Final Letter Report

Focused Site Inspection: Characterization Surveys for Radiological Contaminants of Concern

Shpack Landfill Superfund Site
Norton/Athol Area, Massachusetts

Contract No. ACW33990

Prepared for:
U.S. Army Corps of Engineers
New England District

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April 2003
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Norton/Attleboro, Massachusetts

Contract No. DACW33-99-C-0023

Prepared for:
U.S. Army Corps of Engineers
New England District

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**Acronyms and Abbreviations**

AEC       U. S. Atomic Energy Commission  
ALI       Attleboro Landfill, Inc.  
CENAE     US Army Corps of Engineers – New England District  
CFR       Code of Federal Regulations  
cm/s      centimeter per second  
cm³/g     cubic centimeters per gram  
cpm       counts per minute  
CPR       Cardio Pulmonary Resuscitation  
DCGL      derived concentration guideline level  
DOE       Department of Energy  
DPT       direct push technology  
DQO       data quality objective  
EE/CA     Engineering Evaluation/Cost Analysis  
EM        electromagnetic  
EPA       United States Environmental Protection Agency  
EZ        exclusion zone  
FIDLER    Field Instrument for Detection of Low Energy Radiation  
FOL       Field Operations Lead  
FSI       focused site inspection  
FUSRAP    Formerly Utilized Sites Remedial Action Program  
G-M       Geiger-Mueller  
GPR       ground penetrating radar  
GPS       global positioning system  
GSSI      Geophysical Survey Systems, Inc.  
GWS       gamma walkover survey  
HPGe      high purity germanium  
Hz        hertz  
IDW       investigation derived waste  
ISOCS®    In-Situ Object Counting System  
Kd        Distribution Coefficient  
keV       kilo electron volt  
kHz       kilohertz  
kV        kilovolt  
LQAP      Laboratory Quality Assurance Plan  
MHz       megahertz
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MIT  Massachusetts Institute of Technology
MSP  Massachusetts State Plane
NaI  sodium iodide
NIST  National Institute for Standards and Technology
NPL  National Priorities List
NRC  U.S. Nuclear Regulatory Commission
ORNL  Oak Ridge National Laboratories
pCi/g  picoCuries per gram
pCi/L  picoCuries per liter
PID  photionization detector
PRP  potentially responsible party
PVC  polyvinyl chloride
QA  quality assurance
QC  quality control
$^{226}$Ra  Radium-226
RCOPC  radiological contaminant of potential concern
RCRA  Resource Conservation and Recovery Act
RESRAD  RESidual RADioactivity (computer code)
RI/FS  remedial investigation and feasibility study
SNM  special nuclear material
SOP  standard operating procedure
SOW  scope of Work
SSHP  Site Specific Health and Safety Plan
SZ  support zone
$^{99}$Tc  Technetium-99
$^{234}$Th  Thorium-234
TCLP  toxicity characteristic leaching procedure
$^{234}$U  Uranium-234
$^{235}$U  Uranium-235
$^{238}$U  Uranium-238
USACE  United States Army Corps of Engineers
V  volt
WAC  waste acceptance criteria
1.0 INTRODUCTION

Cabrera Services, Inc. (CABRERA) completed field activities between April 2002 and July 2002 in support of the early phases of a project to characterize surface and sub-surface radiological contamination at the Shpack Landfill Superfund Site (the Site). The work was carried out on behalf of the U.S. Army Corps of Engineers (USACE) New England District (CENAE), under Contract Number DACW33-99-C-0023. The Site, located on the boundary between Norton and Attleboro, Massachusetts, is being characterized to investigate potential remedial actions under the Formerly Utilized Sites Remedial Action Program (FUSRAP).

This report provides the methodologies and results of Site characterization activities. It should be noted that, while the Site contains both radiological and chemical contamination, activities discussed in this report are limited to tasks designed to address only radiological contaminants being remediated under FUSRAP. Chemical constituents are discussed only as they apply to processes pertaining to Site radiological contamination.

1.1 Site Description and History

The Site is an 8-acre abandoned domestic and industrial landfill that operated from 1946 to 1965, when a court order forced its closing. Located along the Norton/Attleboro, MA town boundary line (Figure 1), the Site consists of land formerly owned by Lea and Isadore Shpack, now owned by the town of Norton, and land formerly owned by Albert Dumont, now owned by Attleboro Landfill, Inc. (ALI). Approximately 5-1/2 acres is on the Norton side of the town line and 2-1/2 acres is on the Attleboro side. The Shpack Landfill directly borders the 50-acre former Attleboro Landfill. A civil survey map of the site as surveyed during the GWS is included as Figure 2.

In 1980, approximately 800 to 900 pounds of metal fragments, “...enriched in $^{235}$U...” were removed from the Site under armed guard and transported to Oak Ridge National Laboratories (ORNL) for retention (CABRERA 2002). On June 10, 1986, the Site was listed on the National Priorities List (NPL) and the U.S. Environmental Protection Agency (EPA) signed an Administrative Order by Consent in September 1990 with a group of settling parties for the performance of a remedial investigation and feasibility study (RI/FS). The initial phase of the RI has been completed. The Site was designated for remedial action under FUSRAP in 1981.

Four sets of high voltage transmission lines, operating at 115 kilovolt (kV) and 345 kV, cross the site near the Norton/Attleboro line. These lines were raised in early 2002 prior to the start of the characterization field effort due to safety concerns that arose during the initial GWS (CABRERA 2001).

1.2 Previous Investigations

Numerous investigations have taken place at the Site since its NPL listing. The details of these investigations were presented in the Work Plan (CABRERA, 2002) and are not repeated in this report. A brief summary, however, is included below.

• EG&G (1979) Radiological Survey of the Shpack Site, October 3, 1979. As a follow-up to the initial ground site surveys, the U.S. Department of Energy (DOE) authorized an aerial radiological survey of the Shpack site. The study concluded that "No evidence of any man-made anomalies were detectable."

• Norton Conservation Commission (1980) Shpack Site, March 17, 1980. The Norton Conservation Commission (NCC) compiled local data including: property deed and easement information; zoning classifications; aerial photograph analyses; geology, soil, and ground water information; and, information from local citizens.

• Shearer, D.R. (1980) Report on Results of Analyses of Test Well Water at Attleboro Landfill Site, March 10, 1980. Shearer (1980) evaluated the results of radiological testing (gross alpha and beta analysis and gamma spectrographic analysis) of 10, unfiltered, ground-water samples from the Attleboro landfill collected on January 24, 1980. This report was submitted as part of the GHR (1980) report.

