

**QUALITY ASSURANCE PROJECT PLAN
FOR GROUNDWATER, SURFACE WATER, AND SEDIMENT
AREA IV RADIOLOGICAL STUDY
SANTA SUSANA FIELD LABORATORY
VENTURA COUNTY, CALIFORNIA**

Prepared for:



**U.S. Environmental Protection Agency Region 9
75 Hawthorne Street
San Francisco, California 94105**

**EPA AES Contract Number: EP-S7-05-05
Task Order Number: 0038**

August 11, 2010



HGL
HydroGeoLogic, Inc

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75 Hawthorne Street
San Francisco, California 94105**

Prepared by:

**HydroGeoLogic, Inc.
5800 Woolsey Canyon Road
Building 204
Canoga Park, California 91304**

August 11, 2010

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Appendix A	Statistical Methods to Determine Radiologically Affected Media at the Area IV Study Area
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LIST OF ACRONYMS AND ABBREVIATIONS

AgPRG	Agricultural Preliminary Remediation Goal
ASTM	American Society for Testing and Materials
CFR	Code of Federal Regulations
CSU	combined standard uncertainty
CV	critical value
%D	percent difference
DOE	Department of Energy
DQO	data quality objective
EDD	electronic database deliverable
FSP	Field Sampling Plan
GPS	global positioning system
HAZWOPER	Hazardous Waste Operations and Emergency Response
HGL	HydroGeoLogic, Inc.
ISO	International Organization for Standardization
LCS	laboratory control sample
μm	micron
MARLAP	Multi-Agency Radiological Laboratory Analytical Protocols Manual
MCL	maximum contaminant level
MDC	minimum detectable concentration
MQC	minimum quantifiable concentration
MQO	measurement quality objective
MS	matrix spike
ϕ_{MR}	relative method uncertainty
pCi/L	picocuries per liter
PRG	preliminary remediation goal
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
%R	percent recovery

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

SMP	Site Management Plan
SOP	Standard Operating Procedure
SSFL	Santa Susana Field Laboratory
SSHO	Site Safety and Health Officer
SSHP	Site Safety and Health Plan
UMR	absolute method uncertainty
USEPA	U.S. Environmental Protection Agency

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1.0 INTRODUCTION

HydroGeoLogic, Inc. (HGL) has been tasked by the U.S. Environmental Protection Agency (USEPA) to conduct an extensive radiological characterization study of the Santa Susana Field Laboratory (SSFL) at Area IV and the Northern Buffer Zone located in Ventura County, California. This work is being executed under USEPA Region 7 Architect and Engineering Services Contract EP-S7-05-05, Task Order 0038. The technical lead on the project is USEPA Region 9. The scope of work for this Task Order includes conducting site characterization activities at Area IV and the adjacent Northern Buffer Zone, hereafter collectively referred to as the “Area IV Study Area.” The location of the Area IV Study Area is illustrated on Figure 1.1. Sampling activities will consist of collecting samples from the following media: surface soil, subsurface soil, groundwater, surface water (including seeps and springs), and sediment in accordance with the scope of work presented in the Task Order Proposal submitted by HGL under Contract Number EP-S7-05-05, Task Order 0038 (HGL, 2009a).

This Quality Assurance Project Plan (QAPP) presents the Quality Assurance (QA)/Quality Control (QC) measures that will be used to ensure that the data collected under Task Order 0038 are of acceptable quality and sufficient quantity to support future decision-making, assist USEPA in evaluating human health and ecological risks, and assess remedial options. This QAPP is subject to review and approval by the Region 9 Quality Assurance Management Section. The contents and organization of this QAPP are based on Requirements for Quality Assurance Project Plans, USEPA QA/R-5, Interim Final, March 2001 (USEPA, 2001). This QAPP is intended to support all field sampling and laboratory analytical activities described in the groundwater, surface water, and sediment sampling Field Sampling Plans (FSP) for this project. One FSP, describing Phase I activities, has been completed (HGL, 2010b). A future FSP for Phase II work will be prepared in late 2010 or early 2011. References to FSP section numbers in this QAPP will be consistent between the Phase I FSP and future Phase II FSP. Because this QAPP applies to both the current and future FSP, references to “HGL, 2010b” are not included further in this document. A separate FSP and QAPP have been prepared for the surface and subsurface soil investigations also being conducted under this project.

