Background Shallow Soil Summary Report

BMI Complex

and

Common Areas Vicinity

Basic Remediation Company
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Henderson, Nevada

Submitted to

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BACKGROUND SOIL SUMMARY REPORT

Basic Remediation Company
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Henderson, Nevada

Approvals:

JURAT: *I, Ranajit Sahu, hereby certify that I am responsible for the services described in this document and for the preparation of this document. The services described in this document have been provided in a manner consistent with the current standards of the profession and to the best of my knowledge comply with all applicable federal, state, and local statutes, regulations, and ordinances.*

LAB JURAT: *I, Ranajit Sahu, hereby certify that all laboratory analytical data was generated by a laboratory certified by the NDEP for each constituent and media presented herein.*

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JURAT: *I, Kirk J. Stowers, hereby certify that I am responsible for the services described in this document and for the preparation of this document. The services described in this document have been provided in a manner consistent with the current standards of the profession and to the best of my knowledge comply with all applicable federal, state, and local statutes, regulations, and ordinances.*

LAB JURAT: *I, Kirk J. Stowers, hereby certify that all laboratory analytical data was generated by a laboratory certified by the NDEP for each constituent and media presented herein.*

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ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of variance
bgs	Below ground surface
BMI	Basic Management, Inc.
BRC	Basic Remediation Company
CEC	Cation exchange capacity
CL	Concentration limit
DOE	U.S. Department of Energy
DQA	Data quality assessment
DVSR	Data validation summary report
Environ	Environ International Corporation
EPA	Environmental Protection Agency
ERM	Environmental Resources Management
GISdT	Guided Interactive Statistical Decision Tool
HSD	Honest Significant Difference
ICP	Inductively coupled plasma
IQR	Interquartile range
IRIS	Integrated Risk Information System
LCS	Laboratory control sample
MARLAP	Multi-Agency Radiological Laboratory Analytical Protocols Manual
MDC	Minimum detectable concentration
MDL	Method diction limit
mg/kg	Milligram per kilogram
MLE	Maximum likelihood estimation
MS	Mass spectroscopy
msl	Mean sea level
n	Sample size (number of samples)
Navy	U.S. Department of Navy
NBMG	Nevada Bureau of Mines and Geology
ND	Nondetect or censored
NDEP	Nevada Department of Environmental Protection
Neptune	Neptune and Company, Inc.

ACRONYMS AND ABBREVIATIONS (continued)

pCi/g	PicoCurie per gram
PQL	Practical quantitation limit
QC	Quality control
RPD	Relative percent difference
Site	BMI Common Areas and Complex
SOP	Standard operating procedure
SQL	Sample quantitation limit
STL	Severn Trent Laboratories, Inc.
Tetra Tech	Tetra Tech EM Inc.
TIMET	Titanium Metals Corporation
TOC	Total organic carbon
UCL	Upper confidence limit
UTL	Upper tolerance limit
USDA	U.S. Department of Agriculture
VSP	Visual Sampling Plan
Workplan	Background Soil Sampling Workplan
WRS	Wilcoxon rank sum

1.0 INTRODUCTION

This report documents the collection and evaluation of analytical data for background soil that are considered representative of background[1] conditions at the Basic Management, Inc. (BMI), Complex and Common Areas in Clark County, Nevada. For simplicity, the BMI Complex and Common Areas are hereafter referred to in this report as the "Site." The BMI Complex includes the Titanium Metals Corporation (TIMET) facility and other industrial facilities. The BMI Common Areas include former TIMET, Upper, and Lower Ponds (see the Workplan in Appendix A, Figure 1). The former TIMET and Upper Ponds occupy the southern portion of the BMI Common Areas, and the Lower Ponds occupy the northern portion of the BMI Common Areas.

The background soil data were collected in accordance with the "Background Soil Sampling Workplan for BMI Common Areas and Complex Vicinity" (Workplan) dated April 2005 (see Appendix A) (Environmental Resources Management [ERM] and Tetra Tech EM Inc. [Tetra Tech] 2005). The Nevada Division of Environmental Protection (NDEP) approved the Workplan with comments on May 27, 2005 (see comment letter from NDEP in Appendix A). The Workplan was prepared and implemented jointly by Basic Remediation Company (BRC) and TIMET, whose properties at the Site are located near each other and have similar geology and soil types. The general scope of work included the collection of soil samples from background areas upgradient of Site industrial areas and analysis of these samples for site-related metals, radionuclides, general chemistry ions, and soil characteristics.

This report summarizes the background soil investigation (Section 2.0), discusses statistical methods used on the data gathered during the investigation (Section 3.0), provides a summary

[1]The term "background" as used in this report is identical to the term used by Environ International Corporation (Environ) in its report of background conditions for the City of Henderson (Environ 2003) and is based on the U.S. Environmental Protection Agency's (EPA) Integrated Risk Information System (IRIS), which states, "Two types of background levels may exist for chemical substances: (a) Naturally occurring levels: Ambient concentrations of substances present in the environment, without human influence; (b) Anthropogenic levels: Concentrations of substances present in the environment due to human-made, non-site sources (e.g., automobiles, industries)."

and conclusions (Section 4.0), provides a statistical guidance (Section 5.0), and lists references used to prepare this report (Section 6.0). The project objectives, purpose, and site location and geographic setting are discussed below.

1.1 OBJECTIVES

The main objective of this study is the development of a representative background soil dataset that can be used to evaluate whether concentrations of site-related chemicals detected in Site soil samples statistically exceed concentrations of these chemicals in background soil. Soil samples were collected from three depth intervals at each sampling location: surface soil (0 to 0.5 foot below ground surface [bgs]) and two subsurface depths (4 to 6 and 9 to 11 feet bgs). The background soil study collected data for site-related metals, radionuclides, and anions. Soil characteristics data were also collected for soil texture, pH, conductivity, cation exchange capacity (CEC), salinity, total organic carbon (TOC), and percent moisture to evaluate whether the background soil sampling locations are representative of Site soil characteristics.

Specific goals and comparisons proposed for the background soils study included the collection of data

- From sampled soil units that are representative of Site soils;
- That form a sufficient sample population that can be used to support statistical comparison of on-site and background datasets;
- That are sufficient to form more than one background dataset, if required, based on statistical comparisons of data from different geologic settings (origins) and depths;
- That could be used to evaluate the comparability of background data collected during this study to data collected by Environ International Corporation (Environ) for the City of Henderson (Environ 2003); and
- That could be used to evaluate the comparability of soil originating from geologic units in the northern McCullough Range and the River Mountains.

1.2 PURPOSE

The purpose of the background soil study is to develop a data set to support the statistical comparison of Site and background datasets that will be used in evaluating Site conditions during future investigations. This document is intended to be a working document that provides a validated background dataset along with extensive statistical summaries of the data. Descriptive summary statistics and a variety of statistical plots are included in this document to facilitate future evaluations of Site data and Site-to-background data comparisons. Selection of statistical tests for future comparisons will depend on site-or project-specific objectives and conditions. The background data in this report are referred to as the "BRC/TIMET dataset."

1.3 SITE LOCATION AND GEOLOGIC SETTING

The Site is located in Clark County, Nevada, approximately 2 miles west of the River Mountains and 1 mile north of the McCullough Range (see Figure 1 of the Workplan in Appendix A). The Upper Ponds occupy the southern portion of the BMI Common Areas, and the Lower Ponds occupy the northern portion of the BMI Common Areas. According to the Nevada Bureau of Mines and Geology's (NBMG) 1965 geologic map of Clark County, Nevada, the River Mountains and northern McCullough Range consist of tertiary volcanic rocks including dacites and andesites (see Figures 1 and 1a). The land surface slopes from east to northwest from the River Mountains and from south to northeast from the McCullough Range. Near the Site, the surface topography slopes north toward the Las Vegas Wash.

Based on the U.S. Department of Agriculture's *Soil Survey of Las Vegas Valley Area, Nevada,* the following soil types are present in the vicinity of the Site (USDA 1985):

- Caliza (map units 184 and 187): This soil type represents the dominant soil type in the immediate vicinity of the Site. Unit 184 is a very gravelly sandy loam and a very deep soil formed from different types of rock that forms in alluvium. Unit 184 soil generally forms on slopes of 2 to 8 percent. Unit 187 is present (1) west of the unit 184 occurrences west of the Site along the western boundary of the BMI Complex

and transecting the northwestern Lower Ponds, and (2) south of the BMI Common Areas and southeast of the BMI Complex. This unit is similar to unit 184 except that it is "extremely cobbly" sandy loam. Unit 184 is primarily located downgradient of the River Mountains and McCullough Range, and unit 187 is located north of the McCullough Range and also in the areas east-northeast of the McCullough Range and west of the River Mountains.

- Caliza-Pittman-Arizo (map unit 182): This soil type is located in a thick band east of the Site and transects the southeastern most corner of the Upper Ponds. This soil type also occurs south and adjacent to an area of unit 184 along the southern boundary of the BMI Complex. This soil consists of approximately 60 percent Caliza, 20 percent Pittman, 15 percent Arizo, and 5 percent Nickel soils on side slopes of erosional fan units. Caliza is a very deep soil formed from different types of rocks on erosional fan remnants. Pittman is a moderately deep soil formed from different types of rock on exposed remnants of alluvial fan deposits. Arizo is a very deep soil formed from different types of rock in channels on slopes of 0 to 8 percent. Unit 182 is located in areas northeast and east of the McCullough Range as well as west of the River Mountains.

- Arizo (map units 112 and 117): These soils are in localized areas south and east of the Site and extend east of the Upper Ponds. They transect the Upper Ponds east of the Beta Ditch. Arizo is a very gravelly loamy sand/very gravelly fine sandy loam and a very deep soil that formed on recent alluvium and in channels from various types of rock. Arizo generally forms on slopes of 0 to 8 percent.

- McCarran (map unit 326): This soil type is located northwest of the Lower Ponds south of the Las Vegas Wash. McCarran is a fine sandy loam/very cobbly fine sandy loam and a very deep soil formed from limestone and lacustrine sediments (high gypsum content) on relict alluvial flats. generally on slopes of 0 to 8 percent.

- Caliza-Pittman (map unit 181): This soil type is located near the base of the McCullough range within 0.25 mile southwest of the BMI Complex and approximately 1.5 miles southwest of the Upper Ponds. This unit consists of approximately 50 percent Caliza, 40 percent Pittman, and 10 percent Arizo (see descriptions of these individual components above for map unit 182). The USDA soil survey describes unit 181 as "extremely stony fine sandy loams" formed on erosional or exposed remnants of alluvial fan deposits derived from various kinds of source rock. This unit is described as deep to moderately deep and well drained.

A soils map reproduced from the 2004 USDA Soil Survey Geographic database shows that the soil type classification for the Upper and Lower Ponds area proper is map unit 600, "slickens," a non-native soil type (artificial fill)(USDA 2004). This term is presumed to reflect the non-native material observed in the ponds, which were used for waste disposal. The soil type classification

for the BMI Complex is map unit 615, "urban land." Native soils underlying the slickens and urban land units are assumed to be consistent with soils shown in map units for the surrounding area (primarily map unit 184 and, to a lesser extent, map units 112, 117, 182, 187, and 326). The USDA soils map is presented in Figure 2 of the Workplan in Appendix A and is based on the 1985 USDA soils survey (USDA 1985). The northern McCullough Range is the primary source of materials upslope of the BMI Complex and the western hook of the Lower Ponds.

Based on the locations of the soil units relative to the McCullough Range and the River Mountains, the topographic slope, and the dendritic geomorphology of the soil units, it is likely that these soils formed on alluvium derived from the weathered volcanic rocks of the McCullough Range and River Mountains. The primary and secondary mineral assemblages in these source rocks would be the primary contributor to background concentrations of metals, radionuclides, and anions in native soils; therefore, based on the similarity in soil descriptions and common parent materials for these soils, units 112, 117, 181, 182, 184, 187, and 326 are expected to exhibit similar ambient chemical concentrations downslope from both ranges.

Parent materials for soils beneath the Site and surrounding areas are presumed to be the following:

Soil Unit	Source Material
112	McCullough Range and/or River Mountains (location-specific)
117	McCullough Range and/or River Mountains (location specific)
181	McCullough Range
182	McCullough Range and/or River Mountains (location specific)
184	McCullough Range and/or River Mountains
187	McCullough Range and/or River Mountains (location specific)
326	McCullough Range

The similarity of chemical concentrations in background samples collected from soils downslope of the McCullough Range and the River Mountains was statistically evaluated after collection and validation of analytical data for the background soil samples. Analytical data from both the BRC/TIMET and Environ studies were used in this evaluation. A discussion of this comparison is presented in Section 3.4 of this report.

2.0 SUMMARY OF THE INVESTIGATION

This section discusses the sampling locations, procedures, analysis, and summarizes the results of data validation.

2.1 SAMPLING LOCATIONS

Soil samples were collected from 33 initial sampling locations on 11 undeveloped properties near and upgradient from the Site. Figures 1 and 2 in the Workplan in Appendix A show these 11 property locations as well as sampling locations for the 2003 Environ study.

The 11 properties and the sampling locations were selected because they exhibited the characteristics summarized below.

- They are off-site locations in relatively close proximity to the Site (see Figure 2 of the Workplan in Appendix A); however, they are upgradient and sufficiently distant from the Site so that impacts from Site operations are not likely.
- They are upwind of the Site (see wind direction plots indicating the predominant wind direction from the south and southwest in Table 2 of the Workplan in Appendix A) and thus unlikely to have been affected by aerial deposition of wind-borne dusts or vapors from Site operations.
- They are upslope of the Site and thus unlikely to have been affected by overland surface-water transport of potentially contaminated site sediments. The elevations of the background sampling locations are approximately 1,900 to 2,580 feet above mean sea level (msl), compared to the elevations of the BMI Common Areas (1,569 to 1,800 feet above msl) and BMI Complex (1,680 to 1,880 feet above msl).

Table 1 identifies the 11 properties, including sampling locations that represent the range of soil units found in the vicinity of the Site. Based on the information provided in Section 1.3, it is reasonable to assume that background soil samples collected from soil units 112, 117, 181, 182, 184, and 187 reflect background conditions for soils at the Site.

Table 1

Background Soil Sampling Locations

Property Area	Associated Mountain Range	Soil Unit from USDA Survey	Rationale for Inclusion in Data Pool
BRC-BKG-01 (A,B,C)[a]	McCullough	181	Unit comparable to units 182, 184, and 187 (Caliza-Pittman-Arizo and Caliza) found in the immediate vicinity of the Site.
BRC-BKG-02 (A,B,C)	McCullough	181	As above, unit comparable to units 182, 184, and 187
BRC-BKG-03 (A,B,C)	McCullough	181	As above, unit comparable to units 182, 184, and 187
BRC-BKG-04 (A,B,C)	McCullough	117	Unit found in the immediate vicinity of the Site.
BRC-BKG-05 (A,B,C)	McCullough	117	Unit found in the immediate vicinity of the Site.
BRC-BKG-06 (A,B,C)	McCullough	182	Unit found in the immediate vicinity of the Site.
BRC-BKG-07 (A,B,C)	McCullough	182	Unit found in the immediate vicinity of the Site.
BRC-BKG-08 (A,B,C)	McCullough	117	Unit found in the immediate vicinity of the BMI Common Areas and Complex.
BRC-BKG-09 (A,B,C)	McCullough	117 / 182 / 187	Units found in the immediate vicinity of the Site.
BRC-BKG-10 (A, B, C)[b]	--	--	--
BRC-BKG-11 (A,B,C)	McCullough	184	Predominant soil unit in the immediate vicinity of the Site.
BRC-BKG-12 (A,B,C)	McCullough/River	112 / 182 / 117	Units found in the immediate vicinity of the Site; location planned to augment Environ sampling in vicinity (downslope of the McCullough Range and River Mountains)

Notes:

a Represents three borings installed at each background property (BRC-BKG-01A, BRC-BKG-01B, and BRC-BKG-01C).

b Property BRC-BKG-10 was originally identified but was removed based on input from NDEP. The identification numbers for the remaining 11 properties were retained as originally defined.