• Oak Ridge National Laboratory, ORNL (1981) Radiological Survey of the Shpack Landfill, Norton, Massachusetts, December 1981. This report documents the activities of ORNL in 1981, which were designed as a follow-up to previous USNRC activities. The ORNL investigation included (ORNL, 1981): Geiger-Muller (G-M) survey measurements; measurement of external gamma radiation levels using portable gamma-ray scintillation (Sodium iodide [NaI] crystal) survey meters; collection of surface soil samples and analysis; soil borings to the water table and downhole analysis by NaI scintillation probe; collection of split spoon soil samples; and, collection of ground-water and surface water samples from the boreholes, existing monitoring and potable water wells, and radiological analysis.

• Ecology and Environment (1982) Preliminary Assessment Form, April 9, 1982. The preliminary assessment (PA) was completed April 9, 1982 by the EPA's Region I FIT contractor.


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- **EPA (1984) Hazard Ranking Score Worksheet, May 24, 1984.** The HRS for the site of 29.45 appears to have been driven predominantly by the presence of $^{238}\text{U}$ as well as other radionuclides; the close proximity to residences with drinking water wells, which currently have no alternative source of potable water; and, the close proximity to wetlands and surface water bodies.

- **Bechtel National, Inc. (1988) Record of Telephone Conversation with Eberline, February 18, 1988.** This record indicated that 800 to 900 pounds of metal fragments enriched in $^{235}\text{U}$ were removed from the site under armed guard immediately following the ORNL (1980) investigation. This material was transported to ORNL for retention.

- **Agency for Toxic Substances and Disease Registry (1989) Preliminary Health Assessment for Shpack Landfill, Attleboro/Norton, Massachusetts, March 1989.** This report relied on existing data to define the following exposure pathways: dermal absorption or ingestion of contaminants in soil, sediments, ground water, and surface water; exposure to gamma radioactivity in the ambient air at Shpack landfill; and, dermal exposure to beta-gamma emissions near ground surface level.

### 1.3 Radionuclides of Potential Concern (RCOPCs)

Based on some of the earlier radiological investigations at the Site (ORNL 1981, and BNI 1982), the Site RCOPCs are uranium-238 ($^{238}\text{U}$), uranium-235 ($^{235}\text{U}$), uranium-234 ($^{234}\text{U}$), and radium-226 ($^{226}\text{Ra}$). $^{226}\text{Ra}$ is only considered as a site RCOPC when collocated with uranium contamination.

### 1.4 Objectives

The main objective for this investigation was to estimate the horizontal and vertical distribution of radiological contaminants and the concentrations of those contaminants to support future risk management decisions and for worker safety considerations. The investigation was designed to provide the necessary data to establish whether or not radiological contaminants had been deposited beyond the property line or transported across the property line by overland flow or groundwater transport. Other objectives were to estimate the depth of the landfill, whether or not the wetland areas were natural or the result of excavation activities, and to ascertain whether or not waste had been disposed in the wetland areas.

The answers to these questions provide input for risk management decisions that involve consideration of the entire spectrum of remedial alternatives for this site, including no further action, conducting time critical or non-time critical soil removals and/or groundwater remediation, leading to the eventual implementation of an Engineering Evaluation/Cost Analysis (EE/CA).

Information required to meet the project objectives includes the collection of surface and subsurface radionuclide concentration and distribution data which will lead to the development of radionuclide-specific derived concentration guideline levels (DCGLs). Other
necessary inputs include geotechnical and hydrogeological information, including landfill thickness, soil classification data and hydraulic conductivity, likely pathways for contaminant migration, depth to groundwater, characterization of local wetlands, and derivation of site-specific $K_d$ values for transport modeling in areas with radiological contamination.

The information inputs necessary to satisfy the above objectives were collected during the Focused Site Inspection (FSI). Site activities included a Gamma Walkover Survey (GWS), a geophysical survey, surface and subsurface soil sampling by a direct push technology sampling rig, soil logging by a qualified site geologist, downhole gamma logging, in-situ gamma spectroscopy, off-site analysis of water and soil samples by alpha and gamma spectroscopy, and $K_d$ analysis of site soils by the Actinide Chemistry Group of the Nuclear Engineering Department at the Massachusetts Institute of Technology (MIT). Descriptions of all these activities are included in Sections 4.0 and 5.0, below.
2.0 HEALTH AND SAFETY

Activities performed by CABRERA employees and its subcontractors were performed in accordance with the Site Specific Health and Safety Plan (SSHP) (CABRERA, 2002b) and Sampling and Analysis Plan (CABRERA, 2002). Two changes to the SSHP occurred during the FSI. The first change was the requirement by CENAE that all site personnel wear hard hats, safety glasses, and steel toed boots at all times while inside the exclusion zone (EZ). The second change was the establishment of an on-site uranium criticality control program as described in the section below.

2.1 Enriched Uranium Control

Two separate storage areas were set up on the Site for samples as they were being collected and counted. The first was a storage area for samples that were scheduled to be counted. The second was for investigative derived waste (IDW) generated during the sampling process. Each area had administrative controls that limited the amount of $^{235}$U to no more than 100 grams at each storage location. The CABRERA action level for the control of fissile material is 100 grams of $^{235}$U at either storage location. Therefore, the total site inventory was limited to less than 200 grams of $^{235}$U at any point in time.

The CABRERA Radiation Protection Program limits the quantity of $^{235}$U special nuclear material (SNM), under CABRERA control and possession to 350 grams at any point in time. The conservative procedural controls utilized provided an additional margin of safety during field operations. The onsite activities associated with this work evolution resulted in a final $^{235}$U inventory of 3.4 grams. This is less than one percent of the amount of SNM as permitted by CABRERA NRC license condition 6.D.
3.0 MOBILIZATION AND SITE PREPARATION

3.1 Reference Coordinate System

During previous investigations, various site reference grid systems were established. For the GWS completed in April and May of 2000, a 20-meter square reference grid, tied to the Massachusetts State Plane (MSP), was established. This grid was reused during characterization activities with the objective of collecting spatially correlated data at locations that can be readily reproduced in the future.

Global positioning system (GPS) receivers were used during characterization activities to provide positional accuracy for measurement locations. Through use of GPS, measurement locations have been referenced to the site grid and to the MSP.

3.2 Pre-Survey Tasks

3.2.1 Mobilization

The first tasks during mobilization were to place the field trailer and toilet back into service. The first field personnel arrived on Site on April 15, 2002 to begin the initial preparations for the site characterization field effort.

The portion of the support zone located inside the fence line was left covered with either geotextile or tarpaulins following the GWS in April/May of 2000. During mobilization, these coverings were inspected and repaired or replaced, as appropriate.

