Meters)** | **P/F** |
| 6/2/2004 | AM | 197043.0 | 472450.0 | 0.72 | PASS |
| 6/3/2004 | AM | 197040.0 | 472446.0 | 4.33 | FAIL |
| 6/4/2004 | AM | 197042.0 | 472449.0 | 0.72 | PASS |
| 6/7/2004 | AM | 197043.0 | 472449.0 | 0.85 | PASS |
| 6/11/2004 | AM | 197042.0 | 472450.0 | 0.57 | PASS |
| 6/14/2004 | AM | 197042.0 | 472449.000 | 0.72 | PASS |
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| Trimble #0224048724, Antenna # 0220280009, Handset # 0220151861 | | |
|---|---|---|
| **Initial GPS Readings (meters)** | | |
| **Date** | **Northing** | **Easting** |
| 6/2/2004 | 197043.000 | 472450.000 |
| 6/2/2004 | 197043.000 | 472450.000 |
| 6/2/2004 | 197042.0 | 472449.0 |
| 6/2/2004 | 197042.0 | 472450.000 |
| 6/2/2004 | 197042.0 | 472449.0 |
| 6/2/2004 | 197043.000 | 472450.000 |
| 6/2/2004 | 197043.000 | 472450.000 |
| 6/2/2004 | 197042.0 | 472450.000 |
| 6/2/2004 | 197042.0 | 472449.0 |
| 6/2/2004 | 197042.0 | 472449.0 |
| | Average | |
| | 197042.400 | 472449.600 |

| | | |
|---|---|---|
| max | 197043.0 | 472450.0 |
| Min | 197042.0 | 472449.0 |
| Delta | 1.00000 | 1.00000 |
| Stdev | 0.516400406 | 0.516387273 |
| Max offset (meters) | 1.414213562 | |