2.2 SUMMARY OF SAMPLING PROCEDURES AND FIELD RESULTS

Soil samples were collected from three borings (A, B, and C) drilled approximately 10 to 15 feet apart at each of the 11 properties using a hollow-stem auger rig. Surface soil samples were collected by hand using a stainless-steel shovel. Subsurface samples were collected from the drill core. Samples collected from each boring at each of the 11 properties are considered independent samples. Table B-1 (Appendix B) provides a summary of the sample collection event. Sampling and sample handling procedures for both sampling methods were generally consistent with the standard operating procedures (SOP) developed for the BMI Common Areas as provided in Appendix C of the "Final Hydrogeologic Characterization Workplan" (MWH Americas, Inc. 2003). Exceptions to the SOPs are noted in Table B-1, Appendix B.

For this study, surface soil is defined as the upper 0.5 foot of the soil horizon, and subsurface soil is defined as soil below 0.5 foot bgs. Subsurface soil samples were collected from each 2-foot interval of drill core (from 4 to 6 and 9 to 11 feet bgs) and homogenized in a stainless-steel bowl. Sample aliquots were collected from this homogenized soil and submitted for analysis as follows:

- Surface Soil: 0 to 0.5 foot bgs
- Subsurface Soil: 4 to 6 feet bgs; core homogenized
- Subsurface Soil: 9 to 11 feet bgs; core homogenized

Three borings were advanced at all 11 property locations, and three samples from each zone were collected for an initial total of 99 soil samples. Field conditions required relocating borings at property location BRC-BKG-05 because the auger could not be advanced to the proposed depth. At property location BRC-BKG-05, four surface and subsurface samples were collected from three borings installed before the auger could no longer be advanced. A second attempt to drill three soil borings at property location BRC-BKG-05 was successful, resulting in several additional samples for a final total of 104 independent samples and 3 split samples for quality

control (QC). The original boring is denoted using BRC-BKG-05, and the relocated borings are denoted using BRC-BKG-05R. In a few cases, the sampling interval was modified slightly based on field sampling equipment or conditions. Table B-1 in Appendix B summarizes the site locations, boring identification numbers, sampling intervals, and field observations. The soil boring logs in Appendix B represent each location, and one soil boring log was prepared to represent all three borings (A, B, and C) at each property.

2.3 SAMPLE ANALYSIS

The soil samples were submitted for analysis to Severn Trent Laboratories, Inc. (STL), in St. Louis, Missouri. Analyses were conducted at three STL laboratory locations in St. Louis, Missouri; Burlington, Vermont; and Richland, Washington. At the time of sample analysis, all three STL locations were NDEP-certified laboratories for the analyses conducted. Surface and subsurface sample analytical parameters included a full suite of metals, anions (chloride, fluoride, sulfate, and nitrate and nitrite), and radionuclides. Table 3 of the Workplan in Appendix A summarizes the individual analytes, analytical methods, and practical quantitation limits (PQL). These analytes and methods are consistent with the BRC and TIMET site-related chemicals list and analytical program previously established for the BMI Common Areas project (BRC 2006) and the TIMET site (Tetra Tech 2004), with input from the NDEP. Background soil characteristics were further evaluated for soil texture, pH, conductivity, CEC, salinity, TOC, and percent moisture. Appendix C presents the analytical data summary tables and analytical data.

2.4 DATA VALIDATION SUMMARY

Two soil background datasets were validated: the BRC/TIMET and Environ datasets. Two types of data validation were conducted, full and partial validation. The TIMET project team chemist conducted the data validation for the BRC/TIMET dataset, which included 10 percent full validation and 90 percent partial validation. A project chemist with NDEP's contractor, Neptune and Company, Inc. (Neptune), conducted a partial data validation of the Environ dataset. The

data validation findings for the BRC/TIMET and Environ soil background datasets are summarized in the following sections.

2.4.1 BRC/TIMET Dataset

As stated above, full validation was conducted on 10 percent of the BRC/TIMET dataset, and a partial validation was conducted on the remaining 90 percent. Stable chemistry (metals and anions) results for background soil samples were validated in accordance with the U.S. Environmental Protection Agency (EPA) guidance documents "U.S. EPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review" and "Region 9 Superfund Data Evaluation/Validation Guidance" (EPA 2004b and 2001b). EPA has not standardized the validation of radionuclide data, so the reviewer relied on professional judgment and other sources for data qualification. Radionuclide data validation was conducted using several documents, including the EPA document "Multi-Agency Radiological Laboratory Analytical Protocols Manual (MARLAP)" (EPA 2004a), the U.S. Department of Energy (DOE) reference document titled "Evaluation of Radiochemical Data Usability" (DOE 1997), QC requirements and criteria summarized in the applicable methods.

Based on data validation and review, data qualifiers were added to the electronic BRC/TIMET background database to signify if the data were acceptable, acceptable with qualification, or rejected. When applicable, result bias is indicated. In addition, for every data validation qualifier, a secondary comment code was entered to indicate the reason for qualification. The data validation summary report (DVSR) in Appendix D provides the definitions for the data validation qualifiers and comment codes used in the BRC/TIMET background database. Validation qualifiers and definitions are based on those used by EPA in current data validation guidelines (EPA 2004b). Appendix C presents the electronic validated background database.

A number of sample results were qualified as estimated based on the following issues (corresponding to Tables 5 through 13 in the DVSR in Appendix D):

- Holding time exceedances
- Laboratory blank contamination
- Spike sample recoveries (including matrix spike and laboratory control samples [LCS])
- Duplicate precision
- Stable chemistry results less than the required reporting limit or PQL
- Interferences indicated by serial dilutions results (listed as other stable chemistry qualifications)
- Radiochemical results less than the required reporting limit
- Extra results from less sensitive analytical runs

Results qualified as estimated may generally be usable for the purposes of establishing background concentrations and for comparison to Site-specific sample data; however, a total of 22 soil sample results in the BRC/TIMET background database were rejected and qualified as "R." Rejected results are presented in Table 14 of the DVSR (provided in Appendix D). The rejected results include pH and radium-228. The pH result was rejected due to holding time issues. Specifically, the pH analysis for one sample was conducted past the extended holding time of 14 days. The effect of extended holding times on soil pH analysis is uncertain; therefore, the result was rejected. Radium-228 results were rejected because of high LCS recoveries and concerns that the results were biased high, confirmed by comparison of radium-228 results to inter-element correlations. The rejection of radium-228 data resulted in an insufficient number of points to evaluate the mixed sample origin (location BRC-BKG-12).

The data validation indicates that the valid (not rejected) BRC/TIMET background dataset as reported in this document (and provided in electronic format in Appendix C) is usable for the intended purposes. With 98.5 percent of the dataset validated as usable, the overall objective of the data collection event was met.

2.4.2 Environ Dataset

As stated above, a partial validation was conducted on the entire Environ dataset by Neptune (NDEP's consultant because the analytical reports provided by the laboratory (STL) were in a format that includes results and QC summaries only. No raw data, instrument calibration data, instrument reporting criteria, or internal standard data were presented for review by Neptune. Stable chemistry sample results for the Environ background soil samples were validated in accordance with the "U.S. EPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review" (EPA 2004b). Professional judgment and analytical method requirements were used to validate radionuclides data.

Based on data validation and review, Neptune prepared the validation summary memorandum included in Appendix D. The general conclusion is that the validated Environ dataset is suitable for inclusion in the overall soil background dataset based on data quality criteria with the provision that results for hexavalent chromium, radium-224, radium-226, and radium-228 in all samples not be used as discussed below.

The findings indicate that the hexavalent chromium results for the Environ dataset may not be accurate based on holding time exceedances. In this case, samples were analyzed 2 days after the 24-hour holding time (for a total of 3 days past sample extraction). It is recommended that the hexavalent chromium results in the Environ dataset be rejected and not used in the overall soil background dataset.

The Environ dataset for radium-224, -226, and -228 are considered suspect for several reasons, and their inclusion in the overall soil background dataset is not recommended. Specifically, it is unclear how the laboratory calculated the radioactivity of the radium-224 isotope. In addition, a lack of relevant QC information regarding radium-224 builds the case for rejection of results and exclusion of the results from the overall soil background dataset. Similarly, the radium-226 and

radium-228 results should be excluded from the overall soil background dataset. The quality control information, including barium yields, generally met the method requirements. However, recent data from STL St. Louis for these analytes indicated a bias due to the barium yields. It is likely that the barium yields in this data set do not include the radioisotope barium and may be subject to the same bias. The data is not rejected purely due to analytical considerations however the data should be used with caution. The NDEP recommended that this data be reevaluated or rejected. Since full data packages were not available for reevaluation, the data were rejected.

The data validation indicates that the Environ dataset as reported in this document is usable for the intended purposes except for the results for hexavalent chromium and the radium isotopes discussed above.

3.0 STATISTICAL METHODS

Exploratory data analysis and statistical evaluation of background soils data generally followed industry-standard guidance documents and sources from the technical literature (EPA 2000a and 2000b; U.S. Department of Navy 1999 and 2002; Gilbert 1987). These guidance documents discuss graphical presentation of data, selection and application of statistical test of hypotheses, calculation of summary statistics conduct of distributional testing, and treatment of censored (nondetect or ND) data. The following sections discuss data preparation, graphical presentations of data, calculation of descriptive summary statistics, and conduct of statistical tests and comparisons.

3.1 DATA PREPARATION

As discussed in Section 2.4 and Appendix D of this report, BRC/TIMET and Environ datasets were validated before the data were used in the statistical evaluation. All data (except outliers determined to be reporting errors, rejected (R-qualified) data, and QC data) were used in the statistical evaluation. The sections below summarize the details of data preparation.

3.1.1 Spatial Independence Assumptions

Thirty-three soil boring locations were sampled on 11 different properties for the BRC/TIMET data set.. The 33 soil boring locations are treated as spatially independent in this background soil study. The concentrations of each analyte at each sampling location and depth depend on the origin of the sediment and the composition of the parent material (except for anthropogenic deposition of analytes such as lead). Naturally occurring variability is associated with the deposition of sediments, and these variations may never be fully characterized and result in unexplainable data clusters. The naturally occurring variability may be impacted by sediment transport, leaching, weathering, and other geochemical processes within the alluvium; therefore,

when statistical tests are performed, it is expected that some spatial correlation may be seen, but the impact of this on the background evaluation is assumed to be negligible, and all sampling locations were therefore treated as independent in the statistical tests and calculations performed for this study.

3.1.2 Data Filtering and Combining Rules

Results from each of the two background analytical datasets were validated. Summaries of the validation of each dataset are presented in Appendix D. In order to prepare the datasets for statistical evaluation, results from each dataset were filtered so that each background soil sample had one result per analyte. The two datasets were then combined into one database. The following steps were taken to filter and combine the Environ and BRC/TIMET datasets into one.

1. Determined initial number of records in each set was determined. The BRC/TIMET dataset contained 11,268 records, and the Environ dataset contained 2,076 records.
2. All laboratory QC sample results were filtered out from both datasets.
3. All field duplicate and split sample results were filtered out from both datasets.
4. A field was added to the Environ dataset to include validation qualifiers consistent with BRC/TIMET qualifiers (only J, U, and R). Appropriate validation qualifiers were then added to the Environ dataset.
5. All rejected (R-qualified) results in both datasets were eliminated (21 individual results for the BRC/TIMET dataset and all hexavalent chromium, radium-224, radium-226, and radium-228 results in the Environ dataset).
6. The gamma spectroscopy-generated duplicate thorium-232 results (designated as Thorium-232DA) in the Environ dataset were filtered out. Results from isotopic thorium analysis were used instead.
7. Chemical names for both datasets were made exactly consistent.
8. Units for both datasets were made exactly consistent.
9. All records for the Environ dataset except for metals and radionuclides results (which originally included pesticides, herbicides, and dioxins/furans results) were filtered out.
10. For both datasets, pH results were filtered out because pH was not included in the statistical evaluations.

11. Percent moisture and cation exchange capacity results were filtered from the BRC/TIMET dataset because percent moisture and CEC were not included in the statistical evaluations.
12. The following fields were added to both datasets: Dataset (Environ or BRC/TIMET), Origin (McCullough, River, or Mixed), and Depth (0, 5, or 10).
13. Field names for both datasets were made consistent so that the datasets could be combined for statistical evaluation.
14. A final subset of fields was identified to conduct the data analysis. All other fields were eliminated. The remaining fields are listed below.

    - ID: Cross-referenced identification number for the data record in the combined dataset
    - Data Set: BRC/TIMET or ENVIRON
    - Origin: McCullough, River, or Mixed
    - Sample ID: Sample identification numbers
    - Location ID: Boring location identification numbers
    - Chemical: Standardized names consistent between datasets
    - Reported Result: Numerical concentration value and actual activity for radionuclides (or sample quantitation limit [SQL] for nondetect metals)
    - Qualifier: Standardized validation qualifiers (U, UJ, J, +, -)
    - Units: Standardized units
    - Rad Error: Two-sigma error for reporting results for radionuclides
    - PQL: Practical quantitation limit (included for comparison purposes only)
    - MDL: Method detection limit (term used by Environ; represents the SQL for BRC/TIMET data)
    - Depth: Single identifier in feet bgs (0, 5, 10)
15. Determined final number of records was determined. The BRC/TIMET dataset contained 8,091 records (representing 78 chemicals for 104 samples minus 21 individual rejected data points). The Environ database contained 608 records (representing 38 chemicals for

16 samples). Note that all results for radium 224, radium 226, radium 228, and Hexavalent chromium were rejected (101 results) and not counted in the final dataset.

16. For direct comparison of the BRC/TIMET and Environ datasets, any chemical analyzed in one study, but not the other, was not considered in the comparison.
17. For direct comparison of the McCullough Range versus River's datasets, any chemical analyzed in one area, but not the other, was not considered in the comparison.

After filtering and prior to final combination of the two datasets, a comparison table was prepared. Table 2 shows the comparison of analyte lists and detection frequencies between the two datasets for metals, anions, and radionuclides. Based on the information shown in Table 2, the observations summarized below were made.

- The BRC/TIMET dataset contains results for 43 metals and anions and 35 radionuclides, and the Environ dataset contains results for 23 metals and anions and 15 radionuclides.
- The sample size for the BRC/TIMET dataset is generally 104 results for each analyte (with a few exceptions). The sample size for the Environ dataset is generally 16 results for each analyte.
- When analyte results are available for both datasets, the detection frequencies were compared. Detection frequencies were notably different for antimony, cadmium, mercury, selenium, silver, thallium, bismuth-212, lead-210, thorium-234, and uranium-235.