For this field effort, an additional office trailer was mobilized to serve as a base for the field screening laboratory and to provide additional storage space to support field activities. It arrived at the site during the week of April 15, 2002 and was placed east of the existing trailer. It was prepared consistent with the SSHP, enlarging the existing support zone to include the second trailer. Geotextile or tarpaulins were spread on the surrounding ground between the two trailers to prevent exposure to surface soil contaminants, although soil contamination was anticipated to be minimal in this portion of the site.

3.2.2 Wetlands Delineation

The site wetlands boundaries were delineated and mapped on July 30 to 31, 2002. USACE personnel, Peter J. Trinchero, Wetland Ecologist, and Robert W. Davis, Environmental Resource Specialist, led the effort with assistance from CABRERA. Wetlands flags were located and placed with a Trimble GPS unit. The work was conducted in consultation with Jennifer Carlino, the Director of the Town of Norton’s Conservation Commission. Figure 3 presents a map showing the seven jurisdictional wetland areas that were mapped at the Shpack Landfill during the delineation effort.

Some areas of the wetlands were not located with GPS due to interference caused by the tree canopy. This was true for most of Wetland 1, a portion of Wetland 2, and one point in Wetland 5. Wetland 1 required additional surveying, which CABRERA completed with a compass and tape measure. Wetland 4 is a small rectangular area, approximately 8 feet
across, and was defined by a single GPS fix taken near the middle of the area. The wetland flags were numbered by wetland (i.e., W1 through W7) and point (1 through as many points as were required to map the wetland boundary). Therefore, the first flag in Wetland 1 was W1-1; the second flag was W1-2, and so forth. In Wetland 2, a jog was later added along the west side between points W2-47 and W2-48. These eight additional points were numbered W2-47.1 through W2-47.8.

A trip report by the USACE representatives (Davis and Trinchero) is included in Appendix A.

3.2.3  Site Clearing

Prior to commencing characterization measurements, site vegetation, including trees less than two inches in diameter, were cut to the lowest practically achievable level. Site clearing activities took place over the 8-acre site by a team of four CABRERA employees between April 15 and April 19, 2002. Per instructions from the Norton Conservation Director, phragmites, an invasive plant species located in site wetlands, were cut and the cuttings left in place to avoid spreading this species unnecessarily. Before cutting began, the Conservation Director was consulted to ensure that clearing activities were within Town guidelines.

3.2.4  Reestablish Site Reference Coordinate Grid

Following site clearing, the reference coordinate grid stakes installed during the January 2001 GWS were inspected and replaced, as appropriate, by CABRERA personnel. The grid stakes were installed every 20 meters within the site boundary using Trimble GPS unit that was accurate to less than one meter. The grid permitted site personnel to readily determine their location. Soil borings were planned at each grid node, to include collecting subsurface soil samples in a continuous soil core, scanning for gross beta/gamma count rate using a Geiger-Mueller (G-M) detector, and measuring downhole gamma count (for further discussion, refer to Sections 4.3, 4.4, and 4.5). Additional grid stakes were placed at planned bias locations in accordance with the work plan, where prior characterization data (historical data from previous investigations by others and the 2001 GWS) had indicated radiological anomalies that warranted further investigation. And finally, grid stakes were installed at field bias locations, which were chosen based on data collected and evaluated during the ongoing field investigation during the FSI. A table summarizing all of the grid stakes established and used during this investigation is included in Appendix B as Table B-1. Also shown on Table B-1 are the planned bias locations (N2 through N62) and the field bias locations (BIAS01 through BIAS30). Figure 4 shows their locations relative to site features.
4.0 FIELD ACTIVITIES AND METHODOLOGY

Descriptions of the various field activities during the FSI are presented below. Appendix C contains selected annotated photographs taken during the field investigation.

4.1 Gamma Walkover Survey

The GWS was completed on May 3, 2002, during the time interval of 0800 to 1330. It was carried out to:

- Provide an indication of the areal extent of elevated RCOPCs,
- Guide the selection of direct surface and possible future downhole measurement and sampling locations, and
- Provide data to determine radiological health and safety requirements for future field characterization activities.

The GWS was performed in accordance with the Work Plan and applicable radiological and industrial safety procedures, as supplemented by additional field guidance developed and applied as the project progressed.

The survey area was limited to a portion of the Site that had not been surveyed during the previous GWS in January 2001, the so-called “Tongue Area”, located south and east of the (then) existing fence line (Figure 2). At the time of the GWS, the site perimeter fence did not extend around the Tongue Area. Fencing was installed around the Tongue Area in June 2002. This disposal area reportedly contains materials from a nearby chemical facility may have included, warehouse debris, warehouse chemicals, PVC liquids and powder in containers (Norton Conservation Commission, 1980). There is ample evidence of the remains of the facility on the surface of the debris pile, which is from six to eight feet thick, and extends southeasterly 10 to 50 meters into the Chartley Swamp from the southeastern edge of the Shpack landfill.

Gamma detectors selected for this survey were chosen to provide gross detection of a broad spectrum of gamma energies. The GWS was performed using a Bicron Model G5 field instrument for detection of low-energy radiation (FIDLER). The Bicron was coupled to a Ludlum Model 2221 ratemeter with a lower level discriminator set just above electronic noise (i.e., open window). The FIDLER is sensitive to gammas from approximately 10 kilo electron volts (keV) to greater than 100 keV. This range of detectable gamma energies provided confidence that not only would suspected RCOPCs be detected, but also other gamma emitting radionuclides that may have been disposed at the Site. It should be noted that these detectors will only reliably detect gamma emitters located on or in close proximity to the land surface.

The Model 2221 ratemeters were connected to the TSC-1 data logger of a Trimble Pro XR GPS receiver. The ratemeters and GPS data logger were configured such that radiation count rate data was downloaded every two seconds to the datalogger. The GPS unit also collected
positioning data every second and stored this data in tandem with the count rate data. The GPS unit associated gamma readings with spatial locations by interpolating between the locations immediately preceding and following its receipt of a gamma reading. The GPS unit was operated such that positional accuracy was maintained to less than one meter.

Other survey support instrumentation included one Ludlum Model 3 ratemeter coupled to a Ludlum 43-5 alpha radiation detector; two Ludlum Model 3 ratemeters coupled to 44-9 beta/gamma radiation detectors; a Ludlum 2224 ratemeter coupled to a 43-89 alpha/beta radiation detector; a Bicron microrem exposure meter; and a Ludlum 2224-1 ratemeter coupled to a Ludlum 120 gas proportional alpha/beta radiation detector.

The results of the GWS are summarized in Section 5.1.