This project will be conducted in two phases and will potentially involve multiple project laboratories. The project laboratories selected to support each phase of this project the Phase I sampling event will be the subject of laboratory-specific QAPP Addenda included as attachments to this QAPP. The main text of this QAPP presents the overall project objectives

and requirements and includes references laboratory-specific attachments at appropriate locations.

1.1 PROJECT OBJECTIVES AND SCOPE

The primary project objective is to provide data to characterize radiological conditions resulting from historical activities in the Area IV Study Area of SSFL to determine whether those radiological conditions exceed specified criteria for radiological contamination and whether those radiological conditions are distinguishable from surrounding areas that are presumably unaffected by historical activities on the SSFL site. Specifically, the sampling and analysis of these media are designed to:

- Provide high quality data for comparison to data reported by others;
- Provide data on radionuclides not previously assessed; and
- Provide data for areas that may require additional assessment.

The purpose of this QAPP is to provide guidance to ensure that all data collection procedures and measurements are scientifically sound; are of known, acceptable, and documented quality; and are conducted in accordance with the requirements of the project.

1.2 ORGANIZATION OF THIS QUALITY ASSURANCE PROJECT PLAN

This QAPP, together with the Phase I and future Phase II FSP, represents the complete Sampling and Analysis Plan for investigating site groundwater, surface water, and sediment. Site background information is provided in Section 2.0 of the FSP. General project and site management activities are presented in the Site Management Plan (SMP) (HGL, 2010a).

- Section 1.0 presents project management information;
- Section 2.0 presents data quality objective (DQO) information;
- Section 3.0 details measurement and data acquisition strategies;
- Section 4.0 details assessment and oversight aspects of the project;
- Section 5.0 addresses data validation and usability;
- Section 6.0 addresses data management and visualization; and
- Section 7.0 lists the documents referenced in this QAPP.

1.3 PROJECT MANAGEMENT

This section discusses the project organization, documentation, and training.

1.3.1 PROJECT ORGANIZATION

Field activities for this project will be executed primarily by field staff deployed from HGL's onsite Field Operations Office established in Building 204 on the SSFL site. Table 1.1 identifies the personnel responsibilities specific to this task order. Table 1.2 describes project-specific communication pathways. The Palladino Company, Inc. is a key subcontractor for this project and will provide general radiological consulting services and gamma survey support. Other services, such as drilling, vegetation clearing, and investigation-derived waste

disposal will be subcontracted as necessary. USEPA Region 9 will be responsible for reviewing and approving all planning documents.

The project laboratory(ies) are identified in the addenda that are included as attachments to this QAPP.

1.3.2 DOCUMENTATION AND RECORDS

Documents used or generated during the course of the project will be accounted for and become a part of the project files upon completion of the task order. Original records will be transferred to USEPA. Copies of the complete project file records will be maintained in HGL's California office for the duration of field activities and will be updated by the Document Control Manager under direction of the Project Manager. Table 1.3 shows the project records that will be generated and included in the file.

The contents of the project files, both electronic and hardcopy documentation, will be retained at HGL's Kansas City office for a minimum of 10 years from completion of the project. The Document Control Manager will be responsible for ensuring that appropriate backup of the project documentation exists in case of destruction of primary documentation (e.g., due to computer malfunction or inappropriate discarding of files). The Document Control Manager also will be responsible for maintaining a current distribution list for all project planning documents and for transmitting any plan updates or amendments to all recipients.

1.3.2.1 Field Data

Logbooks for sampling and field investigation purposes must meet the requirements provided in the FSP sections referenced in Section 3.3.3 and HGL standard operating procedures (SOP). The logbook must contain sufficient information to distinguish samples from each other. Logbooks must have a sewn binding and sequentially numbered pages with printed page numbers. Entries should be recorded in waterproof ink.

1.3.2.2 Laboratory Data

In addition to the documentation requirements listed in Table 1.3, the laboratory will also be responsible for providing analytical reports to HGL. These analytical reports must contain all information required to verify and validate the analytical results that are the subject of each report in accordance with the requirements presented in Section 5.0. The laboratory will also be required to provide all supporting documentation, including personnel training records, control charts, SOPs, method validation reports, and performance evaluation sample results, to project personnel performing laboratory audits.