Differences in detection frequencies were investigated by reviewing the analytical data to determine if apparent differences in methodology or level of quality may have produced the differences. The same laboratory performed the metals analysis for both background studies; however, a different analytical technique was used to measure the concentrations of antimony, cadmium, selenium, silver, and thallium. Inductively coupled plasma (ICP) was used to measure concentrations of these metals for the BRC/TIMET study, but ICP/mass spectroscopy (MS) was

TABLE 2
DATASET ANALYTE LIST AND DETECTION FREQUENCY

Metals and Anions	BRC/TIMET Dataset		Environ Dataset		Comments on Frequency of Detection and Analytical Differences
	Sample Size	Detection Frequency	Sample Size	Detection Frequency	
Aluminum	104	100.0%	16	100.0%	
Antimony	104	47.1%	16	0.0%	Due to difference in analytical technique; ICP versus ICP/MS
Arsenic	104	100.0%	16	100.0%	
Barium	104	100.0%	16	100.0%	
Beryllium	104	100.0%	16	100.0%	
Boron	104	32.7%	NA	NA	
Cadmium	104	0.0%	16	100.0%	Due to difference in analytical technique; ICP versus ICP/MS
Calcium	104	100.0%	NA	NA	
Chloride	104	69.2%	NA	NA	
Chromium	104	100.0%	16	100.0%	
Chromium Hexavalent	104	0.0%	NA	NA	
Cobalt	104	100.0%	16	100.0%	
Copper	104	100.0%	16	100.0%	
Fluoride	104	12.5%	NA	NA	
Iron	104	100.0%	16	100.0%	
Lead	104	100.0%	16	100.0%	
Lithium	104	100.0%	NA	NA	
Magnesium	104	100.0%	16	100.0%	
Manganese	104	100.0%	16	100.0%	
Mercury	104	74.0%	16	100.0%	Reporting limits are consistent; no comment
Molybdenum	104	100.0%	16	100.0%	
Nickel	104	100.0%	16	100.0%	
Niobium	104	0.0%	NA	NA	
Nitrate	104	86.5%	NA	NA	
Nitrite	104	4.8%	NA	NA	
Palladium	104	100.0%	NA	NA	
Phosphorus	104	100.0%	NA	NA	
Platinum	104	4.8%	NA	NA	
Potassium	104	100.0%	NA	NA	
Selenium	104	38.5%	16	75.0%	Due to difference in analytical technique; ICP versus ICP/MS
Silicon	104	100.0%	NA	NA	
Silver	104	0.0%	16	100.0%	Due to difference in analytical technique; ICP versus ICP/MS
Sodium	104	100.0%	NA	NA	
Strontium	104	100.0%	NA	NA	
Sulfate	104	77.9%	NA	NA	
Thallium	104	25.0%	16	100.0%	Due to difference in analytical technique; ICP versus ICP/MS
Thorium	NA	NA	16	100.0%	
Tin	104	99.0%	NA	NA	
Titanium	104	100.0%	16	100.0%	
Tungsten	104	0.0%	NA	NA	
Uranium	103	100.0%	NA	NA	
Vanadium	104	100.0%	16	100.0%	
Zinc	104	100.0%	16	100.0%	
Zirconium	104	100.0%	NA	NA	

TABLE 2 (Cont.)
DATASET ANALYTE
LIST AND DETECTION
FREQUENCY (cont.)

Radionuclides	BRC/TIMET Dataset		Environ Dataset		Comments on Frequency of Detection and Analytical Differences
	Sample Size	Detection Frequency	Sample Size	Detection Frequency	
Actinium-227	104	0.0%	NA	NA	
Actinium-228	104	100.0%	16	100.0%	
Bismuth-210	104	1.0%	NA	NA	
Bismuth-211	104	0.0%	NA	NA	
Bismuth 212	104	61.5%	16	25.0%	No apparent analytical difference
Bismuth-214	104	100.0%	16	100.0%	
Cobalt-57	104	0.0%	NA	NA	
Cobalt-60	104	0.0%	NA	NA	
Lead-210	104	1.0%	16	6.3%	No apparent analytical difference
Lead-211	104	0.0%	NA	NA	
Lead-212	104	100.0%	16	100.0%	
Lead-214	104	100.0%	16	100.0%	
Polonium-210	104	1.0%	NA	NA	
Polonium-212	104	61.5%	NA	NA	
Polonium-214	104	100.0%	NA	NA	
Polonium-215	104	0.0%	NA	NA	
Polonium-216	104	100.0%	NA	NA	
Polonium-218	104	92.3%	NA	NA	
Potassium-40	104	100.0%	16	100.0%	
Protactinium-234	104	0.0%	NA	NA	
Radium-223	104	0.0%	NA	NA	
Radium-224	104	100.0%	NA	NA	
Radium 226	104	92.3%	NA	NA	
Radium 228	84	81.0%	NA	NA	
Thallium-207	104	0.0%	NA	NA	
Thallium-208	104	100.0%	16	100.0%	
Thorium-227	104	0.0%	NA	NA	
Thorium-228	104	100.0%	16	100.0%	
Thorium-230	104	100.0%	16	100.0%	
Thorium-231	104	10.6%	NA	NA	
Thorium-232	104	100.0%	16	100.0%	
Thorium-234	104	61.5%	16	6.3%	No apparent analytical difference
Uranium 233/234	104	43.3%	16	100.0%	
Uranium 235	104	43.3%	16	56.3%	No apparent analytical difference
Uranium-238	104	100.0%	16	100.0%	

NA Not analyzed

used for the Environ study. This difference resulted in two apparent distinctions between the study results: (1) ICP alone is not as effective in isolating the analyte of interest and may be affected by spectral interference compared to ICP/MS, and (2) ICP alone has higher detection limits than ICP/MS. For antimony, ICP indicated detectable concentrations of antimony, whereas ICP/MS did not, even though the ICP detection limit is 10 times higher than the ICP/MS detection limit. The differences in antimony results may be due to spectral interference using ICP alone or differences in how vigorously the samples were digested (antimony has a tendency to volatilize during vigorous digestion). In the cases of cadmium, selenium, silver, and thallium, the higher detections in the Environ dataset seem to be attributable to the fact that the ICP/MS detection limit is 10 times lower (more sensitive) that that of ICP alone. In the case of mercury, no analytical differences are apparent that would account for the difference in detection frequencies.

The analytical methods and laboratory used for the radionuclides analyses were the same for both background studies. In addition, the minimum detectable concentrations (MDC) for the identified radionuclides were calculated on a sample-by-sample basis and do not account for the difference in detection frequency. No apparent analytical differences account for the difference in detection frequencies.

3.1.3 Treatment of Data Qualified as Nondetects

Treatment of censored or nondetect results for metals, anions, and other parameters generally followed EPA and Navy guidance (EPA 2000a, 2000b; Navy 1999, 2002). Treatment of radionuclide data qualified as nondetects followed DOE guidance (DOE 1997), which states that, for radionuclide activity data,

> "All of the actual values, including those that are negative, should be included in the statistical analysis. Practices such as assigning a zero, a detect limit value, or some in-between value to the below-detectable data point, or discarding those data points can severely bias the resulting parameter estimates and should be avoided."

For metals and anions, a value of one-half the reported SQL was used as a replacement value for nondetect data in the statistical calculations. Guidance documents discuss a range of replacement methods when the detection frequency is less than 85 percent; however, of the 43 metals and anions in the BRC/TIMET dataset, 28 were detected in at least 85 percent of the samples, 3 were detected in 50 to 85 percent of the samples, 7 were detected in less than 50 percent of the samples, and 5 were not detected in any sample. When detection frequencies fall below 50 percent, no replacement method works particularly well. For simplicity, the summary statistics and plots in this report were prepared using a simple substitution of one-half the SQL. This approach does not preclude use of other methods in future evaluations. The tables in Appendices E through G list the detection frequencies and descriptive summary statistics for the inorganic constituents. Specifically, Tables E-1 through E-5 in Appendix E list the detection rates and other information for the BRC/TIMET dataset, Tables F-1 through F-3 in Appendix F list this information for the Environ dataset and compare the Environ and BRC/TIMET data, and Tables G-1 through G-10 in Appendix G present the statistical summary for combined Environ and BRC/TIMET data.

For radionuclides, the actual reported activities (in picoCuries per gram [pCi/g]) were used in all calculations and plots as specified by DOE guidance (DOE 1997). The detection frequency based on data qualifiers was calculated and reported for all radionuclides in the tables of summary statistics. It is always critical to note and consider detection frequencies when assessing the data for each analyte. The tables of descriptive summary statistics in Appendices E, F and G include the minimum and maximum detected concentrations for radionuclides. When radionuclides are not detected (specifically, below the MDC), the actual measured activity (positive or negative) is reported.

3.1.4 Treatment of Field Duplicate and Split Sample Results

The heterogeneity of soils is typically sufficient so that field QC duplicate samples (co-located) are often handled as independent samples; however, split samples (taken from a single

homogenous mixture of the matrix) may be sufficiently similar so that the data should not be handled independently; therefore, the dataset used to construct the plots and summary statistics presented in this document contains data for the original samples only and not for the split samples. The BRC/TIMET dataset contained 107 samples (104 field samples and 3 split samples), so the descriptive summary statistics show a sample size of 104. The Environ dataset contained 17 samples (16 field samples and 1 split sample), so the descriptive summary statistics show a sample size of 16. The combined BRC/TIMET/Environ dataset includes a total of 120 samples.

Table E-6 in Appendix E presents relative percent differences (RPD) for the BRC/TIMET split samples. Although there are no validation rules for qualifying data based on duplicate/split sample results, RPDs between results can be used to evaluate the homogeneity of a given sample matrix. As a general rule, an RPD greater than 50 percent may indicate that the split sample is not homogeneous. Based on the RPDs presented in Table E-6, RPDs for boron, cobalt, copper, manganese, and fluoride in one or more split sample pair exceeded 50 percent. In the case of boron, the sample result was just above the reporting limit, and the split sample result was just below. For the remaining metals and anions, a review of the analytical data did not reveal any QC issues or miscalculations that would explain the differences. As such, the conclusion is that the matrix is not entirely homogenous for metals and anions. The radionuclide split sample results, with RPDs exceeding 50 percent, have one or both results at or below the MDC; therefore, the RPDs are not meaningful in determining the homogeneity of the matrix for radionuclides.

3.1.5 Identification and Treatment of Outliers

Outliers are measurements that are extremely large or small relative to the rest of the data, and therefore may not be representative of the population sampled (EPA 2000a). Outliers can be identified using formal statistical tests or by qualitative assessment methods, such as examination of graphical displays of the data. For this investigation, quintile probability plots and outlier box

plots were used to identify potential outliers for further investigation. If the potential outlier could not be confirmed to be a transcription or other verifiable error, statistical quantities were calculated with the outlier.

Two outliers were found in the dataset, which is not unusual for a set of this size (more than 8,600 records). Reporting errors were verified and then corrected in the database. One high-value outlier for uranium mass was identified when all uranium data were checked by converting the isotopic activity of uranium-238 to mass (uranium-238 constitutes more than 99 percent of the mass of naturally occurring uranium). This calculation yielded a mass of 2.4 milligrams per kilograms (mg/kg) for the outlier instead of the 7.6 mg/kg result reported by the laboratory. As a result of this calculation, the value of 7.6 mg/kg was excluded from the working dataset. A group of results for radium-228 were also rejected and excluded based on high bias.

A high-value outlier was noted for zinc (121 mg/kg). This outlier had no apparent cause or method for checking the outlier as there was for the high-value outlier for uranium. As a result, this outlier was retained.

3.1.6 Distributional Testing

The Shapiro-Wilk W test was used to test residuals from the parametric analysis of variance (ANOVA) conducted using the combined BRC/TIMET/Environ dataset. Tables G-9 and G-10 include results of the Shapiro-Wilk W test and provide a statistical comparison of metals, anions, and radionucides collected from background soil of different dept and geologic origin. A p-value less than or equal to 0.05 indicates that the null hypothesis of normality is rejected at the 95 percent confidence level.

The estimated underlying distribution of data, along with the detection frequency and sample size, was used to select the most appropriate statistical test for comparing background soil results from different depths and different origins. Parametric tests were selected when the detection frequency was 100 percent and when the Shapiro-Wilk W test indicated that the residuals

followed a normal distribution. Nonparametric tests were selected when censored (nondetected) measurements were present in one or more groups and for cases where when the Shapiro-Wilk W test indicated that the residuals did not follow a normal distribution.

The estimated distribution, detection frequency, and samples size will also be used to select the most appropriate statistical test for future Site-to-background concentration comparisons needed to meet various project-specific objectives.

3.2 STATISTICAL PLOTS

Statistical plots are used in exploratory data analysis to summarize particular characteristics or identify relationships within the data, evaluate goodness-of-fit to normal or other distributions, identify anomalous data points or outliers, and provide a general data overview. A number of different graphical presentations of the data were used in this background study, including frequency distribution, box-and-whisker, and individual value (location) plots. The preliminary data evaluation included both qualitative (graphical) and graphical and quantitative assessment methods. The BRC/TIMET data was summarized overall and by depth interval, and data was plotted for the various groupings. The BRC/TIMET data was compared to the Environ background data (Environ 2003) using the distribution, box-and-whisker, and individual value plots. In addition, the comparability of data collected from soils in the northern McCullough Range and River Mountains was evaluated. The following sections discuss the graphical analysis of the analytical data. Appendices F and G provide the statistical plots.

3.2.1 Distribution Plots

Frequency histograms, quantile probability plots, and box plots (see Section 3.2.2 were prepared for individual chemicals and data groupings (for example, discrete depth intervals and soil origins) to provide a qualitative summary of the data and to complement goodness-of-fit tests used to evaluate the underlying distribution of the data. Quantile probability plots are also useful for visually identifying outliers and for evaluating the potential presence of multiple populations

in the dataset. Multiple populations are typically identified by inflection points or by discrete clusters of measurements on the probability plots.

Normal probability plots are graphs of measurements, ordered from lowest to highest and plotted against a standard normal distribution function. The vertical axis is scaled in units of concentration (or activity in the case of radionuclides), and the horizontal axis is scaled in units of the normal distribution function (normal quantile). Data that are normally distributed will fall along the diagonal line in the plots of concentration versus the expected normal quantile,

Normal probability plots were created for each analyte and are grouped by dataset in the appendices identified below.

- BRC/TIMET dataset for all samples
  - Figure F-1, Appendix F
  - Figure G-1, Appendix G for BRC/TIMET analytes not included in Environ data
- Environ dataset for all samples (see Figure F-1 in Appendix F)
- Combined BRC/TIMET and Environ dataset
  - Figures G-1 and G-2, Appendix G, for all samples
  - Figures G-3 and G-4, Appendix G, by depth interval
  - Figures G-5 and G-6, Appendix G, by origin

This section discusses the probability plots for the BRC/TIMET data. Probability plots for the Environ dataset, the combined BRC/TIMET and Environ dataset, and data evaluated by origin and by depth are discussed in Section 3.4.

Normal probability plots were used to identify anomalous data points (outliers) and data clusters in the BRC/TIMET dataset. All anomalous data points and clusters were investigated further. Outliers identified from the probability plots are discussed in Section 3.1.5 and included (1) one datum for uranium that was excluded as an analytical error, (2)a group of results for radium-228 that were qualified as rejected and excluded based on high bias, and (3) one high value for zinc that was not excluded from the dataset.

Several data clusters are apparent on the probability plots for the combined data, indicating the potential for more than one population. For example, the probability plots for barium (see Figure F-1 in Appendix F) show a cluster of high values that correspond to samples from location BRC-BKG-12. The samples from location BRC-BKG-12 were reanalyzed for barium, but this approach confirmed the veracity of the original analysis, and inter-element correlations (see Section 3.4.5) did not provide further data insights. In addition, the plots for calcium (see Figure G-1 in Appendix G) show five high-value data points that do not correspond to any one sampling location, and the plots for lead (see Figure F-1 in Appendix F) include some higher concentrations in surface soil that are likely related to anthropogenic background concentrations. The plots also show a few high-value measurements for manganese (see Figure F-1), molybdenum (see Figure F-1), nickel (see Figure F-1), silicon (see Figure G-1), and strontium (see Figure G-1).

None of the five anions (chloride, fluoride, nitrate, nitrite, and sulfate) were detected in all samples, and only nitrate had a detection rate greater than 85 percent. As a result of the presence of a large proportion of nondetect values for anions, the probability plots (see Figure G-1) generally show two populations -- one of all nondetects and the other of all detected concentrations. The detected concentrations appear to constitute a single population for each anion.

Activities of all radionuclides (both measured and back-quantitated) were also plotted for all the BRC/TIMET data (see Figures F-2 and Figure G-2). The probability plots show a range of activities and generally suggest one population for each species. Unlike for some of the metals (such as lead), there does not appear to be anthropogenic enrichment of radionuclides in surface soils.; however, the study does not analyze for fission products (such as cesium or plutonium isotopes) that are typically referred to as “anthropogenic radionuclides.” Analysis for fission products was not done because they do not generally occur naturally and are not site-related chemicals (NAS 1971).

3.2.2 Box-and-Whisker Plots

Box-and-whisker plots provide a method for side-by-side comparison of data groupings or datasets. The box-and-whisker plots generated for this evaluation are outlier box-plots. Outlier box -plots display the full range of data as well as key summary statistics, such as the median, 25th and 75th percentiles (quartiles), and minimum and maximum values. A box-and-whisker plot consists of a box (rectangle) with lines. The length of the box is the interquartile range (IQR); therefore, the box represents the middle 50 percent of the data. The top and bottom of the box are the 25th and 75th percentiles of the distribution. The width of the box is arbitrary. The horizontal line across the middle of the box depicts the median value (the 50th percentile). The upper or lower whisker extends to the highest or lowest data value within the upper or lower) limit. Outliers are operationally defined as measurements that exceed the 75th or 25 percentile by 1.5 times the IQR.