4.2 Geophysical Survey

A geophysical survey was conducted prior to and in conjunction with invasive site activities (e.g., collection of soil samples). The survey was conducted with two complimentary technologies:

- Multifrequency electromagnetic (EM) profiling, and
- Ground penetrating radar (GPR).

The purpose for this investigation was to aid invasive site activities in avoiding buried containers that might contain hazardous materials, both from the aspect of reducing the chances for an unintended release, and for the safety of investigative teams.

The EM survey was completed between May 1 and May 13, 2002, and preceded all invasive site activities. The EM survey utilized a Geophysical Survey Systems, Inc. (GSSI) GEM 300 profiler, which collected data at four different frequencies simultaneously (user selectable from 330 hertz (Hz) to 20,970 kilohertz (kHz). For each frequency, two components of the signal are recorded: the quadrature (a measure of the conductance of the soil beneath the transmitter/receiver array), and the in phase (sensitive to the presence of metallic objects). Data was collected at a rate of two readings per second in open, accessible areas, and at a lesser rate in portions of the site where maintaining a constant walking speed was impossible due to the necessity of traversing around or carefully over surface debris, thick vegetation, or swampy areas. Individual traverses were operated in a north-south orientation along the established site grid. The east-west separation between traverses was two meters.

GPR profiling was conducted between May 10 and June 27, 2002. The GPR survey was conducted with a GSSI Subsurface Interface Radar system 2 with a 500 megahertz (MHz) antenna. The 500 MHz antenna is an excellent choice for mapping shallow geologic structure and objects of environmental concern, as it is a high resolution antenna capable of penetrating from 6 to 12 feet under good geologic conditions. The effectiveness of a GPR survey and the amount of penetration of the radar signal is highly dependent on geologic conditions, particularly soil moisture content and grain size. Dry sandy soils are ideal, although GPR results can be satisfactory with moist soil conditions and some silt or clay content in local soils.
A total of 125 locations were screened during the GPR field program (not all locations were screened with GPR, [Section 4.3, below], as several locations were determined to be in areas with no landfilled materials). GPR profiling was conducted only at specific, prestaked grid locations where invasive activities were planned, and typically consisted of two or three parallel traverses, each three meters long and separated by 0.5 to 1.0 meter. The array of traverses at each location was centered on the desired location for the proposed exploration.

After completing the traverses at a proposed location, the geophysicist inspected the GPR recordings and selected four to six alternate locations where no obstructions were observable, including the prestaked location, if appropriate. Alternate locations were marked with temporary pin flags. Several locations were sometimes required because invasive activities were frequently impeded by the presence of cobbles or boulders, which are often not readily apparent on GPR recordings. These obstructions often caused refusal of the Geoprobe® rig, and necessitated moving to an alternate location.

The results of the Geophysical Survey are summarized in Section 5.2.

4.3 Soil Sample Collection

Soil samples were collected at 135 locations during the FSI with a direct push technology (DPT) system manufactured by Geoprobe®. Sampling began on May 14 and was completed on June 28, 2002. The Geoprobe® DPT system uses hydraulics to push a 4-foot long 2.5-inch diameter stainless steel sampling barrel into the subsurface soils, using the weight of the DPT rig and vibration from a rotary hammer to advance the drill string. An acetate sleeve is inserted into the sample barrel, which collects a 4-foot long column of soil as the casing is advanced. Although soil recovery is not always the full length of the sample barrel, particularly in dry granular materials, an adequate quantity of soil was nearly always recovered to characterize the soil column in the depth interval of interest. Portions of an exploration deeper than 4 feet were achieved by stringing one-inch diameter threaded steel rods onto the sample barrel. The Geoprobe® system is designed to collect soil samples and install small diameter monitoring wells to depths, under ideal conditions, up to 30 feet deep.

A total of 327 samples were collected during the field characterization study. Typically, one sample was collected from each 4-foot section, generally yielding samples from depths of 2 feet, 6 feet, 10 feet, 14 feet, etc., until native soil was reached. Native soil was found between a depth of 0 feet and approximately 16 feet at the site. One of the objectives of the site characterization was to fully penetrate the landfill materials to native soil, so that landfill thickness could be characterized. During the site characterization, the maximum depth achieved in order to fully penetrate the waste layer, was 18 feet.

Each sample was labeled and annotated with a unique sample identifier, the sampler’s name, the sampling date and time, the sample location and any comments. For each sample or related batch of samples, a sample chain-of-custody form was filled out. The samples were individually listed or batch listed (by chain of custody form number) in the Project Logbook. Samples awaiting shipment to the contract offsite laboratory were stored in a designated secure location. Original chain-of-custody forms remained with the samples to which they
applied throughout their life cycle and were annotated with the shipper’s tracking number during times when they were in transit.

The results of the soil sampling effort are summarized in Section 5.3.

4.4 Soil Core Scanning

Following removal of soil cores from the sample barrel, each core was scanned for gross beta/gamma count rate using a G-M detector. The scan included the full length of the core. Based on the results of the scan, the Field Operations Lead (FOL) selected samples for further analysis, including field gamma spectroscopy screening (Section 4.6) and offsite quantitative analysis (Section 4.7). Samples were selected from the section of each core that exhibited the highest instrument response.

4.5 Downhole Gamma Logging

At Geoprobe® locations, polyvinyl chloride (PVC) casings were inserted to the depth of the exploration, and downhole gross gamma measurements were collected at a 6-inch interval to the bottom of the exploration. These measurements used a CABRERA proprietary waterproof configuration consisting of a Bicron model G1 1” x 1” Nal detector system enclosed in a thin stainless steel casing coupled to a ratemeter/scaler. The system was used to measure gross gamma count rates over the full length of each casing, where practically achievable. This system is capable of reliably detecting unshielded gamma radiation in an energy range from approximately 60 keV to in excess of 1,000 keV. The logging results were used to select samples for on-site gamma analysis by the In-Situ Object Counting System (ISOCS®) (see Section 4.6).

The results of the Downhole Gamma Logging are summarized in Section 5.4.

4.6 Gamma Spectroscopy Field Screening Laboratory (ISOCS®)

Samples collected during the characterization program were screened in the field gamma spectroscopy screening laboratory prior to shipment to the offsite laboratory. Field laboratory analyses were performed using an ISOCS® system consisting of a reverse electrode high purity Germanium (HPGe) coaxial detector.