1.4 FIELD PERSONNEL TRAINING AND CERTIFICATION

Before initiating the field work, all field personnel will receive training on the project-specific requirements and sampling procedures. This training will be completed before mobilizing to the field. The personnel responsible for conducting sampling and other field activities will have adequate experience to perform the tasks assigned to them. All field personnel will read

and familiarize themselves with all pertinent planning and quality documents, including this QAPP. Field personnel will be cognizant of the importance and level of QC that must be maintained to produce the most representative samples. The generation of acceptable data relies on the proper collection of samples; therefore, sampling activities will be appropriately monitored by the Field Team Leader throughout the site investigation activities.

To ensure that all project activities are performed in accordance with SOPs, good practices, and safety requirements, proper training of all project personnel must be maintained and documented. Field work cannot be performed in a manner that meets the required levels of quality and safety unless all project personnel are properly trained and are experienced in performing their job functions. The training requirements specific to this project are presented in the following subsections.

1.4.1 Training Needs Assessment and Implementation

Generally, the training requirements for field personnel will be those required under the Hazardous Waste Operations and Emergency Response (HAZWOPER) standard published in 29 Code of Federal Regulations (CFR) 1910.120. Personnel who work in potentially contaminated portions of the site will be required to have received initial 40-hour HAZWOPER training and 24 hours of supervised field experience that conforms with the requirements of 29 CFR 1910.120(e)(3). Field work will be supervised by a Field Team Leader or designee who has participated in management and supervisor training in accordance with 29 CFR 1910.120(e)(4).

Site workers who have 40-hour HAZWOPER training also are required to have documentation of 8 hours of annual refresher training within the past 12 months. Site personnel who are covered by the HAZWOPER standard will be required to participate in a medical monitoring program as described in 29 CFR 1910.120(f). The HGL Project Manager will be responsible for ensuring that all project personnel are appropriately trained before working on the project. The Field Team Leader and Site Safety and Health Officer (SSHO) will verify that all documentation is in place before allowing site work to proceed.

Site-specific training also will be conducted. This training will address sampling procedures as described in the SOPs and health and safety requirements (including emergency response and contact information) as described in the Site Safety and Health Plan (SSHP). Due to the hazards presented by poisonous snakes indigenous to the area (specifically, rattlesnakes), site employees will be trained in snake recognition and avoidance procedures. Daily tailgate safety meetings also will be held to discuss planned activities for the days. All training, including employee acknowledgement that training was received, will be documented.

1.4.2 Training Documentation

Employee training documentation will be maintained in the project file. During field activities, copies of all relevant training documentation will be available on site. Any subcontractor operating on site will be required to provide copies of training documentation to the Field Team Leader or HGL Project Manager before being allowed to begin work. Subcontractor

training documentation will be maintained in the permanent project file. Records will be maintained in accordance with Section 5.0 of the FSP and the SOPs presented in Appendix A of the FSP.

1.5 LABORATORY PERSONNEL TRAINING AND DOCUMENTATION

The project laboratories are required to conduct periodic employee training and maintain training documentation. These records will be made available for review and evaluation during external audits conducted by HGL; the auditor will also review the laboratories' training, documentation, and recordkeeping SOPs.

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2.0 QUALITY PROGRAM AND DATA QUALITY OBJECTIVES

The end use of the field and laboratory analytical data is to achieve the objectives identified in Section 1.1. The data quality objectives process is a series of planning steps that are designed to ensure that the type, quantity, and quality of environmental data used in decision-making are appropriate for the intended purpose.

2.1 DATA CATEGORIES

The relative quality of analytical data is commonly described in three general categories: “definitive data,” “screening data with definitive confirmation,” or “screening data without definitive confirmation”. The laboratory analytical data collected for this project will be used for decision-making and will be required to meet the requirements of definitive data, including the use of validated methods, laboratory participation in performance evaluation analysis programs, documentation of conformance to project and method QC requirements, and data validation to ensure performance criteria were met on a per-result basis. The field data that will be collected for the project activities addressed by this QAPP will not be used for decision-making and will be considered screening data without definitive confirmation.