Various data groups were examined using outlier box- plots. In Figures F-1 and F-2 in Appendix F, box-and-whisker plots for the BRC/TIMET data are presented alongside the plots for the Environ data. For each chemical and data set, box- plots of the data for individual depth intervals are provided along with probability and individual value plots for the combined depths.. Appendix G provides plots of the combined BRC/TIMET and Environ data (see Figures G-1 and G-2) and plots of the combined BRC/TIMET and Environ data by depth (see Figures G-3 and G-4) and geologic origin (see Figures G-5 and G-6).

The plots in Appendices F and G summarize data for more than 8,000 records. The plots are presented to (1) provide a comprehensive overview of the BRC/TIMET and Environ background soil datasets, (2) compare the BRC/TIMET background dataset to the Environ background dataset, and (3) compare the data for the combined BRC/TIMET and Environ dataset by depth and geologic origin.

3.3 DESCRIPTIVE SUMMARY STATISTICS

Descriptive summary statistics for metals, anions, and radionuclides were calculated for the BRC/TIMET dataset (see Appendix E), the Environ dataset (see Appendix F), and the combined BRC/TIMET and Environ dataset (see Appendix G). Descriptive summary statistics for each dataset were also prepared for each depth interval separately (indicated as 0, 5, and 10 feet bgs intervals for simplicity) and for the subsurface depths combined (data for 5 and 10 feet bgs intervals, if applicable). Statistical calculations were prepared using Neptune's "Guided Interactive Statistical Decision Tool" (GISdT) website for statistical analysis (Neptune 2006).

The descriptive summary statistics calculated for each analyte include the sample size and detection frequency; and for both censored and detected data, the minimum and maximum concentrations, the median, the mean, and the 25th and 75th percentiles (quantiles).

Table 2 summarizes the dataset analyte list and detection frequencies for the BRC/TIMET and the Environ background sample datasets. The following sections discuss the descriptive summary statistics for metals and anions, radionuclides, and other parameters.

3.3.1 Metals and Anions

Cadmium, hexavalent chromium, niobium, silver, and tungsten were not detected in any BRC/TIMET background soil sample. Antimony was not detected in any Environ background soil sample. Antimony, platinum, selenium, and thallium were detected in fewer than 50 percent of the BRC/TIMET samples. Mercury was detected in 74 percent of the BRC/TIMET samples and in all of the Environ samples and the other metals were detected in more than 85 percent of the samples. The comment column in Table 2 includes an explanation where analyte detection frequencies varied significantly between the BRC/TIMET and Environ results. Detection rates for anions in the BRC/TIMET samples ranged from 4.8 percent for nitrite to 86.5 percent for nitrate, with fluoride (12.5 percent), chloride (69.2 percent), and sulfate (77.9 percent) all having detection rates less than 85 percent.

3.3.2 Radionuclides

Activities for 35 radionuclides are reported for the BRC/TIMET dataset, including 22 from direct analysis and 13 that were back-quantitated from longer-lived members of the decay chain, assuming secular equilibrium. The back-quantitated results are designated by an "X" suffix in Table E-6 and more specifically described below. Activities for 15 radionuclides are reported for the Environ dataset. The same descriptive summary statistics for metals and anions are reported for radionuclides with one main difference -- for radionuclides, the actual reported activity is used for all statistical calculations and tests (no substitutions were made for results qualified as nondetections).

Radionuclides results may define a normal distribution around the value defined as calibrated background at the laboratory, even if the results are qualified as nondetect. This situation occurs because of the random nature of counting statistics and the decay processes. Although an MDC is reported by the laboratory and some results are qualified as nondetect, the actual results (including zero and negative results) are used in all statistical calculations. The data are reported as activity (not mass) in units of pCi/g, where a pCi is equal to 10^{-12} Curies and a Curie is defined as 3.7E10 disintegrations per second, the approximate specific activity of one gram of radium in equilibrium with its disintegration products.

Results for some radionuclides, especially the short-lived species, were back-quantitated from parents in the decay chain, assuming secular equilibrium. Secular equilibrium is radioactive equilibrium that occurs in a closed system when the half-life of the daughter is much less than that of the parent. Figures 2 through 4 show the three major decay chains for uranium-238, uranium-235, and thorium-232.

Radionuclides qualified as nondetect in all BRC/TIMET sample include cobalt-57, cobalt-60, protactinium-234, and thorium-227, along with all the species back-quantitated from these isotopes.

3.3.3 Other Parameters

Supporting parameters analyzed as part of the BRC/TIMET background study included soil texture (particle size analysis), conductivity, CEC, TOC, pH, and percent moisture. As is typical for desert soils, the pH values were slightly alkaline, ranging from about 8.0 to 9.3. Soil texture was dominated by sand and gravel size fractions as expected based on the USDA soil survey (USDA 1985). These soil data are summarized in Table C-4 in Appendix C. These parameters were not analyzed during the Environ study.

3.4 STATISTICAL TESTS AND COMPARISONS

The statistical methods described in EPA (2000a and 2000b) and Navy (1999 and 2002) guidance assume that the data were collected using random sampling and, that measurements are independent. The actual sampling locations for the BRC/TIMET study were selected randomly from accessible upgradient areas. Three borings were installed at each location, with the main selection factor being accessibility rather than judgment of the areas or bias in sample selection. Samples were systematically collected from discrete depth intervals of 0 to 0.5, 4 to 6, and 9 to 11 feet bgs from each boring. A few exceptions to these depths occurred were based on auger refusal during boring or sample retrieval success.

The main statistical problem was determining if the data form more than one population based on statistical comparisons of data from different settings, including (1) Environ and BRC/TIMET sampling locations; (2) sampling depth intervals (0 to 0.5, 4 to 6, and 9 to 11 feet bgs); and (3) soils derived from source materials in the northern McCullough Range and River Mountains. To answer these questions, the following groups of data were compared using statistical tests and statistical plots (see Section 3.2):

- BRC/TIMET and Environ dataset

- Combined BRC/TIMET/Environ dataset among depth intervals (0 to 0.5, 4 to 6, and 9 to 11 feet bgs)

- Data for soils derived from the River Mountains and the McCullough Range

Results are discussed below.

3.4.1 Statistical Hypothesis Testing

Statistical hypotheses are framed in terms of a null hypothesis (H_o) and an alternative hypothesis (H_A). For this study, the null hypothesis (H_o) was that the datasets were derived from the same population; therefore, rejection of the null hypothesis means acceptance of the alternative hypothesis (H_A), that the populations are different.

In setting up the hypotheses for testing, the tolerable limits on decision errors are specified on the basis of the consequences of making decision errors. There is always uncertainty when dealing with a sample from a population, so these limits can never be zero. Decision errors in statistical hypothesis testing may be described as Type I or Type II errors. In a Type I (false positive) error, the null hypothesis is rejected when in fact it is true. In a Type II (false negative) error, the null hypothesis is accepted when in fact it is false. To set these probability limits on decision errors, alpha (α, the level of significance) and beta (β, complement to the power) are defined below.

- $1-\alpha$ is the confidence level, whereas α is the significance level. So, at 95 percent confidence, α is set at 0.05.

- $1-\beta$ is the power of the test, whereas β is the complement to the power. So, at 80 percent power, β is set at 0.2.

Methods used to evaluate and compare the data groups for this investigation are summarized below.

Dataset	Distribution Plots	Box-and-Whisker Plots	Individual Value Plots	ANOVA plus Tukey HSD, or Kruskal-Wallis plus Behrens-Fisher
BRC/TIMET	X	X	X	
Environ	X	X	X	
Combined BRC/TIMET and Environ	X	X	X	
Combined BRC/TIMET and Environ – Depth Comparison	X	X	X	X
Combined BRC/TIMET and Environ – Geologic Origin Comparison	X	X	X	X

Note: HSD = Honest Significant Difference

Additional details and discussions of these lists may be found in standard statistical texts (Gilbert 1987, Zar 1998) and in EPA DOA guidance (EPA 2000a, 2006a)

Comparison of concentrations/activities among different depths and geologic origins was conducted for all chemicals in the combined BRC/TIMET and Environ dataset. The R statistical package was used to perform parametric and non-parametric ANOVA modeling and the corresponding post-hoc multiple comparison tests. Neptune conducted the analysis and provided the results to BRC/TIMET for further assessment.

The assessment of differences in concentrations and activities begins with examination of the descriptive summary statistics (see Tables G-1 through G-8 in Appendix G) and exploratory data analysis (see Figures G-3 and G-4) to facilitate interpretation of test results. Tables G-2 through G-4 present the descriptive summary statistics for comparison of data among depths. Figures G-3 and G-4 include the plots comparing data among depths. Tables G-6 through G-8 present descriptive summary statistics for comparison of data among geologic origins. Figures G-5 and G-6 include the plots comparing data among geologic origins. The exploratory data analysis plots contain distributional plots, box-and-whisker plots, and individual result plots for each chemical.

For comparison of data from each depth or geology origin, both the parametric ANOVA and the non-parametric Kruskal-Wallace test were used. ANOVA assesses differences in mean concentrations among groups, and the Kruskal-Wallace model looks for differences in the sum of the ranks among groups. Nondetect results were replaced with half the detection limit (the MDL was used for detection status) in the ANOVA model, and Gehan ranking was used to accommodate nondetects in the Kruskal-Wallace model. Activities are reported as actual values; therefore, there is no meaningful detection status for radionuclides.

Multiple comparison tests were performed for both the ANOVA and the Kruskal-Wallace models. For the ANOVA model, a Tukey Honestly Significant Difference (HSD) test was used for all pair-wise comparisons for the post –hoc multiple comparisons. For the Kruskal-Wallace model, a Behrens-Fisher multiple comparison test was used. The ANOVA model requires that the residuals be normally distributed. The Shapiro-Wilk W test was used to assess the normality of the residuals from the ANOVA model (see Tables G-9 and G-10). If Shapiro-Wilk W test results indicate that the normality assumption is reasonable (for example, a p-value > 0.05), then the ANOVA and Tukey HSD tests provide a reasonable assessment of differences among concentrations and activities; however, if the Shapiro-Wilk W test results indicate that the normality assumption may be unreasonable (for example, a p-value ≤ 0.05), then the Kruskal-Wallace and Behrens-Fisher results probably provide a better assessment of differences among concentrations and activities. Additionally, the nonparametric Kruskal-Wallace and Behrens-Fisher tests were selected when censored data were present in one or more groups. The shaded cells in Tables G-9 and G-10 indicate the results selected for test interpretation. When a minimum of four detected measurements was not applicable, statistical testing was not conducted.

One caveat about the Behrens-Fisher multiple comparison tests is the existence of some sensitivity to relative sample sizes. When there is a large discrepancy between the sample sizes among groups (that is, strongly unbalanced data), the power of the test is low. In these cases, the Kruskal-Wallace test may indicate a difference in concentration or activity, but the Behrens-

Fisher test may find no significant difference in any of the pair-wise comparisons. When there is a large discrepancy between sample sizes among groups, examination of graphical displays of the data are useful for interpreting test results declared significant by the Kruskal-Wallace test.

3.4.2 Comparison of BRC/TIMET and Environ Data

The BRC/TIMET and Environ datasets were evaluated to determine if they could be combined into one dataset for future consideration. Frequency histograms, normal probability plots, outlier box-plots, and individual value plots were used in quantitative or semi-quantitative comparison of the BRC/TIMET and Environ data (see Figures F-1 and F-2 in Appendix F). Besides the exceptions discussed below, much of the Environ data fall within the range of the BRC/TIMET data.

Differences were observed between the two data sets. Arsenic generally had higher concentrations in the BRC/TIMET samples than the Environ samples. Barium generally had higher concentrations in the Environ samples than the BRC/TIMET samples except for the sample from BRC/TIMET location BRC-BKG-12. Copper, magnesium, titanium, and vanadium generally had higher concentrations in BRC/TIMET samples from many locations.

Other differences between the BRC/TIMET and Environ datasets are summarized below.

- The BRC/TIMET dataset is considerably larger (n = 104) than the Environ dataset (n = 16).
- Environ did not analyze samples for anions, calcium, lithium, potassium, sodium, strontium, and others.
- The reporting limits differed between the two studies for some analytes (such as antimony, hexavalent chromium, and silver).
- The level of data validation between the two studies was inconsistent.
- The Environ dataset included invalidated data for radium-224, radium-226, and radium-228.

- Different analytical methods were used in the two studies.
- Sampling intervals differed. For example, the Environ sampling intervals were 0 to 1 and 3 to 4 feet bgs, and the BRC/TIMET sampling intervals were 0 to 0.5, 4 to 6, and 9 to 11 feet bgs.

Overall, the samples for the BRC/TIMET study appear to have captured a fair range of natural variability and heterogeneity and typically show a wider range of concentrations and activities than samples from the Environ study. Because the BRC/TIMET data span a broader geographic area and include 104 samples (compared to 16 samples for the Environ study), this outcome is not unexpected. The results of this analysis indicate that the BRC/TIMET and Environ datasets are generally comparable and can be combined for further statistical evaluation and comparison.

3.4.3 Comparison of BRC/TIMET/Environ Data by Depth Interval

As discussed in the Workplan (see Appendix A), soil samples were collected from three depth intervals for the BRC/TIMET background soil study: 0 to 0.5, 4 to 6, and 9 to 11 feet bgs. For the Environ study conducted for the City of Henderson, soil samples were collected from eight borings from 0 to 1 and 3 to 4 feet bgs.

Data for samples from each depth interval were compared using the statistical tests discussed in Section 3.4.1. Multiple population tests were selected and used to compare data among surface, middle, and deep soil samples. Table G-9 in Appendix G summarizes the results. Results that are statistically significant at the 0.05 significance level are shaded in the table. Frequency histograms, normal probability plots, outlier box-plots, and individual value plots presented in Figures G-3 and G-4 compare the data by depth interval and offer a visual qualitative or semi-quantitative assessment of differences for each analyte among the data groups. Statistical tests provide a quantitative analysis to determine if the differences are statistically significant at a specified level (for example, 0.05).

Table 3 summarizes the statistical comparison results for metals, anions, and radionuclides among the depths intervals for the BRC/TIMET/Environ background samples. The conclusions and recommendations for the dataset and the data subset use presented in Table 3 are based on further review and comparison of analyte plots and summary statistics, analytical methods, mineralogical considerations, and chemical characteristics (such as mobility).