The on-site screening laboratory was used to estimate concentrations of discrete gamma-emitting radionuclides. The screening laboratory results were used for various purposes, including the selection of samples to be analyzed by alpha spectroscopy at the offsite analytical laboratory and for uranium accountability purposes to maintain criticality control. Samples analyzed using the on-site screening laboratory were not ground or dried prior to analysis. Therefore, the accuracy of screening results may be affected by non-homogeneous sample matrix and also by the presence of moisture in the samples. Offsite laboratory gamma spectroscopy analyses were performed following the drying and grinding of samples and, therefore, provide more accurate results. Appendix E presents the CABRERA Standard Operating Procedure for the ISOCS® system.
In the field screening laboratory, activity concentrations of certain radionuclides were estimated directly via their decay photons, while the activity concentrations of others were inferred via gamma-emitting progeny, assuming secular equilibrium. $^{238}$U activity concentrations were primarily inferred via progeny activity concentrations of Thorium-234 ($^{234}$Th) at the 63.3 keV energy line, assuming secular equilibrium. $^{235}$U activity concentrations were directly estimated via the 143.8 keV energy line and other lower yielding energy lines. The $^{235}$U 185.7 keV energy line has a considerably higher yield than that of the 143.8 keV energy line. However, there is a potential of interference between the 185.7 keV energy line and the 186.2 keV energy line of $^{226}$Ra. Due to this interference, the 185.7 keV energy line can only be used to estimate $^{235}$U concentration when there is very little $^{226}$Ra activity present. Given that $^{226}$Ra is a potential RCOPC on this site, the 185.7 keV line was not used to support the quantification of $^{235}$U activity concentrations.

The results of the on-site ISOCS® analyses are summarized in Section 5.5.

4.6.1 Performance of Sample Analyses

Screening laboratory sample analyses were performed using a shielded collimator to reduce the presence of background activity during sample analyses. A background sugar sample of a density equivalent to that of project samples was analyzed weekly and the results used for subtraction of remaining background activity. Typical sample count times were 15 minutes and accumulated spectra were analyzed and archived for future analysis.

4.6.2 ISOCS® Efficiency Modeling

An essential component of the screening laboratory measurement process using ISOCS® was to develop and apply a source geometry model of the sample being analyzed. The source geometry model comprises a description of the specifications of the type of sample being analyzed. This description includes:

- Sample geometry
  - Model geometries were developed assuming various sample container specifications (e.g., container quarter-full, half-full or full of soil).

- Uniformity of contaminant concentration in the sample geometry (i.e., homogeneous distribution).

- Elemental composition of the source term and its density
  - Models were developed using an assumed soil/matrix density.

This description is entered into the ISOCS® software, which uses this information to develop a mathematical model. The ISOCS® software uses the mathematical model in conjunction with an ISOCS® detector-specific characterization to estimate detection efficiency as a function of gamma energy for the model. The gamma spectroscopy software applies the
efficiency file to the spectroscopic data to calculate the concentration of each detected radionuclide.

4.7 Offsite Analytical Laboratory

Soil and water samples were sent to Paragon Analytics, Inc. (Paragon), of Fort Collins, Colorado, who performed radiological analyses on samples collected during the FSI. Paragon is a USACE-validated laboratory and is fully qualified to perform analyses required during this project. Analyses carried out at Paragon were completed in accordance with their Laboratory Quality Assurance Plan (LQAP) (Paragon, 2002) and are summarized in the following sections.

<table>
<thead>
<tr>
<th>Number of Samples</th>
<th>Test</th>
<th>Analytical Method</th>
<th>Media</th>
</tr>
</thead>
<tbody>
<tr>
<td>327</td>
<td>Gamma (canned)(soil)</td>
<td>901.1M</td>
<td>soil</td>
</tr>
<tr>
<td>33</td>
<td>$^{226}$Ra (emanation)(soil)</td>
<td>903.1M</td>
<td>soil</td>
</tr>
<tr>
<td>130</td>
<td>ISO U (soil)</td>
<td>ASTM D3972-90M</td>
<td>soil</td>
</tr>
<tr>
<td>34</td>
<td>ICP-MS Total U (water)</td>
<td>6020</td>
<td>water</td>
</tr>
<tr>
<td>34</td>
<td>$^{226}$Ra (water)</td>
<td>903.0</td>
<td>water</td>
</tr>
<tr>
<td>34</td>
<td>$^{226}$Ra (water)</td>
<td>904.0</td>
<td>water</td>
</tr>
<tr>
<td>34</td>
<td>$^{99}$Tc (water)</td>
<td>Elochrome/LSC</td>
<td>water</td>
</tr>
<tr>
<td>34</td>
<td>ISO U (water)</td>
<td>ASTM D3972-90M</td>
<td>water</td>
</tr>
<tr>
<td>34</td>
<td>Gamma spec (water)</td>
<td>901.1</td>
<td>water</td>
</tr>
<tr>
<td>34</td>
<td>Gross Alpha/Beta (water)</td>
<td>900.0</td>
<td>water</td>
</tr>
</tbody>
</table>

4.7.1 Soil Sample Analyses

(A) Gamma Spectroscopy

Paragon analyzed all samples (a total of 327) using gamma spectroscopy (Table 1, above). The results of these offsite laboratory analyses are summarized in Section 5.6.1.
(B) Alpha Spectroscopy

Paragon analyzed 130 of 327 samples for isotopic uranium using alpha spectroscopy (ISO U [soil]) (Table 1, above).

(C) Radium Analyses

Paragon analyzed 33 samples for radium-226 ($^{226}\text{Ra}$ [emanation][soil]) (Table 1, above).

(D) Waste Acceptance Criteria

Paragon analyzed 10 samples in support of shipping requirements and Envirocare of Utah’s Waste Acceptance Criteria (WAC) (Table 2, below). The Waste Acceptance Guidelines for Envirocare of Utah are included as Appendix F.

Envirocare's Clive, Utah site is a Resource Conservation and Recovery Act (RCRA) facility that is licensed by the State of Utah and the EPA to receive, possess, use, treat, and dispose of mixed radioactive materials. Envirocare's RCRA Part B permit authorizes the disposal of both characteristic and listed wastes meeting land disposal restrictions.