2.2 DATA QUALITY OBJECTIVES

The following subsections describe the development of DQOs for the radiological studies to be conducted for groundwater, surface water, and sediment in the Area IV Study Area. The DQOs outlined below are intended to be general for sampling multiple sites within the Area IV Study Area. Therefore, some specific information, such as criteria for locating individual samples and the rationale for the overall sampling program are addressed in the associated FSP. The DQO process described below is to support a data end use of ‘estimation’ as defined in Section 0.9 of Guidance on Systematic Planning Using the Data Quality Objectives Process (USEPA, 2006a). Estimation, in this case, refers to the overall evaluation of the magnitude of potential radiological contamination on the site, independent of the potential final uses of the data, which are not a component of this project.

2.2.1 State the Problem

Several historical site investigations have been conducted at Area IV and have generated extensive data sets of radioisotope concentrations in site environmental media; however, no detailed and comprehensive multi-medium characterization of radioisotope concentrations at Area IV or the Northern Buffer Zone has been performed. This characterization is necessary for determining the areal distribution, nature, and potential transport of radionuclides present within the study area. The investigation activities described in this QAPP and the associated FSP are designed to address the site characterization activities proposed for the Area IV Study Area groundwater, surface water, and sediment.

2.2.2 Identify the Goals of the Study

The primary objective of the study is to answer the following questions: What are the concentration population characteristics of radionuclides of interest in the groundwater, surface

water, and sediment at the Area IV Study Area? Do those radionuclide concentrations exceed action levels (described in Section 2.2.5)?

To successfully execute this phase of the study, these questions will need to be answered distributionally (developing concentration contours) and locally (investigating individual sites and identifying ‘hot spots’).

2.2.3 Identify Decision Inputs

2.2.3.1 Laboratory Data

Based on the principal study question, the following laboratory analytical data are required:

- Groundwater sample analytical results;
- Surface water sample analytical results; and
- Sediment sample analytical results.

Specific sampling locations will be determined as described in Sections 3.0 and 4.2 of the FSP. Only analytical results that have been determined to be usable after undergoing the data verification, validation, and evaluation process as described in Section 5.0 of the QAPP will be used as decision inputs.

2.2.3.2 Field Data

Screening data collected in the field will be used to determine groundwater stabilization prior to sample collection, as described in Section 4.6 of the FSP and the associated sample collection SOPs. Monitoring wells will be considered to have stabilized when the criteria presented in Section 4.6 of the FSP and the sample collection SOPs presented in Appendix A of the FSP have been met. Screening data will also be collected to determine the depth to water at each monitoring well and to locate each sampling location using a global positioning system (GPS).

2.2.4 Define the Boundaries of the Study

The spatial boundaries of the study are the geographical boundaries of the Area IV Study Area. The medium-specific boundaries are as follows:

- Phase I groundwater samples will be collected from the screened intervals of all existing monitoring wells (see FSP Section 3.5, FSP Table 3.5, and FSP Figure 3.6). The spatial boundaries of the study area for groundwater will extend to off-site monitoring wells selected for sampling during Phase II work. Phase II groundwater sampling locations will be evaluated and modified based on the data set collected during Phase I sampling.
- Surface water and sediment samples will be collected from discrete locations at surface water bodies and seeps. During Phase I, only the 10 seeps identified in the FSP will be sampled. The seep sampling scheme for Phase II based on the results from Phase I.

- Sediment samples will be collected from the top six inches of deposited material, where available.

No background samples will be collected for this project. The data comparison performance criteria presented in Section 2.2.6 may be supplemented by comparison to existing background information. Should background information be required, site groundwater and surface water data will be compared to existing background data and expected fallout concentrations. Data from the 2009 Soil Background Study will be used as a point of comparison for sediment data.

The temporal boundaries of the study are:

- The first onsite groundwater sampling event (Phase I) will occur in August 2010. The second round of sampling (Phase II) will occur during the wet season in the winter of 2010-2011.
- Off-site groundwater sampling will occur in early 2011.
- For the surface water sampling component, two events will be conducted over the duration of the project; each after a significant rainfall event. This is necessary because the site is situated in a very arid environment and surface water is not expected to be present unless rainfall occurs.
- For the sediment sampling component, sediment samples will be co-located with surface water samples collected during the initial surface water sampling event.
- The entire study must be completed within the project schedule (currently, by September 30, 2011).