Table 3

Summary of Statistical Comparison of Metals, Anions, and Radionuclides Among Depth Intervals for BRC/TIMET and Environ Background Soil Samples

Analyte	Statistical Differences Among Depths	Conclusions	Recommended Data Set Use
Metals (mg/kg)			
Aluminum	0>10	Differences attributed to naturally occurring sample variability	Combine data from all depths
Antimony	0>5	Differences attributed to analytical variability; all results near or below reporting limit	Combine data from all depths
Arsenic	None	No significant difference among depths	Combine data from all depths
Barium	None	No significant difference among depths	Combine data from all depths
Beryllium	None	No significant difference among depths	Combine data from all depths
Boron	None	No significant difference among depths	Combine data from all depths
Cadmium	None	No significant difference among depths	Combine data from all depths
Calcium	0<10	Differences between surface (0 foot) and combined subsurface (5 and 10 feet bgs) concentrations	Surface (0 foot), and combined subsurface (5 and 10 feet bgs)
Chromium	0>5, 0>10	Differences between surface (0 foot) and combined subsurface (5 and 10 feet bgs) concentrations	Surface (0 foot), and combined subsurface (5 and 10 feet bgs)

Analyte	Statistical Differences Among Depths	Conclusions	Recommended Data Set Use
Cobalt	None	No significant difference among depths	Combine data from all depths
Copper	None	No significant difference among depths	Combine data from all depths
Iron	0>5, 0>10	Differences between surface (0 foot) and combined subsurface (5 and 10 feet bgs) concentrations	Surface (0 foot), and combined subsurface (5 and 10 feet bgs)
Lead	0>5, 0>10, 5>10	Differences among surface (0 feet), mid-depth (5 feet bgs), and deep (10 feet bgs) concentrations due to anthropogenic sources	Surface, 5-foot-bgs subsurface, and 10-foot-bgs subsurface
Lithium	5<10	Differences attributed to naturally occurring sample variability	Combine data from all depths
Magnesium	0>5, 5<10	Differences attributed to naturally occurring sample variability	Combine data from all depths
Manganese	0>5, 0>10	Differences between surface (0 foot) and combined subsurface (5 and 10 feet bgs) concentrations	Surface, and combined subsurface (5 and 10 feet bgs)
Mercury	0>5, 0>10	Differences attributed to sample and analytical variability; many results below reporting limit	Combine data from all depths
Molybdenum	None	No significant difference among depths	Combine data from all depths
Nickel	0>5	Differences attributed to naturally occurring sample variability	Combine data from all depths
Palladium	0<5, 0<10, 5<10	Differences attributed to naturally occurring sample variability	Combine data from all depths
Phosphorus	None	No significant difference among depths	Combine data from all depths
Platinum	NA	Insufficient number of detected concentrations	Combine data from all depths
Potassium	0>5, 0>10	Differences between surface (0 foot) and combined subsurface (5 and 10 feet bgs) concentrations	Surface, and combined subsurface (5 and 10 feet bgs)

Analyte	Statistical Differences Among Depths	Conclusions	Recommended Data Set Use
Selenium	0>10	Differences attributed to analytical variability; all results near or below reporting limit	Combine data from all depths
Silicon	None	No significant difference among depths	Combine data from all depths
Silver	None	No significant difference among depths	Combine data from all depths
Sodium	0<5, 0<10	Differences between surface (0 foot) and combined subsurface (5 and 10 feet bgs) concentrations	Surface, and combined subsurface (5 and 10 feet bgs)
Strontium	0<5, 0<10, 5<10	Differences attributed to naturally occurring sample variability	Combine data from all depths
Thallium	None	No significant difference among depths	Combine data from all depths
Tin	0>5, 0>10	Differences attributed to analytical variability; all results near or below reporting limit	Combine data from all depths
Titanium	None	No significant difference among depths	Combine data from all depths
Uranium	0<10	Differences between combined surface and mid-depth (0 and 5 feet bgs), and 10-foot-bgs samples	Combined near-surface (0 and 5 feet bgs), subsurface (10 feet bgs)
Vanadium	None	No significant difference among depths	Combine data from all depths
Zinc	0>5, 0>10	Differences between surface (0 foot) and combined subsurface (5 and 10 feet bgs) concentrations	Surface, and combined subsurface (5 and 10 feet bgs)
Zirconium	None	No significant difference among depths	Combine data from all depths
Anions (mg/kg)			
Chloride	0<5, 0<10	Differences between surface and combined subsurface concentrations	Surface, and combined subsurface (5 and 10 feet bgs)
Fluoride	None	Insufficient number of detected concentrations	Surface, and combined subsurface (5 and 10 feet bgs)

Analyte	Statistical Differences Among Depths	Conclusions	Recommended Data Set Use
Nitrate	0<5, 0<10	Differences between surface and combined subsurface concentrations	Surface, and combined subsurface (5 and 10 feet bgs)
Nitrite	None	Insufficient number of detected concentrations	Surface, and combined subsurface (5 and 10 feet bgs)
Sulfate	0<5, 0<10	Differences between surface and combined subsurface concentrations	Surface, and combined subsurface (5 and 10 feet bgs)
Radionuclides (pCi/g)			
Actinium-227	None	No significant difference among depths	Combine data from all depths
Actinium-228	None	No significant difference among depths	Combine data from all depths
Bismuth-210	0>5, 5<10	Insufficient number of detected activities	Combine data from all depths
Bismuth-211	None	No significant difference among depths	Combine data from all depths
Bismuth-212	0<10	No differences among depths	Combine data from all depths
Bismuth-214	None	No significant difference among depths	Combine data from all depths
Cobalt-57	0>5, 5<10	Insufficient number of detected activities	Combine data from all depths
Cobalt-60	0<10	Insufficient number of detected activities	Combine data from all depths
Lead-210	0>5	Insufficient number of detected activities	Combine data from all depths
Lead-211	None	No significant difference among depths	Combine data from all depths
Lead-212	None	No significant difference among depths	Combine data from all depths
Lead-214	0<10, 5<10	Differences between combined surface and mid-depth (0 and 5 feet bgs), and 10-foot-bgs samples	Combined near surface (0 and 5 feet bgs), subsurface (10 feet bgs)
Polonium-210	0>5, 5<10	Insufficient number of detected activities	Combine data from all depths
Polonium-212	None	No significant difference among depths	Combine data from all depths
Polonium-214	0<10	No differences among depths	Combine data from all depths
Polonium-215	None	No significant difference among depths	Combine data from all depths

Analyte	Statistical Differences Among Depths	Conclusions	Recommended Data Set Use
Polonium-216	None	No significant difference among depths	Combine data from all depths
Polonium-218	0<10, 5<10	Differences between combined surface and mid-depth (0 and 5 feet bgs) and 10-foot-bgs samples	Combined near surface (0 and 5 feet bgs), subsurface (10 feet bgs)
Potassium-40	None	No significant difference among depths	Combine data from all depths
Protactinium-234	None	No significant difference among depths	Combine data from all depths
Radium-223	None	No significant difference among depths	Combine data from all depths
Radium-224	None	No significant difference among depths	Combine data from all depths
Radium-226	0<10, 5<10	Differences between combined surface and mid-depth (0 and 5 feet bgs) and 10-foot-bgs samples	Combined near surface (0 and 5 feet bgs), subsurface (10 feet bgs)
Radium-228	None	No significant difference among depths	Combine data from all depths
Thallium-207	None	No significant difference among depths	Combine data from all depths
Thallium-208	None	No significant difference among depths	Combine data from all depths
Thorium-227	None	No significant difference among depths	Combine data from all depths
Thorium-228	0>10	No differences among depths	Combine data from all depths
Thorium-230	0<10	Differences between combined surface and mid-depth (0 and 5 feet bgs), and 10-foot-bgs samples	Combined near surface (0 and 5 feet bgs), subsurface (10 feet bgs)
Thorium-231	None	No significant difference among depths	Combine data from all depths
Thorium-232	None	No significant difference among depths	Combine data from all depths
Thorium-234	None	No significant difference among depths	Combine data from all depths
Uranium-233/234	5<10	Differences between combined surface and mid-depth (0 and 5 feet bgs), and 10-foot-bgs samples	Combined near surface (0 and 5 feet bgs), subsurface (10 feet bgs)

Analyte	Statistical Differences Among Depths	Conclusions	Recommended Data Set Use
Uranium-235	0>5, 0<10, 5<10	Differences between combined surface and mid-depth (0 and 5 feet bgs), and 10-foot-bgs samples	Combined near surface (0 and 5 feet bgs), subsurface (10 feet bgs)
Uranium-238	0<5, 0<10, 5<10	Differences between combined surface and mid-depth (0 and 5 feet bgs), and 10-foot-bgs samples	Combined near surface (0 and 5 feet bgs), subsurface (10 feet bgs)

Notes:
bgs Below ground surface
mg/kg Milligram per kilogram
pCI/g PicoCurie per gram

Metals and Anions

Results of statistical tests comparing the BRC/TIMET metals data grouped by depth indicate that there are no significant differences for 15 of the 35 metals evaluated. Results for all comparisons by depths are summarized in Table 3. The conclusions and recommendations for data sets use are presented in Table 3 are based on a review of results from the statistical analysis as wells as other considerations. The results suggest that data from all depths can be combined for future statistical evaluation of 26 metals. Segregation of lead data by sample depth should be considered for future statistical evaluations. Concentrations of lead were higher at the surface and declined with depth, consistent with likely anthropogenic sources of lead. Metals such as lead that have a high "anthropogenic remobilization factor" (Salomons and Forstner 1984) show slightly elevated concentrations in surface soil compared to subsurface soil. This difference likely results from anthropogenic background, which differs from natural background, but is not site-related contamination. The concentrations of chromium, iron, manganese, potassium, and zinc are higher in surface soils than subsurface soils. Concentrations of calcium and sodium are lower in surface soils than subsurface soils. Segregation of data into surface (0 feet bgs) and combined subsurface (5 and 10 feet bgs) datasets should be considered for future use. Uranium concentrations were lower in surface and mid-depth soils (0 and 5 feet bgs) than in the 10-foot-bgs soils. Segregation of uranium data into surface and mid-depth (0 and 5 feet bgs) and 10-foot-bgs datasets should be considered for future statistical evaluation.

For anions with detection rates greater than 50 percent (chloride, nitrate, and sulfate), the comparisons show statistically significant differences between the surface and each subsurface interval but not between the two subsurface intervals. These results suggest that the two subsurface intervals can be combined and treated as a single population for future comparisons of site and background data but that surface soil data may be better treated as a separate group.

Radionuclides

Results of statistical tests comparing radionuclide activities among different sampling depths are presented in Table G-9 and summarized in Table 3. Results of statistical tests comparing data for BRC/TIMET radionuclides grouped by depths indicate that there are no significant differences for 20 of the 35 radionuclides evaluated. Two radionuclides; uranium-235 and uranium-238, showed significant differences among all depths, with the highest activities at 10 feet bgs.

Significant differences for uranium-238 and daughter product activities were found between 0 and 10, and 5 and 10 feet bgs. These results suggest that the data for uranium-238 and its daughter products can be pooled and treated as a single data set for the 0- and 5-foot-bgs depths, even though there are some statistical differences. The differences between the near-surface (0 and 5 feet bgs) and 10-foot-bgs soils should be considered when using uranium-235 and uranium-238 decay chain background data for future site comparisons.

For the remaining radionuclides, based on professional judgment, the differences are not significant enough to warrant the creation of separate datasets.

3.4.4 Comparison of McCullough Range and River Mountain Data for BRC/TIMET/Environ Dataset

The comparison of background data for the McCullough Range and the River Mountains included an evaluation of the soil types and geology of the two ranges and sample results from the BRC/TIMET and Environ background sampling locations. Several different soil types are mapped across the area as described in Section 1.3 of the Workplan (see Appendix A). The soil types observed downgradient from the McCullough Range and River Mountains are similar, which is expected because the geologic map indicates that similarly mapped rock units comprise the northern McCullough Range and River Mountains (see Figure 1). Because the main factors of soil formation (parent material, climate, topography, biota, and time) are the same for alluvial fans derived from both ranges, the concentrations of metals and the activities of radionuclides

should be comparable (Birkeland 1984). The comparability of anions was not evaluated because the Environ study did not include analyses for anions.

The combined BRC/TIMET/Environ data set was evaluated using frequency histograms, normal probability plots, outlier box-plots, and individual value plots to qualitatively or semi-quantitatively assess the comparability of metals and radionuclides data for areas downgradient of the McCullough Range and River Mountains (see Figures G-5 and G-6). Data for samples from each geologic origin were compared using the statistical tests discussed in Section 3.4.1. Multiple population tests were selected and used to compare data among the McCullough Range, River Mountain, and mixed soil samples (see Table G-10). Results that are statistically significant at a p-level of 0.05 are shaded in Table G-10.

BRC/TIMET sampling locations on properties BRC-BKG-1 through BRC-BKG-9 and BRC-BKG-11, and Environ sampling locations BG-01 through BG-03 are downgradient of the McCullough Range. The BRC/TIMET sampling location on property BRC-BKG-12 and Environ sampling location BG-04 are located in an alluvial fan area downgradient from both the McCullough Range and River Mountains. Environ sampling locations BG-05, BG-06, BG-07, and BG-08 are located downgradient from the River Mountains.

In summary, 33 locations were sampled on alluvial fan materials downgradient of the McCullough Range; 4 soil boring locations were sampled on combined alluvial fan materials from both the McCullough Range and River Mountains; and 4 locations were sampled on alluvial fan materials downgradient of the River Mountains.

Table 4 summarizes the statistical comparisons results for metals and radionuclides among geologic origins for the BRC/TIMET/Environ background samples. The table lists the analytes and summarizes statistical differences among geologic origins, if present. The conclusions and recommendations for dataset and data subset use in Table 4 are based on further review and

comparison of analyte plots and summary statistics, analytical methods, mineralogical considerations, and chemical characteristics (such as mobility).

In general, the box-and-whisker plots show that the heterogeneity of samples collected from the 31 locations downgradient from the northern McCullough Range encompasses the range of concentrations or activities detected at the four sampling locations on the mixed alluvial fan and the four sampling locations downgradient from the River Mountains.

Table 4

Summary of Statistical Comparison of Metals and Radionuclides Among Geologic Origins in BRC/TIMET/Environ Background Soil Samples

Analyte	Statistical Differences Among Depths	Conclusions	Recommended Data Set Use
Metals and Anions (mg/kg)			
Aluminum	Mc>Mx, Mx<R	Data range for Mc generally includes data range for Mx and R[1]	Combine data from all origins
Antimony	None	No significant difference among soil types	Combine data from all origins
Arsenic	Mc>R, Mx>R	Data range for Mc generally includes data range for Mx and R[1]	Combine data from all origins
Barium	Mc<R, Mc<Mx	Differences are unexplained	Mc, combined Mx and R
Beryllium	Mc>R, Mx>R	Data range for Mc generally includes data range for Mx and R[1]	Combine data from all origins
Boron	None	Insufficient number of detected concentrations	Combine data from Mc and Mx
Cadmium	None	No significant difference among soil types	Combine data from all origins
Calcium	Mc>Mx	Data range for Mc generally includes data range for Mx[1]	Combine Mc and Mx
Chromium	None	No significant difference among soil types	Combine data from all origins
Cobalt	Mc>R, Mx>R	Data range for Mc generally includes data range for Mx and R[1]	Combine data from all origins
Copper	Mc>R, Mx>R	Differences between combined Mc and Mx and R samples	Combined Mc and Mx, R

Analyte	Statistical Differences Among Depths	Conclusions	Recommended Data Set Use
Iron	Mc>R	Data range for Mc generally includes data range for Mx and R[1]	Combine data from all origins
Lead	Mc<R, Mc<Mx	Data range for Mc generally includes data range for Mx and R; R data set does not include deep (10-foot-bgs) samples[1]	Combine data from all origins
Lithium	None	No significant difference among soil types	Combine data from Mc and Mx
Magnesium	Mc>R, Mc>Mx	Data range for Mc generally includes data range for Mx and R[1]	Combine data from all origins
Manganese	None	No significant difference among soil types	Combine data from all origins
Mercury	Mc<R, Mx<R	Data range for Mc generally includes data range for Mx and R; many results below reporting limit[1]	Combine data from all origins
Molybdenum	Mc>R, Mx>R	Data range for Mc generally includes data range for Mx and R[1]	Combine data from all origins
Nickel	Mc>R, Mc>Mx	Data range for Mc generally includes data range for Mx and R	Combine data from all origins
Palladium	Mc>Mx	Data range for Mc generally includes data range for Mx[1]	Combine data from Mc and Mx
Phosphorus	Mc>Mx	Mc and Mx differ	Mc, Mx
Platinum	NA	Insufficient number of detected concentrations	Combine data from all origins
Potassium	None	No significant difference among soil types	Combine data from all origins
Selenium	None	No significant difference among soil types	Combine data from all origins
Silicon	None	No significant difference among soil types	Combine data from all origins
Silver	None	No significant difference among soil types	Combine data from all origins
Sodium	None	No significant difference among soil types	Combine data from all origins
Strontium	Mc>Mx	Data range for Mc generally includes data range for Mx[1]	Combine data from Mc and Mx
Thallium	Mx>R	Differences due to different detection limits from different analytical methods	Combine data from all origins
Tin	Mc>Mx	Data range for Mc generally includes data range for Mx[1]	Combine data from Mc and Mx