<table>
<thead>
<tr>
<th>Table 2: Chemical Waste Characterization Analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>• TCLP Pesticides</td>
</tr>
<tr>
<td>• TCLP Chlorinated Herbicides</td>
</tr>
<tr>
<td>• TCLP Volatiles</td>
</tr>
<tr>
<td>• TCLP Semi-volatiles</td>
</tr>
<tr>
<td>• RCRA Metals</td>
</tr>
<tr>
<td>• Hexavalent Chromium</td>
</tr>
<tr>
<td>• Total Extractible Hydrocarbons-Diesel</td>
</tr>
<tr>
<td>• PCBs</td>
</tr>
<tr>
<td>• Organophosphorous Pesticides</td>
</tr>
<tr>
<td>• Volatile Organics</td>
</tr>
<tr>
<td>• Semi-Volatile Organics</td>
</tr>
<tr>
<td>• pH</td>
</tr>
<tr>
<td>• Oil &amp; Grease</td>
</tr>
<tr>
<td>• Proctor Test</td>
</tr>
<tr>
<td>• Paint Filter Liquids Reactive Cyanide</td>
</tr>
<tr>
<td>• TCLP Standard</td>
</tr>
<tr>
<td>• TCLP ZHE</td>
</tr>
<tr>
<td>• Total Organic Halide</td>
</tr>
<tr>
<td>• Ignitability</td>
</tr>
<tr>
<td>• Pesticides</td>
</tr>
</tbody>
</table>

4.7.2 Water Sample Analyses

CABRERA did not install monitoring wells during the site characterization. However, ERM, the potentially responsible party (PRP) contractor conducting the Remedial Investigation, was given this task as part of their continuing field effort. ERM collected a total of 57 samples for chemical analyses between July 10 and July 22, 2002. These included 39 water samples (8 surface water samples and 31 groundwater samples), 8 sediment samples, and 10 soil samples. Selected surface water and groundwater samples (34 in all) were split with
CABRERA so that radiological, as well as chemical, analyses could be completed. Figure 5 shows the locations of wells and surface water/sediment sampling locations for the ERM sampling episode.

Surface water and sediment samples were taken at the same location. Sediments were collected with a 1-1/2-inch hand auger within the upper 1-1/2 feet of sediment. Soil samples were collected using a split spoon sampler that was advanced with a 10-pound sledgehammer. Groundwater samples were collected using a low-flow sampling device.

In addition, ERM dug a total of 10 test pits to depths below the water table. After the water levels in the pits had equilibrated and the sediment had settled, the two pits with the highest photoionization detector (PID) readings were sampled. Thirty-four water samples collected by ERM and split with CABRERA were submitted to Paragon for analysis by ICP-MS, $^{226}\text{Ra}$, $^{228}\text{Ra}$, Technetium-99 ($^{99}\text{Tc}$), ISO U, Gamma spectroscopy, and Gross Alpha/Beta as part of the site characterization process.

The results of the surface water and groundwater sampling are summarized in Appendix J.

4.8 $K_d$ Analysis

The Actinide Chemistry Group of the Nuclear Engineering Department at MIT performed $K_d$ analysis on ten soil samples representing collected at the site. The $K_d$ value, or distribution coefficient, for soil is a measure of how tightly a contaminant binds to soil particles, and is an excellent indicator of how a contaminant will behave in a leaching environment and how likely it is that contaminants will be transported by groundwater (or overland) flow.

The results of the $K_d$ analysis are included in Section 5.7.

4.9 Decontamination

All decontamination of field instruments, vehicles, and other equipment was performed in accordance with the SSHP. A summary of decontamination procedures for each major activity is included below.

4.9.1 Gamma Walkover Survey

Gamma detectors selected for this survey included a Bicron Model G5 field instrument for detection of low energy radiation (FIDLER). This instrument was coupled to a Ludlum Model 2221. At the end of the field survey, the equipment was carefully scanned, and surface smears were taken of the equipment surfaces that had come in contact with site soils. The smears were analyzed with a Ludlum Model 43-10-1 alpha/beta smear counter for clearance prior to removal of the equipment from the EZ and the results of those scans are on file with CENAE.

4.9.2 Geophysical Survey

Geophysical equipment for this survey included a GSSI GEM 300 profiler, and a GSSI Subsurface Interface Radar system 2 with a 500 MHz antenna. The equipment was scanned
for gross beta/gamma count rate using a G-M detector whenever equipment exited the EZ. Particular attention was paid to surfaces of the equipment that had come in contact with site soils. At the end of the field program, the equipment was carefully scanned, and surface smears were taken of the equipment surfaces that had come in contact with site soils. The smears were analyzed with a Ludlum Model 43-10-1 alpha/beta smear counter for clearance prior to removal of the equipment from the EZ and the results of those scans are on file with CENAE.

4.9.3 Geoprobe® Rig

Geoprobe® casings and sampling equipment were steam cleaned between sample locations to prevent cross-contamination between exploration sites. Steam cleaning was conducted at a decontamination pad bermed on all sides and covered with a double thickness of visqueen to collect rinsate waters. After each decontamination cycle, waters were collected and drummed, and are currently stored at the site, in the locked shed, as IDW. At the end of the field program, sampling equipment was carefully scanned, and surface smears were taken of the equipment surfaces that had come in contact with site soils. The smears were analyzed with a Ludlum Model 43-10-1 alpha/beta smear counter. Soil was removed from the tracks of the Geoprobe® rig, which was then steam-cleaned. After the rig had dried, surface smears were taken and analyzed. The results of those scans are on file with CENAE. The rig was then permitted to exit the EZ for transport off site.

4.9.4 Soil Sampling Equipment

Other soil sampling equipment, including mixing utensils and homogenizing bowls were also decontaminated between samples in accordance with the Sampling and Analysis Plan.

4.9.5 Demobilization

Upon completion of field activities, equipment inside the EZ was decontaminated, frisked and swiped prior to being cleared from the EZ. Records of these decontamination activities reside on file with CENAE. Expendable field items (e.g., gloves and tyvek suits) were bagged and drummed and are currently stored as described in section 7.0.
5.0 RESULTS

The results of the FSI are briefly presented below. Interpretation of the results, and their meaning relative to Site decommissioning, is not presented in this letter report, as such evaluations will be presented in subsequent planning documents as part of the CERCLA process. Appendix C contains selected annotated photographs taken during the field investigation.

5.1 GWS Survey Results

The results of the GWS from the current investigation were combined with the GWS conducted in January 2001. As mentioned previously, the most recent GWS was completed in the Tongue Area, along the southeastern portion of the site. Gamma contours are presented as Figure 6. Compared to other areas on the site, the Tongue Area did not exhibit elevated surface gamma emissions (i.e., surface gamma emissions were in the range of only 10,000 to 15,000 cpm). The origin of the materials in this area is from a chemical facility (see discussion in Section 4.1) and apparently is not underlain by radiological materials.

5.2 Geophysical Results

The results of the geophysical survey are included in Appendix G as quadrature and inphase contour maps, and as a table summarizing GPR survey activities. The four EM frequencies collected during the multifrequency EM survey were 330 Hz, 1290 Hz, 5070 Hz, and 19950 Hz. The EM contour maps show that broad areas of the site are underlain by buried (or partially buried) debris evident as anomalous "highs" and "lows" significantly different from general background EM conditions. Chain link fencing also produces, depending on frequency, significant EM interference.