2.2.5 Develop the Analytic Approach

Sediment sample results will be compared to the agricultural preliminary remediation goals (AgPRG) in soil established for each radionuclide of interest. These AgPRGs have been calculated in accordance with the requirements established by USEPA and were put in effect as of January 2007.

AgPRGs have not been established for the groundwater or surface water matrices. Where a maximum contaminant level (MCL) in drinking water has been promulgated for a radionuclide of interest, the action level for aqueous matrices will be set at the MCL. In all other cases, the preliminary remediation goals (PRG) for tap water established by the USEPA have been selected as the comparison criterion for aqueous matrices.

These comparison criteria have been incorporated into the DQO process that was used to determine the measurement quality objectives (MQO). This process is presented in detail in Sections 2.2.6 and 2.2.7.

The following decision rules have been developed for the analysis of data obtained to address the primary objective:

- All sample locations will be logged in the field using a GPS operated in accordance with HGL SOP 2.33 (see FSP Section 6.0).
- In order to obtain samples representative of the matrix, groundwater samples will be collected only after stabilization has been achieved and documented at each well in accordance with Section 4.6 of the FSP and associated SOPs.
- For each field duplicate pair, the results from the parent sample and duplicate sample will be considered to have equal validity (unless affected by a QC issue). The decision rule for this project will be to treat the higher of the two detected results in a field duplicate pair (or the single detected result if it is paired with a non-detected result) as the single result for that sampling location. If both results for a duplicate pair are non-detections, the results associated with the lower set of sensitivity limits will be considered to be the single result for that sampling location.
- Samples will be analyzed for specific radionuclides listed in Tables 2.1 and 2.2, either in entirety or a selected subset of radionuclides. The full list was initially developed for the Final Sampling and Analysis Plan, Radiological Background Study (HGL, 2009b). Due to the evolving nature of this project, readers should refer to Section 3.0 of the FSP and to the QAPP Addendum for the specific list of analytes to be tested for each sampling event conducted for each medium.
- Where insufficient material is available to sample for the full list of analyses, the collected sample aliquots will be designated for analyses in accordance with the priority criteria established in Section 3.1 of the FSP.
- Only analytical data that have been reviewed or validated and identified as acceptable, in accordance with this QAPP, may be used to support other decisions.
- Statistical evaluations for site characterization will use the following general decision rules:
 - Statistical and graphical techniques will be utilized that are classical, robust, and resistant to outliers.
 - The use of logarithmically transformed data will be avoided due to uncertainties introduced by such transformations. Alternatives to performing logarithmic transformations will be employed when isotope populations are found to deviate from normal distribution characteristics.
 - Non-detected results (see Section 2.2.7.2) will not be arbitrarily replaced by ad hoc values in the data evaluation process but will be addressed employing statistical evaluation techniques that have been designed to accurately account for the impact of non-detected results on the characterization of analyte data sets.

2.2.6 Specify Performance or Acceptance Criteria

A description of the set of statistical tools that will be utilized to develop the population parameters of each radionuclide data set are presented in Appendix A. These tools were developed by USEPA, HGL, and other project stakeholders. These methods may be modified or supplemented by additional techniques as required; however, any modifications will require stakeholder input and acceptance.

Once the population parameters are developed based on the data set, these populations will be evaluated to determine whether they show evidence of contamination at the site. The null hypotheses for the data that will be collected from the Area IV Study Area are:

- Sediment concentrations of radionuclides are above the respective AgPRGs.
- Groundwater and surface water concentrations of radionuclides are above the corresponding MCL or tap water PRGs.

The AgPRG are considered the action levels for the radionuclides of interest in sediment and the MCLs or and the tap water PRGs are considered the action levels for the radionuclides of interest in groundwater and surface water. The null hypotheses will be tested on a per-analyte basis. Decision errors may occur through two scenarios.

A Type I (commonly referred to as a false acceptance) decision error would be to conclude that the null hypothesis is true, when in fact, it is false. This error would take the form of an incorrect conclusion that a radionuclide concentration was above the action level. The consequence of this decision error would be to incur unnecessary expense to study, monitor, and remediate contamination that does not exist.