Analyte	Statistical Differences Among Depths	Conclusions	Recommended Data Set Use
Titanium	Mc>R, Mc>Mx	Data range for Mc generally includes data range for Mx and R[1]	Combine data from all origins
Uranium	Mc>Mx	Data range for Mc generally includes data range for Mx and R[1]	Combine data from all origins
Vanadium	Mc>R, Mc>Mx	Data range for Mc generally includes data range for Mx and R[1]	Combine data from all origins
Zinc	Mc>R	Data range for Mc generally includes data range for Mx and R[1]	Combine data from all origins
Zirconium	Mc>Mx	Mc and Mx may differ	Mc, Mx
Radionuclides (pCi/g)			
Actinium-227	None	No significant difference among soil types	Combine data from all origins
Actinium-228	Mc>R, Mc>Mx	Data range for Mc generally includes data range for Mx and R[1]	Combine data from all origins
Bismuth-210	None	No significant difference among soil types	Combine data from all origins
Bismuth-211	None	No significant difference among soil types	Combine data from all origins
Bismuth-212	Mc>R, Mc>Mx	Data range for Mc generally includes data range for Mx and R; many results below reporting limit[1]	Combine data from all origins
Bismuth-214	None	No significant difference among soil types	Combine data from all origins
Cobalt-57	None	No significant difference among soil types	Combine data from all origins
Cobalt-60	None	No significant difference among soil types	Combine data from all origins
Lead-210	Mc<R, Mx<R	Insufficient detected data to allow comparison	Combine data from all origins
Lead-211	None	No significant difference among soil types	Combine data from all origins
Lead-212	Mc>R, Mc>Mx	Data range for Mc generally includes data range for Mx and R[1]	Combine data from all origins
Lead-214	Mc>R, Mc>Mx	Data range for Mc generally includes data range for Mx and R[1]	Combine data from all origins
Polonium-210	None	No significant difference among soil types	Combine data from all origins
Polonium-212	None	No significant difference among soil types	Combine data from all origins

Analyte	Statistical Differences Among Depths	Conclusions	Recommended Data Set Use
Polonium-214	Mc>Mx	Data range for Mc generally includes data range for Mx and R[1]	Combine data from all origins
Polonium-215	None	No significant difference among soil types	Combine data from all origins
Polonium-216	Mc>Mx	Data range for Mc generally includes data range for Mx[1]	Combine data from Mc and Mx
Polonium-218	Mc>Mx	Data range for Mc generally includes data range for Mx[1]	Combine data from Mc and Mx
Potassium-40	Mc<R, Mc<Mx	Data range for Mc generally includes data range for Mx and R[1]	Combine data from all origins
Protactinium-234	None	No significant difference among soil types	Combine data from all origins
Radium-223	None	No significant difference among soil types	Combine data from all origins
Radium-224	Mc>Mx	Data range for Mc generally includes data range for Mx[1]	Combine data from Mc and Mx
Radium-226	Mc>Mx	Data range for Mc generally includes data range for Mx[1]	Combine data from Mc and Mx
Radium-228	Mc<Mx	Insufficient number of valid results for Mx and R	Combine data from all origins
Thallium-207	None	No significant difference among soil types	Combine data from all origins
Thallium-208	Mc>R	Data range for Mc generally includes data range for Mx and R[1]	Combine data from all origins
Thorium-227	None	No significant difference among soil types [1]	Combine data from all origins
Thorium-228	Mc>R, Mc>Mx	Data range for Mc generally includes data range for Mx and R[1]	Combine data from all origins
Thorium-230	Mc>Mx, Mx<R	Data range for Mc generally includes data range for Mx and R[1]	Combine data from all origins
Thorium-231	None	No significant difference among soil types	Combine data from all origins
Thorium-232	Mc>R, Mc>Mx	Data range for Mc generally includes data range for Mx and R[1]	Combine data from all origins
Thorium-234	Mc>R, Mc>Mx	Data range for Mc generally includes data range for Mx and R; many results below reporting limit[1]	Combine data from all origins
Uranium-233/234	None	No significant difference among soil types	Combine data from all origins

Analyte	Statistical Differences Among Depths	Conclusions	Recommended Data Set Use
Uranium-235	Mc>R, Mc>Mx	Data range for Mc generally includes data range for Mx and R; many results below reporting limit; R data set does not include any deep (10-foot-bgs) samples[1]	Combine data from all origins
Uranium-238	Mc>R, Mc>Mx	Data range for Mc generally includes data range for Mx and R; R data set does not include any deep (10[1]-foot-bgs) samples[1]	Combine data from all origins

Notes:

Mc = McCullough Range sample
Mx = Mixed McCullough Range and River Mountain sample
NA = Insufficient number of detected measurements to conduct tests
R = River Range sample
1 No known anthropogenic geological or geo-chemical differences to support the creation of more than one dataset.

Several exceptions to this generalization were noted. Barium concentrations appeared significantly greater in samples from BRC/TIMET location BRC-BKG-12a, b, and c (on material derived from both the River Mountains and the McCullough Range) and in samples from the Environ locations BG-05 through BG-08 (sampled fan materials derived from the River Range) than for samples collected from the other 31 locations. Data for other alkaline and alkaline-earth metals (calcium, lithium, potassium, sodium, and strontium) were evaluated for similar differences, but none were apparent. Concentrations of copper appeared to be generally but not consistently lower in the River Range than the McCullough Range and mixed soils samples. Concentrations of phosphorus and zirconium, which were not analyzed in the River Range samples (Environ), are generally but not consistently lower in the mixed soils than the McCullough Range soils samples. These differences should be considered when using these data for future comparisons.

Statistical differences shown by the multiple population tests for other metals and radionuclides were evaluated, but the results, were confounded by the disparity in sample size among origins as well as the high frequency of measurements at or near the reporting limit. The data range for the McCullough Range soil samples in these cases generally includes the data range for the River Mountains and the mixed soil samples. These results suggest that data from all origins can be treated as a single population for future comparisons of site to background data.

In summary, with the few exceptions described above, the concentrations of metals and activities of radionuclides in samples from the McCullough Range, the River Mountains, and mixed soils are comparable.

3.4.5 Inter-Element Correlations for BRC/TIMET Data

In addition to statistical tests and plots comparing data for soil samples from different depths, locations, and studies, the data were evaluated with respect to inter-element correlations. Correlations or “measures of association” are of interest because they offer another line of

evidence to distinguish background and non-background data (Navy 2002) or multiple populations of data.

Scatter plots with regression lines (and 95 percent confidence intervals for the regression) provide a visual assessment of inter-element associations, and calculated correlation coefficients provide a quantitative measure of the association. The plots in Appendix E show the data and the correlation coefficients for linear regression. EPA statistical guidance discusses several different types of correlation measures (EPA 2000a). Pearson's product-moment correlation coefficient was used and is the most common measure of association, although this calculation does assume a linear relationship and is sensitive to outliers.

Correlations between alkaline metals and alkaline-earth metals; aluminum and trace metals; silicon with selected metals; and radionuclide decay chain parent and daughter products were evaluated as summarized below.

Metals and Anions

Relationships were examined through the use of regression analysis and creation of scatter plots with regression estimates as a measure of the associations between alkaline metals and alkaline-earth metals; silicon with selected metals; and aluminum and trace metals. Selected plots are provided in Appendix E and discussed below.

Certain inter-element relationships are expected on the basis of geochemical behavior and expected mineralogical associations. For example, alkaline metals (such as lithium, sodium, and potassium) and alkaline-earth metals (such as barium, calcium, and magnesium) can be expected to behave similarly in solution and may therefore be expected to show an association in certain environmental media. Other metals are found in association in common minerals and show correlations in soils containing these minerals (such as feldspars; metal oxides such as hematite, goethite and pyrolusite; and carbonate minerals such as calcite). These associations are useful in

distinguishing soils derived from different source materials and in distinguishing site-related contamination from natural background.

The association of aluminum with trace metals was evaluated, and statistically significant associations were found for cobalt, chromium, nickel, copper, iron, manganese, phosphorus, titanium, and vanadium (see Appendix E). Trace metals such as cobalt, chromium, copper, nickel, and vanadium may occur as impurities in the common alumino-silicate family of minerals known as feldspars. Clays and other secondary aluminum minerals in soils may host sorption sites for trace metals, thereby associating these metals.

Strong inter-element correlations are normally expected between alkaline and alkaline-earth metals. A secondary population of samples with higher concentrations of barium resulted in poor correlations of barium with these and other analytes. The higher concentrations of barium in some samples, although greater than much of the BRC/TIMET background population, are not greater than the natural range for barium. As such, the barium results are accepted as background conditions because of the diligence used in the selection of sampling locations and the lack of known anthropogenic sources of barium. Correlations between most of the other alkaline and alkaline-earth metals are stronger, as expected. Table E-7 summarizes the correlation coefficients for alkaline and alkaline-earth metals.

A few samples contained silicon at concentrations at the high end of the range for most of the BRC/TIMET background soil samples. Whereas most samples contained about 300 to 1,400 mg/kg silicon, nine samples contained about 2,500 to 4,300 mg/kg silicon. Scatter plots of silicon versus several metals clearly show the cluster of high-silicon samples. Potassium is the only metal that shows a statistically significant correlation with silicon for all samples together or for the small cluster. Clay minerals and potassium feldspar contain potassium and silicon, so this association is expected; however, the lack of other metals (vanadium, aluminum, and iron) correlating with silicon suggests that most silicon is present as quartz. Despite this lack of

correlation, the range of silicon concentrations represents background conditions and should not impact the validity or use of the BRC/TIMET background dataset.

Radionuclides

Data for radionuclides in the thorium-232 and uranium-238 decay chains were evaluated for correlations of the parent and daughters within each decay chain. Relationships were examined through the use of regression analysis and creation of scatter plots with regression estimates as a measure of the associations.

Scatter plots with correlation analysis were constructed for radionuclides within the thorium-232 and uranium-238 decay chains and are included in Appendix E. Tables E-8 and E-9 summarize the correlation coefficients for radionuclides in the thorium-232 and uranium-238 decay chains. Species within the decay chains (parents and daughters) should show statistically significant correlations in most cases unless there are great differences in geochemical behavior and sufficient mechanisms to separate the species. The same generally holds true for radionuclides in the thorium-232 decay chain (actinium-228, bismuth-212, radium-228, thorium-228, and thallium-208). In general, most of the radionuclides in the uranium-238 decay chain (bismuth-214, lead-210, lead-214, protactitnium-234, radium-226, thorium-230, thorium-234, and uranium-234) did show statistically significant associations. Appendix E provides scatter plots of the correlation of radium-226 activities with lead-214, thorium-230, uranium-234, and uranium-238.

Scatter plots are also useful for showing outliers, such as the reported value of 7.6 mg/kg uranium in one sample, and for checking the accuracy of analytical results. For example, the measured activity (in pCi/g) for uranium isotopes should correlate directly with the measured mass (in mg/kg) of uranium. If the correlation coefficient for this relationship is calculated including the 7.6 mg/kg outlier, the correlation coefficient (r) is 0.153 and is not statistically significant. Without plotting the data, the reason for the poor correlation may not be obvious.

Excluding this outlier results in a statistically significant correlation coefficient of 0.519 (see Appendix E).

Another check of the accuracy of the analytical results for uranium isotopes is the comparison of uranium-234 and uranium-238 activities. Although uranium-238 constitutes more than 99 percent of the mass of natural uranium, uranium-234 is much more radioactive than uranium-238. This results in an activity ratio of 1 for uranium-234: uranium-238 in naturally occurring uranium. Regression analysis shows a strong relationship (r = 0.876) between the activities of these two uranium isotopes (see Appendix E).

4.0 SUMMARY AND CONCLUSIONS

The purpose of the BRC/TIMET background study was to collect and analyze background soil samples for metals and radionuclides to develop a background dataset for comparison to Site soil data. Sampling was conducted in 2005, and soil samples were analyzed to provide a large dataset considered representative of background conditions for future site-to-background data statistical comparisons. The specific goals of this study are outlined in the Workplan (see Appendix A). The goals of the background study were met, and a valid background dataset has been generated.

Samples were collected from 11 properties from 33 soil boring locations that represent the range of soils found in the vicinity of the Site. It is reasonable to conclude that the background samples collected reflect background conditions for Site soils based on sampling location characteristics information obtained from published documentation, site inspection, and sample collection.

A total of 104 independent soil samples were collected from the 33 borings for analysis. The TIMET project team chemist conducted data validation for the BRC/TIMET dataset that included 10 percent full validation and 90 percent partial validation. Results qualified as estimated based on the data validation are usable for the purposes of establishing background concentrations and for comparison to site-specific sample data. A total of 22 soil sample results (1.5 percent) were rejected. With 98.5 percent of the dataset validated as usable, the overall data collection objectives for the event were met.

Based on the Workplan, the minimum number of samples required to adequately characterize the chemistry of background samples was determined to be 24 samples from each depth interval, with a minimum of 72 samples. A sufficient sample of the population is available to support statistical comparisons of on-site and background datasets because at least 33 samples were collected from each depth interval and 104 samples were collected and analyzed. The dataset is

large enough to provide high levels of confidence and power in future Site-to-background statistical comparisons. The data can be used as one dataset or as subsets of several datasets depending on site-specific needs (such as surface soil analysis only). In addition to the analysis presented in Section 3.4, combining or separating the background dataset by depth for subsequent comparison with Site data will be influenced by potential exposures at varying depth ranges of a particular receptor – in other words, based on data usability considerations.

NDEP's contractor Neptune prepared a validation summary memorandum for the Environ background data set prepared for the City of Henderson (see Appendix D). The general conclusion is that the Environ dataset is suitable for inclusion into a soil background dataset; however, Environ dataset results for hexavalent chromium, radium-224, radium-226, and radium-228 should not be used.

The validated BRC/TIMET and Environ data were evaluated statistically using statistical plots, calculation of summary statistics, and statistical tests of hypothesis. Only two outliers were found in the BRC/TIMET dataset. One high-value outlier for uranium-238 was excluded from the working dataset. A high-value outlier for zinc was also noted but retained. Hexavalent chromium, radium-224, radium-226, and radium-228 results from the Environ dataset were excluded from statistical evaluation.

Normal probability plots and box-and-whisker plots were prepared to conduct comparison of BRC/TIMET data by depth intervals and location, comparison of BRC/TIMET and Environ data, and comparison of results for the combined BRC/TIMET/Environ dataset among depths and origins.

The statistical test of background soil sample data, based on location, suggest a number of statistically significant differences; however, because the data represent the range of background conditions at the site, there is no rationale for dividing the data into separate datasets based on location, soil origin, or study. The data are taken to represent the range of background

conditions of the site because (1) the analytes are naturally occurring; (2) samples were collected from soil materials derived from the same geologic source materials, exposed to the same weathering processes and in the same general vicinity; and (3) the sampling locations are not impacted by Site industrial activity or localized anthropogenic sources. In some cases, separate datasets may be used based on the statistical analysis results among depth intervals.

The following sections summarize the results for metals and anions, radionuclides, other parameters, comparison of BRC/TIMET and Environ data, comparison of BRC/TIMET/Environ data by depth intervals, and comparison of BRC/TIMET/Environ data by geologic setting.

4.1 METALS AND ANIONS

The BRC/TIMET data for naturally occurring metals and anions show a wide range of concentrations. The natural heterogeneity in soil chemistry reflects source material subjected to various soil-forming processes. Each BRC/TIMET sample was analyzed for a total of 43 metals and anions. Each Environ sample was analyzed for a total of 23 metals. No anions were analyzed in the Environ study.

4.2 RADIONUCLIDES

Activities for 35 radionuclides were reported for the BRC/TIMET study, including 22 from direct analysis and 13 that were back-quantitated. Activities for 15 radionuclides were reported for the Environ background study.

4.3 OTHER PARAMETERS

The BRC/TIMET background soil sample analyses included parameters such as pH, conductivity, TOC, and soil texture to provide additional insights into the comparability of soil samples collected from site and background areas or from different areas within a site. Because the concentrations of metals in solid media (such as soil and sediment) may be correlated with

grain size or TOC and because pH can radically affect the mobility of metals, collection and evaluation of data for supporting parameters may be used to assist in data evaluation.