Table G-1 (Appendix G) summarizes the 125 Geoprobe® locations that were screened with GPR to avoid potential buried obstructions. The combined EM and GPR investigations were successful in allowing investigators to avoid drilling through buried debris, as there were no known instances in which a drum or other piece of debris was penetrated by the Geoprobe® rig during the FSI.

5.3 Soil Sampling Results

The geology of the area consists of organic silt and glacial deposits overlying bedrock. Locally, the glacial overburden ranges in thickness from 15 to 25 feet and is overlain by organic deposits (peat) varying in thickness from 5 to 30 feet (ORNL 1981, Environmental Resources Management [ERM] 1993). Groundwater in the area is produced from both bedrock and surficial aquifers. Within the landfill, the depth of the water table is generally 5 feet or less (ORNL 1981).

Groundwater studies conducted as part of the remedial investigation for the site have determined that the direction of groundwater flow at the site is predominantly downward through the overburden, with the dominant lateral component of flow in the deep overburden and upper bedrock toward the southeast in the direction of Chartley Swamp. Hydraulic
Original includes color coding.
conductivities are estimated as 3.82 x 10^-3 centimeter per second (cm/s) in fill material, 8.42 x 10^-2 cm/s in organic silt and peat, 1.33 x 10^-2 cm/s in glacial sand and gravel, 6.40 x 10^-3 cm/s in glacial till, and 9.79 x 10^-4 cm/s in bedrock (ERM 1993).

As was mentioned in Section 4.3, 135 soil borings were completed during the field investigation and logged by a qualified geologist (Appendix H). The landfill thickness varied from 0 to 16 feet, and was generally thickest in the southwest portion of the property near the Attleboro Landfill (Figure 7). The soil from 0 to 10 feet typically included dark brown to black peat that was thickest in the central and south-central portion of the Site. Peat was generally absent along the northern, eastern, and southeastern portions of the site within approximately 50 to 100 feet of the property line. Occasionally, the peat was underlain by a clay layer two to eight inches thick, but more often, the peat graded abruptly to a fine to coarse sand with some silt and gravel, typical of glacial deposits in this area.

5.4 Downhole Gamma Logging Results

Downhole gamma logging was conducted to provide subsurface gross gamma count rate results as a function of depth. Downhole gamma logging was performed to provide data in support of soil sample analytical results. The results of the downhole gamma logging are presented on the soil boring logs included in Appendix H.

Summary statistics of downhole gamma logging results are as follows. The average of the downhole logging results recorded was 5,314 counts per minute (cpm); the standard deviation was 57,307 cpm; the maximum was 1E6 cpm; and the minimum was 42 cpm.

5.5 Gamma Spectroscopy Field Screening Laboratory Results (ISOCS®)

Samples were analyzed by the ISOCS® following standard QC procedures. Results were used for various purposes, including identification of samples to be submitted to Paragon for isotopic uranium analysis by alpha spectroscopy and also for purposes of supporting the Site criticality control program. Samples analyzed by the ISOCS® were then submitted to Paragon for gamma spectroscopy analysis. QA/QC checks on field data indicate that the data set met established criteria. Field screening laboratory results are summarized in Appendix I. Included in Appendix I are Table 1-1, ISOCS® Quality Control Comparison Results, and Table 1-2, ISOCS® Gamma Spectroscopy Results.

5.6 Offsite Analytical Laboratory Results

5.6.1 Soil Sample Analyses Results

CABRERA submitted 327 soil samples to Paragon for radiological analysis. All samples were analyzed using gamma spectroscopy, and 130 samples were analyzed using alpha spectroscopy. Analytical laboratory results for site RCOPC radionuclides in soil are summarized in Appendix J as Table J-1, Offsite Analytical Laboratory Results - Soil.

Summary statistics of the results in Table J-1 were calculated. The data presented in Table J-1 encompass both systematic and biased sample analysis results. The data were first sorted to
separate alpha and gamma spectroscopy results; then the average, standard deviation, maximum, and minimum values by analyte were calculated for the gamma spectroscopy results. The results for $^{235}\text{U}$, $^{238}\text{U}$, and $^{226}\text{Ra}$ gamma spectroscopy measurements are presented in Table 3 below. $^{238}\text{U}$ concentration results are inferred via $^{234}\text{Th}$ activity concentrations, assuming secular equilibrium. $^{226}\text{Ra}$ is only an RCOPC when collocated with uranium contamination. The alpha spectroscopy results for soil are not included here due to the potential inhomogeneity of the small sample aliquots used for alpha spectroscopy sample analyses and the potential deviant results those small aliquots may generate. The sorted tables used in the statistical analysis are included in Appendix J as Tables J-1A and J-1B.

### Table 3: Gamma Spectroscopy (Soil) Data Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Statistic</th>
<th>Result (pCi/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{238}\text{U}$</td>
<td>Average</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation</td>
<td>570</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>7500</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>&lt; MDC</td>
</tr>
<tr>
<td>$^{235}\text{U}$</td>
<td>Average</td>
<td>1.70</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>178</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>&lt; MDC</td>
</tr>
<tr>
<td>$^{226}\text{Ra}$</td>
<td>Average</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation</td>
<td>143</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>1600</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>&lt; MDC</td>
</tr>
</tbody>
</table>

5.6.2 Water Sample Analyses Results

In addition, during the sampling episode conducted by ERM between July 10 and July 22, 2002, of the 39 water samples (8 surface water samples and 31 groundwater samples), 8 sediment samples, and 10 soil samples that were collected, CABRERA received 34 water samples so that radiological, as well as chemical, analyses could be completed. The analytical laboratory results for site RCOPC radionuclides in water are summarized in Appendix J as Table J-2, Offsite Analytical Laboratory Results - Water.
A statistical analysis of the results was conducted and is presented as Table J-2. The data were first sorted to separate alpha and gamma spectroscopy results; then the average, standard deviation, maximum, and minimum values by parameter were calculated for alpha spectroscopy. The results of Gross Alpha, Gross Beta, $^{234}$U, $^{235}$U, and $^{238}$U alpha spectroscopy measurements are presented in Table 4 below. The gamma spectroscopy results for water are not included here because gamma spectroscopy is less sensitive for water analysis.

The Paragon data package, including Electronic Data Deliverables (EDD) and Adobe files, are also included as Appendix J.