4.4 COMPARISON OF BRC/TIMET AND ENVIRON DATA

The background soil samples for the BRC/TIMET study have a fair range of natural variability and heterogeneity; including as wide or wider range of concentrations as those found for the Environ background study. As such, the two data sets are not inconsistent with each other. Because the BRC/TIMET data span a broader geographic area and include 104 samples compared to 16 samples collected for the Environ study, this outcome is not unexpected. The results of this analysis indicate that the BRC/TIMET and Environ datasets are generally comparable and can be combined for further statistical evaluation and comparisons.

4.5 COMPARISON OF BRC/TIMET/ENVIRON DATA BY DEPTH INTERVAL

The results from comparison of the BRC/TIMET/Environ dataset among depth intervals suggest that data from all sampling intervals can be combined for future statistical evaluation for most metals; however, statistical evaluation and other considerations indicate significant differences for nine metals. The differences for lead likely result from anthropogenic background conditions, which differ from natural background conditions but which are not attributable to site-related contamination. Calcium, sodium, and uranium results indicate increasing concentrations with depth. Conversely, chromium, iron, lead, manganese, potassium, and zinc concentrations decrease with depth. These differences in surface and subsurface soil concentrations should be considered when using these background data for future comparisons.

Two radionuclides; uranium-235 and uranium-238 showed significant differences among all depths, with the highest activities at the 10 foot depth. The differences between the near surface (0 to 5 foot) and 10 foot depths soils should be considered when using uranium- 235 and uranium-238 decay chain background data for future site comparisons. For the remaining

radionuclides, based on professional judgment, the differences are not significant enough to create separate data sets.

4.6 COMPARISON OF MCCULLOUGH RANGE AND RIVER MOUNTAINS BACKGROUND DATA FOR BRC/TIMET/ENVIRON DATASET

The source rocks and soil types for the McCullough Range and River Mountains are similar, and the main factors for soil formation are the same for the alluvial fans derived from both ranges. The heterogeneity of the samples collected from alluvial fan materials from the northern McCullough Range generally encompass the range of concentrations found in the mixed alluvial fan locations and the River Range alluvial fan locations. Based on comparison of the BRC/TIMET/Environ dataset for areas downgradient from the McCullough Range and the River Mountains, with a few exceptions, the concentrations of metals and radionuclides in soil samples are comparable.

5.0 STATISTICAL GUIDANCE

Decisions on how best to use the background soils data for future Site-to-background comparisons will be made on a case-by-case basis. Exploratory data analysis using quantative statistical analysis and statistical plots will be conducted in all cases. Understanding the characteristics and structure of the data for each chemical in each data set is an important facet of exploratory data analysis. Statistical plots show how the site and background data sets compare with one another, and statistical plots such as normal probability and box-and-whisker plots are complementary illustrations of the data set that readily convey a large amount of information.

Guidance documents related to project planning and data collection as well as statistical evaluation and testing are available from the EPA and will be used in future studies.

6.0 REFERENCES

Basic Remediation, Inc. (BRC). 2006. "Site-Related Chemicals." Basic Remediation, Inc. (BMI) Common Areas Project. February 9.

Birkeland, P. 1984. *Soils and Geomorphology.* Second Edition. Oxford University Press.

Environ International Corporation (Environ). 2003. "Risk Assessment for the Water Reclamation Facility Expansion Site, Henderson, Nevada." Volume II, Appendices D and E. October 15.

Environmental Resources Management (ERM) and Tetra Tech EM Inc. (Tetra Tech). 2005. "Background Soil Sampling Workplan for BMI Common Areas and Complex Vicinity." April.

Gilbert, R.O. 1987. *Statistical Methods for Environmental Pollution Monitoring.* Van Nostrand Reinhold Company. New York, New York.

Hassig, N.L., and others. 2005. "Visual Sampling Plan Version 4.0 User's Guide." PNNL-15247. Pacific Northwest National Laboratory, Richland, WA. July.

Helsel, D.R. 1990. "Less than Obvious, Statistical Treatment of Data Below the Detection Limit." *Environmental Science and Technology.* 24(12): 1767-1774.

Helsel, D.R. 2005a. "Nondetects and Data Analysis." *Statistics for Censored Environmental Data.* John Wiley and Sons, Inc. Hoboken, NJ.

Helsel, D.R. 2005b. "More than Obvious: Better Methods for Interpreting Nondetect Data." *Environmental Science and Technology.* 39(20): 419A-423A.

Helsel, D. R., and R. M. Hirsch. 2002. "Statistical Methods in Water Resources." U.S. Geological Survey Techniques of Water Resources Investigations, Book 4, Chapter A3. On-Line Address: http://water.usgs.gov/pubs/twri/twri4a3/

MWH Americas, Inc.. 2003. "Final Hydrogeologic Characterization Workplan." BMI Site. Clark County, Nevada. December.

National Academy of Sciences (NAS). 1971. "Radioactivity in the Marine Environment." Report of the Panel on Radioactivity in the Marine Environment of the Committee on Oceanography. Washington, DC.

Neptune and Company, Inc. (Neptune). 2006. "Guided Interactive Statistical Decision Tool" (GISdT) Website for Statistical Calculations." On-line Address: http://www.neptuneandco.com/main/html

Nevada Bureau of Mines and Geology (NBMG). "Geology and Mineral Deposits of Clark County, Nevada." Bulletin 62. MacKay School of Mines. University of Nevada-Reno.

Nevada Division of Environmental Protection (NDEP). 2006. "Settlement Agreement and Administrative Order on Consent: BMI Common Areas." Phase 3. February 15.

Salomons, W., and U. Forstner. 1984. *Metals in the Hydrocycle.* Springer-Verlag, Berlin. Page 349.

Sheppard, C. R. C. 1999. "How Large Should My Sample Be? Some Quick Guides to Sample Size and the Power Of Tests." *Marine Pollution Bulletin*. 38: 439-447.

Tetra Tech. 2004. "Site-related Chemicals Technical Memorandum, Titanium Metals Corporation, Henderson, Nevada." Revision 3. October 13.

U.S. Department of Agriculture (USDA). 1985. *Soil Survey of Las Vegas Valley Area Nevada-Part of Clark County.* Soil Conservation Service. July.

U.S. Department of Energy (DOE). 1990. "General Environmental Protection Program." DOE Order 5400.1. Revision 1. Assistant Secretary for Environment, Safety, and Health. Washington, DC. On-line Address: http://www.eh.doe.gov/orders/o54001c1.pdf

DOE. 1997. "Evaluation of Radiochemical Data Usability." Office of Environmental Management. Oak Ridge, Tennessee. April.

U.S. Department of Navy (Navy). 1999. "Handbook for Statistical Analysis of Environmental Background Data."

Navy. 2002. "Guidance for Environmental Background Analysis. Volume I: Soil, NFESC User's Guide." UG-2049-ENV, NAVFAC. Washington, DC. April.

U.S. Environmental Protection Agency (EPA). 1989. "Methods for Evaluating the Attainment of Cleanup Standards. Volume 1: Soils and Solid Media." EPA 230/02-89-042. Office of Policy, Planning and Evaluation. Washington, DC. February.

U.S. Environmental Protection Agency (EPA). 2000a. "Guidance for Data Quality Assessment: Practical Methods for Data Analysis." EPA QA/G-9. July. EPA/600/R-96/084.

EPA. 2000b. "Guidance for the Data Quality Objectives Process." EPA QA/G-4. EPA/600/R-96/055. August.

EPA. 2001a. "Data Quality Objectives, Decision Error Feasibility Trials Software (DEFT) – Users Guide." EPA QA/G-4D. EPA/240/B-01/007. September.

EPA. 2001b. "Region 9 Superfund Data Evaluation/Validation Guidance." Draft. R9QA/006.1. Quality Assurance Office. San Francisco, CA. December.

EPA. 2002. "Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites." EPA 540-R-01-003. Office of Emergency and Remedial Response. Washington, DC. September.

EPA. 2004a. "Multi-Agency Radiological Laboratory Analytical Protocols Manual (MARLAP)." EPA 402-B-04-001A. Washington, DC. July.

EPA. 2004b. "U.S. EPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review." EPA 540/R-04/004. OSWER. Washington, DC. October.

EPA. 2006a. "Data Quality Assessment: Statistical Methods for Practitioners, EPA QA/G-9R." EPA/240/B-06/003. Office of Environmental Information, Washington, DC. February.

EPA. 2006b. "On the Computation of a 95% Upper Confidence Limit of the Unknown Population Mean Based Upon Data Sets with Below Detection Limit Observations." Prepared by A. Singh, R. Maichle, and S.E. Lee. EPA/600/R-06/022. March.

FIGURES

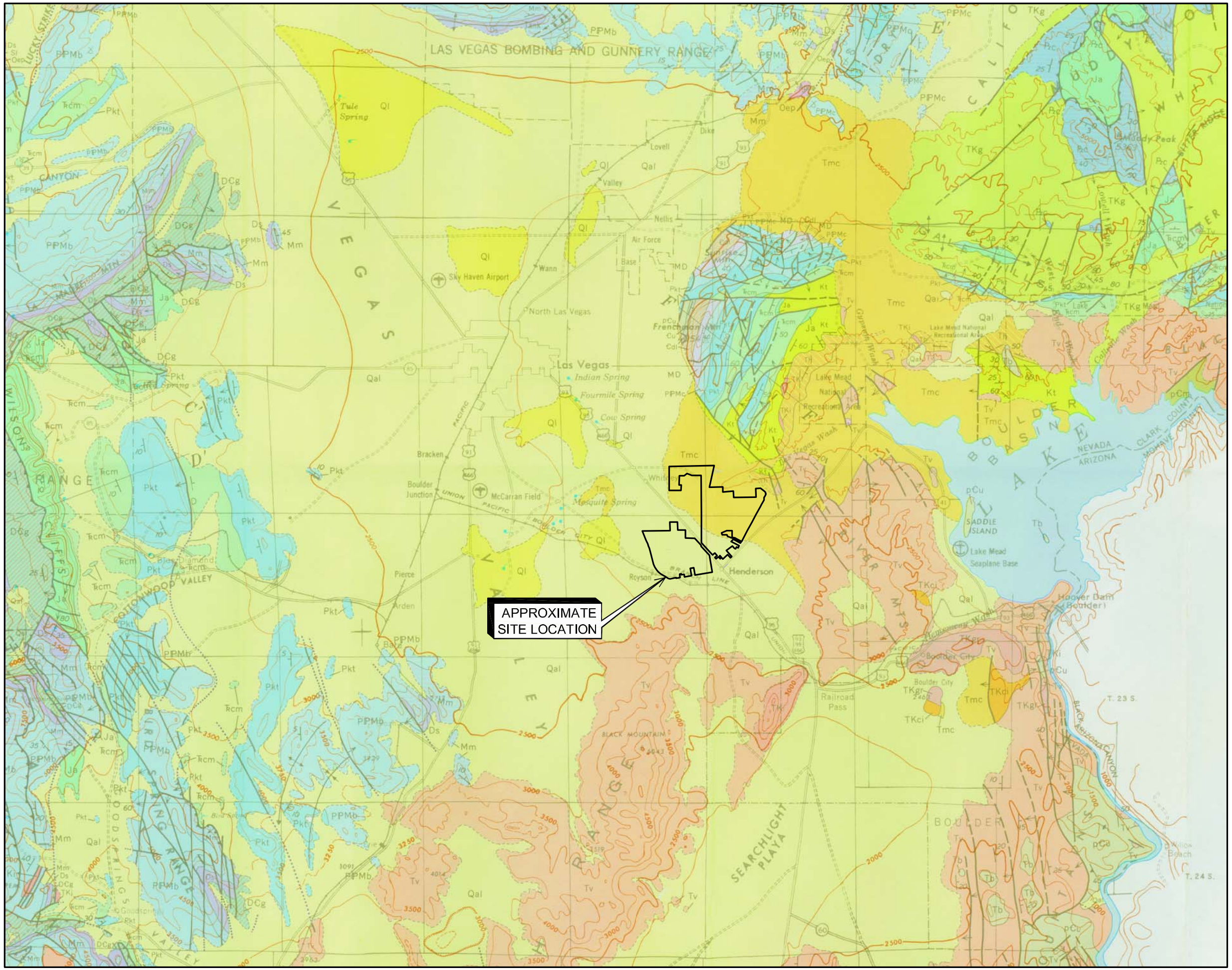
Includes:

Regional Geologic Map Legend (Figure 1A)

Uranium-238 Decay Chain (Figure 2)

Uranium-235 Decay Chain (Figure 3)

Thorium-232 Decay Chain (Figure 4)



0 1.5 3

SCALE IN MILES

NOTE: FOR REGIONAL GEOLOGIC MAP LEGEND, REFER TO FIGURE 1A.

SOURCE: GEOLOGIC MAP OF CLARK COUNTY, NEVEADA - C.R. LONGWELL, E.H. PAMPEYAN, AND BEN BOWYER.

Background Soil Summary Report
BMI Complex and Common Areas
Basic Remediation Company
Titanium Metals Corporation
Henderson, Nevada

FIGURE 1
REGIONAL GEOLOGIC MAP

TETRA TECH, Inc.

S:\Projects Directory\Private Sector - Houston\P3554 - TIMET\P0655 - Timet\CI Response 2004\No Further Action Requests\New Figure\Figure 1.dwg 05/09/2006 wxy,fegier DN

EXPLANATION

WESTERN CLARK COUNTY

PPMb — Bird Spring Formation (MISSISSIPPIAN, PENNSYLVANIAN AND PERMIAN; CARBONIFEROUS)

Mm — Monte Cristo Limestone (*Lower and Upper Mississippian*; MISSISSIPPIAN; CARBONIFEROUS)

Ds — Sultan Limestone (*Middle and Upper Devonian*; DEVONIAN)

Sl — Lone Mountain Dolomite
Found only in northern Spring Mountains and west of Dry Lake Valley (SILURIAN)

Oep — Ely Springs Dolomite, Eureka Quartzite, and Pogonip Group, undifferentiated
Eureka Quartzite, where present, shown as marker bed. Found only in northern Spring Mountains and west of Dry Lake Valley (*Lower, Middle, and Upper Ordovician*; ORDOVICIAN)

pCg — Goodsprings Dolomite
(Found only in the area west and southwest of Las Vegas) (CAMBRIAN TO DEVONIAN (?))

pCsj — Stirling Quartzite and Johnnie Formation, undivided (PRECAMBRIAN)

Ja — Aztec sandstone

Ŧcm — Chinle and Moenkopi Formations, undivided

EROSIONAL UNCONFORMITY

Pkt — Kaibab, Toroweap, and Coconino Formations, and red beds, undivided

Cdl — Dolomite and limestone, undivided (*Middle and Upper Cambrian*)

Cu — Quartzite, shale, and limestone, undivided
Includes Tapeats Sandstone, Wood Canyon Formation, Pioche Shale, Lyndon Limestone, Chisholm Shale, and Carrara Formation (*Lower and Middle Cambrian*; CAMBRIAN)

UNCONFORMITY

pCu, pCg, pCm — Precambrian rocks
pCu, *Precambrian rocks, undivided (mapped separately in the Virgin and South Virgin Mountains)*
pCg, *Gold Butte Granite of Longwell, 1936.*
pCm, *gneiss and schist.*
(PRECAMBRIAN)

CLARK COUNTY

Qal — Alluvium (QUATERNARY)

Ql — Las Vegas Formation

UNCONFORMITY

Tv, Tb — Volcanic rocks
Tv, *undifferentiated volcanic rocks.*
Tb, *Fortification Basalt Member of Muddy Creek Formation*

TKgr, TKi, TKci — Intrusive rocks
TKgr, *holocrystalline rock; mainly granite, quartz monzonite, granodiorite, and diorite*
TKi, *undivided porphyritic rocks. Includes granite porphyry, rhyolite, trachydolerite, and other intrusives ranging from basaltic to rhyolitic*
TKci, *undifferentiated intrusive rocks; mainly quartz monzonite and diorite containing roof pendants of volcanic rock, Paleozoic limestone and dolomite, and Precambrian rocks*
(CRETACEOUS(?) AND TERTIARY)

EASTERN CLARK COUNTY

Tmc — Muddy Creek Formation (*Pliocene (?)*; TERTIARY)

ANGULAR UNCONFORMITY

Th — Horse Spring Formation (TERTIARY)

TKg — Gale Hills Formation
Mapped only south of the Muddy Mountains (CRETACEOUS(?) OR TERTIARY(?))