5.7 $K_d$ Analysis Results

5.7.1 Definition

The soil distribution coefficient, $K_d$, is the ratio of the mass of solute species adsorbed or precipitated on the solids per unit of dry mass of the soil, $S$, to the solute concentration in the liquids, $C$. The distribution coefficient therefore represents the partition of the solute in the soil matrix and soil water, assuming that equilibrium conditions exist between the soil and solution phases. A linear Freundlich isotherm, which assumes complete reversibility of ion adsorption, has been extensively used to correlate the relationship between $S$ and $C$. The relation is:

$$S = K_d \times C$$

The transfer of radionuclides from the liquid to the solid phase or vice versa may be controlled by mechanisms such as adsorption and precipitation, depending on the radionuclides involved. The relationship may be used in analysis models to estimate the radioisotope concentration in soil and solutions. The dimensions of the distribution coefficient are given in units of length cubed per mass (l$^3$/M).

5.7.2 Literature Values of $K_d$

There are a variety of literature examples describing experimental distribution coefficients measured from adsorption conditions. These experimental $K_d$ values are not constant for soils but rather are dependent on the soil's physical and chemical characteristics. Soil properties affecting the distribution coefficient include the texture of soils (sand, loam, clay, or organic soils), the organic matter content of the soils, pH values, and the presence of competing cations and complexing agents.

The value of the distribution coefficient for a specific radionuclide in soils may range over several orders of magnitude under different conditions because of its dependence on the many soil properties. For this reason, the $K_d$ is an important input parameter to the RESRAD code, and a site-specific value, if available, should be used for risk assessment.
Table 4: Alpha Spectroscopy (Water) Data Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Statistic</th>
<th>Result (pCi/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Alpha</td>
<td>Average</td>
<td>8.2</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>&lt;MDC</td>
</tr>
<tr>
<td>Gross Beta</td>
<td>Average</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>143</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>&lt;MDC</td>
</tr>
<tr>
<td>(^{234}\text{U})</td>
<td>Average</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>118</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>&lt;MDC</td>
</tr>
<tr>
<td>(^{235}\text{U})</td>
<td>Average</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>&lt;MDC</td>
</tr>
<tr>
<td>(^{238}\text{U})</td>
<td>Average</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>&lt;MDC</td>
</tr>
</tbody>
</table>
5.7.3 Measurement Methodology

There are two common experimental techniques for the determination of $K_d$. These methods are the batch and column methods. The batch method was used to measure the distribution coefficient, $K_d$, under saturated equilibrium conditions for the Shpack soils collected.

Measurement of the distribution coefficient can be performed by the batch method with any radionuclide on any soil material or rock, independent of the porosity, brittleness, or other properties of the soil or rock. In most instances, the soil material or rock is continually agitated to facilitate mixing and contact.

The ASTM D4319 test method has been developed as a standard short-term batch method (ASTM 1992j) to measure the distribution coefficient under steady-state conditions. To demonstrate that a steady state is attained in this short-term test, each set of samples should be run minimally in triplicate. The soil solution mixtures in each contact tube should be gently agitated on a laboratory shaker/rotator for a minimum of 6 hours for every three-day portion of the contact period. The contact periods should be for a minimum of 3 days, and the longest could extend to 14 days or longer. The distribution ratio may be calculated from:

$$K_d = \frac{\text{mass of solute on the solid phase per unit mass of solid phase}}{\text{mass of solute in solution per unit volume of the liquid phase}}$$

5.7.4 Method for Determination of $K_d$

CABRERA selected the Actinide Chemistry Group of the Nuclear Engineering Department at MIT to perform $K_d$ analysis on soils present at the Shpack Site (Czerwinski 2003). A total of 10 soil samples were provided to the Actinide Chemistry Group for development of a $K_d$ at the Shpack Site based upon readily measured parameters. The analysis method for $K_d$ determination at the Shpack Site is presented in Appendix K, “Evaluation of Uranyl Speciation with Sediment from the Shpack Site”, (Czerwinski 2003).

Determination of $K_d$ using (Czerwinski 2002) requires knowledge of the Site soil pH and to a lesser degree the organic content of the soil. The ten soil samples obtained from the Site were sent to Paragon for analysis. The soil samples were analyzed for pH using EPA analysis method 150.1. Organic content was determined using standard ashing techniques. The average pH of soils from the Shpack Site was determined to be 6.8 with a range of 7.6 to 6.2. The soil samples were taken from across the site representing a cross section of expected pHs. The organic content of the soils ranged from 0.9 % to 36.6 % with an average of about 17 %.
5.7.5 Value of $K_d$

The MIT report and Paragon analyzed Site soil pH results are included in Appendix K and Appendix L, respectively. The bulk soil $K_d$, based on sediment containing 17.9% organic fraction in equilibrium with atmospheric carbonate for the ten soil pH samples is 20,950 cm$^3$/g. A $K_d$ range of 4,580 to 65,500 cm$^3$/g with an uncertainty of 14.3 % is indicated by (Czerwinski 2003).
6.0 QUALITY ASSURANCE

Quality Assurance (QA) and Quality Control (QC) measures were implemented as required in the Quality Assurance Project Plan (QAPP) (CABRERA, 2002a). QA measures performed during site activities included procedural compliance evaluations, review of survey documentation, and performance of duplicate radiological field measurements. Measurements were obtained to support the accuracy of data collected during site activities. Daily QC checks were made for the field instruments used, including radiation detectors and GPS units to determine if they were performing within acceptable parameters. Instrument calibration records were kept for review and inspection. QA/QC records and supporting documentation are included as Appendices D and I. A QA Summary Report for all site activities during the FSI is included as Appendix M.
7.0 CURRENT SITE STATUS

By mutual consent between the CABRERA and CENAE Project Managers, when CABRERA
demobilized, the trailers and portable toilet facility were removed from the site and telephone
and electric service were cancelled. Prior to departing the site, expendable field items (i.e.,
used gloves, boots, Tyvek oversuits, etc.), were collected in the EZ, bagged and/or drummed,
and placed in the shed located in the EZ. Site IDW was also placed in the shed. A door to the
shed was constructed and a sturdy lock was installed to deter vandalism. The main site gate
was locked prior to site departure.
8.0 REFERENCES


CABRERA 2002b  Final Site Safety and Health Plan, Focused Site inspection: Characterization Surveys for Radiological Contaminants of Concern, Shpack Landfill Superfund Site, Norton/Attleboro, Massachusetts, Cabrera Services, Inc., May 6, 2002.


NCC 1980  Compilation by Norton Conservation Commission of property deed and easement information; zoning classifications; aerial photograph analyses; geology, soil, and ground-water information; and, information from local citizens, Shpack Superfund Site, March 17, 1980.
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<th>Reference</th>
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<tr>
<td>Paragon 2002</td>
<td><em>Laboratory Quality Assurance Plan, Revision 6, March 8, 2002.</em></td>
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<tr>
<td>Shearer 1980</td>
<td><em>Report on Results of Analyses of Test Well Water at Attleboro Landfill Site, Shearer, D.R., March 10, 1980.</em></td>
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