TKo — Overton Fanglomerate (CRETACEOUS(?) OR TERTIARY(?))

Kt — Thumb Formation
Mapped only northwest of Boulder Basin. May be correlative with lower part of Gale Hills Formation (CRETACEOUS(?))

ANGULAR UNCONFORMITY

Kbu, Kbl — Baseline Sandstone
Kbu, *upper member.*
Kbl, *lower member* (CRETACEOUS)

Kwt — Willow Tank Formation (CRETACEOUS)

ANGULAR UNCONFORMITY

Pc — Paleozoic carbonate rocks, undifferentiated
Found only in Muddy Mountains

Pzt — Remnants of thrust plate
Paleozoic rocks of Pennsylvanian to Cambrian age. Found only in North Muddy Mountains

PPMc — Callville Limestone (PERMIAN; MISSISSIPPIAN, PENNSYLVANIAN AND PERMIAN; CARBONIFEROUS)

Mr — Rogers Spring Limestone (MISSISSIPPIAN; CARBONIFEROUS)

MD — Rogers Spring Limestone and Muddy Peak Limestone, undivided
Grouped only in Frenchman Mountain (DEVONIAN AND MISSISSIPPIAN; CARBONIFEROUS)

Dmp — Muddy Peak Limestone
Mapped only in Virgin and South Virgin Mountains (DEVONIAN; SILURIAN; ORDOVICIAN)

TRIASSIC JURASSIC(?)

SOURCE: GEOLOGIC MAP OF CLARK COUNTY, NEVADA - C.R. LONGWELL, E.H. PAMPEYAN, AND BEN BOWYER.

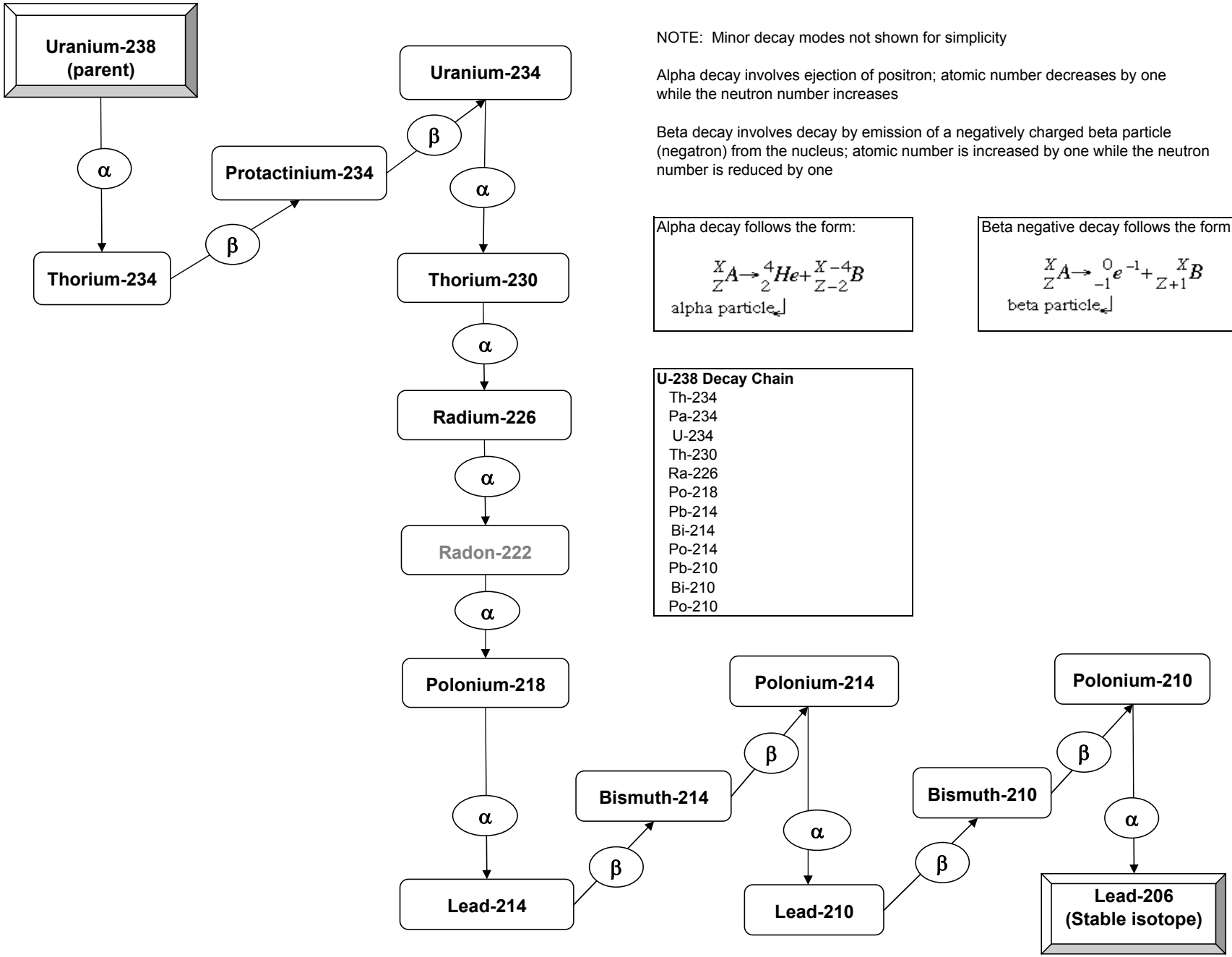
Background Soil Summary Report
BMI Complex and Common Areas
Basic Remediation Company
Titanium Metals Corporation
Henderson, Nevada

FIGURE 1A
REGIONAL GEOLOGIC MAP LEGEND

TETRA TECH, Inc.

S:\Projects Directory\Private Sector - Houston\P3554 - TIMET\P0655 - Time\ECI Response 2004\No Further Action Requests\New Figure\Figure 1A.dwg 05/09/2006 roy-fegter DN

FIGURE 2
URANIUM-238 DECAY CHAIN



NOTE: Minor decay modes not shown for simplicity

Alpha decay involves ejection of positron; atomic number decreases by one while the neutron number increases

Beta decay involves decay by emission of a negatively charged beta particle (negatron) from the nucleus; atomic number is increased by one while the neutron number is reduced by one

Alpha decay follows the form:

$$ {}^{X}_{Z}A \rightarrow {}^{4}_{2}He + {}^{X-4}_{Z-2}B $$

alpha particle

Beta negative decay follows the form:

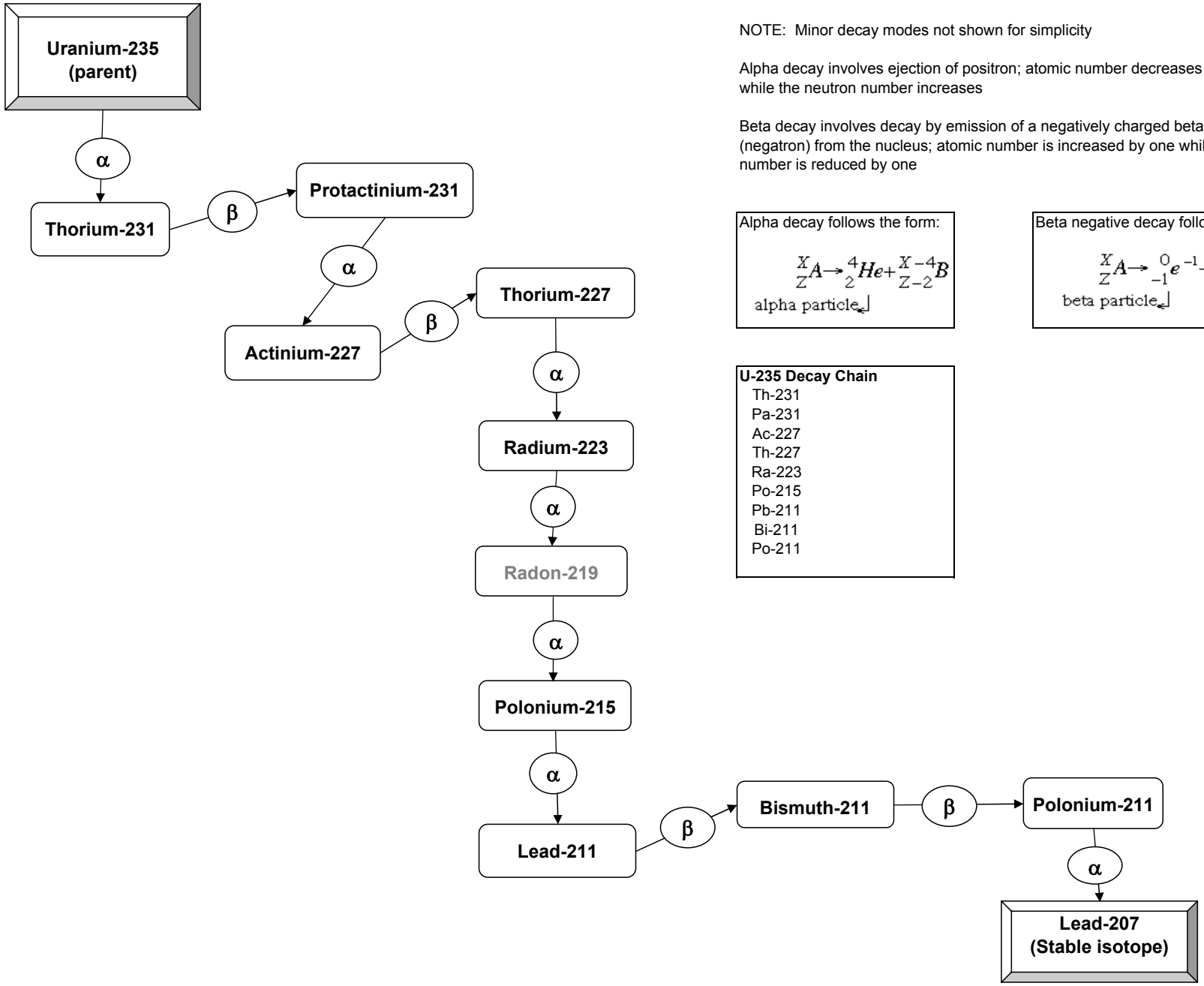
$$ {}^{X}_{Z}A \rightarrow {}^{0}_{-1}e^{-1} + {}^{X}_{Z+1}B $$

beta particle

U-238 Decay Chain

Th-234
Pa-234
U-234
Th-230
Ra-226
Po-218
Pb-214
Bi-214
Po-214
Pb-210
Bi-210
Po-210

FIGURE 3
URANIUM-235 DECAY CHAIN



NOTE: Minor decay modes not shown for simplicity

Alpha decay involves ejection of positron; atomic number decreases by one while the neutron number increases

Beta decay involves decay by emission of a negatively charged beta particle (negatron) from the nucleus; atomic number is increased by one while the neutron number is reduced by one

Alpha decay follows the form:

$$ {}^{X}_{Z}A \rightarrow {}^{4}_{2}He + {}^{X-4}_{Z-2}B $$

alpha particle

Beta negative decay follows the form:

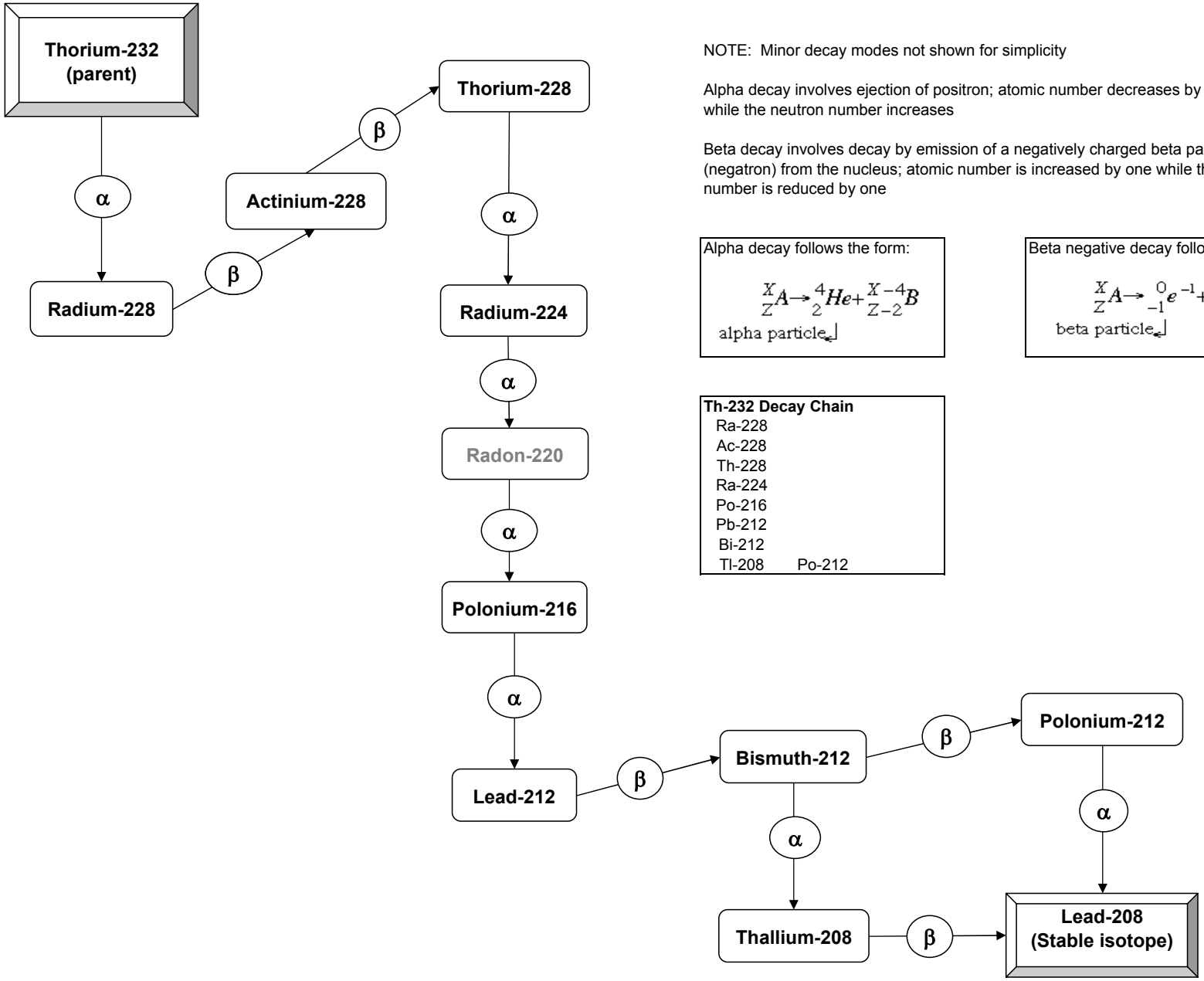
$$ {}^{X}_{Z}A \rightarrow {}^{0}_{-1}e^{-1} + {}^{X}_{Z+1}B $$

beta particle

U-235 Decay Chain

Th-231
Pa-231
Ac-227
Th-227
Ra-223
Po-215
Pb-211
Bi-211
Po-211

FIGURE 4
THORIUM-232 DECAY CHAIN



NOTE: Minor decay modes not shown for simplicity

Alpha decay involves ejection of positron; atomic number decreases by one while the neutron number increases

Beta decay involves decay by emission of a negatively charged beta particle (negatron) from the nucleus; atomic number is increased by one while the neutron number is reduced by one

Alpha decay follows the form:

$$ {}^{X}_{Z}A \rightarrow {}^{4}_{2}He + {}^{X-4}_{Z-2}B $$

alpha particle

Beta negative decay follows the form:

$$ {}^{X}_{Z}A \rightarrow {}^{0}_{-1}e^{-1} + {}^{X}_{Z+1}B $$

beta particle

Th-232 Decay Chain

Ra-228
Ac-228
Th-228
Ra-224
Po-216
Pb-212
Bi-212
Tl-208 Po-212