The Type II (commonly referred to as a false rejection) decision error would be to conclude that the null hypothesis is false, when in fact, it is true. This error would take the form of an incorrect conclusion that a radionuclide concentration was below the corresponding action level. The consequences of this decision error would be to not study, monitor, or remediate the full extent of contamination, potentially leading to unaddressed risks to human health and the environment.

The consequences of making the false acceptance error are considered to be less serious than making a false rejection error. Consequently, the framework of statistical hypothesis testing, such as the formulation of the null hypotheses, biases decisions by design toward false acceptance. Judgmental sampling will tend to exaggerate population means over areas, and the action levels that have been established incorporate scenarios that make very conservative assumptions about exposure and effects of radionuclides.

Both types of errors are limited by the decision rules. When comparing population characteristics, decisions are not based on a single data point, but rather on the entire body of data available. The comparison criteria for populations or individual points can be established using statistical methods to control decision errors and to quantify the probability of a false acceptance or a false rejection for each comparison. Analytical method sensitivity is a critical component of these comparisons; the procedures for controlling false positive and false negative errors for individual analytical data points are discussed in Section 2.2.7.2.

The requirement that project decisions be based only on data that have been accepted through the data review and validation process also serves to limit the occurrence of decision errors.

This data review and validation process is designed to identify and correct sources of error for individual data points (sporadic) and for entire data sets (systematic).

2.2.7 Develop the Plan for Obtaining Data

The program that will be conducted to address the primary objective is summarized in the following subsections.

2.2.7.1 Sample Locations

In accordance with the sampling design requested by USEPA, HGL conducted an extensive site reconnaissance to identify appropriate locations for sampling. The sampling locations proposed for this investigation are presented in Section 3.0 of the FSP.

2.2.7.2 Analytical Sensitivity and Error

The null hypothesis for evaluating individual analytical results is that the concentration in the sample is sufficient for the laboratory to detect and quantify that concentration. The sensitivity performance criteria for individual data points will be established by setting acceptable error rates for false acceptance (Type I) and false rejection (Type II) errors. A nonzero instrument signal may be (and usually is) produced even when no analyte is present. A false acceptance error corresponds to accepting a result as a detection when the actual concentration is not distinguishable from the concentration that would be produced by the instrument background. A false rejection error corresponds to failing to consider an analytical result as a detection when the actual concentration in the sample is distinguishable from a background result. Note that these errors relate to laboratory analytical detection decisions only; although they can contribute to project decision errors, as discussed in Section 2.2.6, they are not the sole source of those errors.

To control the Type I error, laboratories must establish an analyte-specific critical value (CV) above which an analyte is considered to be positively identified with a specified probability of an erroneous identification, designated α . For this project, α is set at 0.05. If $\alpha = 0.05$, then one expects the net instrument signal to exceed the CV in only about 5 percent of cases when analyte-free samples are analyzed. Calculation of the CV is presented in Section 3.6.1.

To control the Type II error, laboratories must establish analyte-specific minimum detectable concentrations (MDC), which equal the smallest true concentration of an analyte at which the probability of a Type II error does not exceed a specified value, β . The MDC is the smallest true concentration of an analyte that has a specified probability, $1-\beta$, of generating an instrument signal greater than the CV. For this project, the value of β , like that of α , is chosen to be 0.05, or 5 percent. If a target radionuclide is present in a sample at the MDC, there will be a 95 percent probability that the instrument will record a concentration greater than the CV. Calculation of the MDC is presented in Section 3.6.2.

For the CV and MDC to be reliable tools for controlling laboratory reporting errors, the instrument conditions must be the same during sample analysis as they were when CVs and

MDCs were determined. Factors that can disrupt the link between the sensitivity criteria and sample results include:

- Difficulty in preparing and measuring appropriate blanks,
- Variable instrument background,
- Sample-specific interferences, and
- Statistics of low-background radiation counting.

All analytical results will be reported by the project laboratory as the calculated value with the associated combined standard uncertainty (CSU) at one standard deviation, the associated CV, associated MDC, and associated minimum quantifiable concentration (MQC). Non-detected results will not be reported solely as “< CV” or “< MDC”, although it is acceptable for the laboratory to include this evaluation in addition to the required data reporting format.

Analytical data reported by the laboratory will be subject to data verification and validation (Section 5.0). Following this process, the data will be compiled into a project database.

2.2.7.3 Radionuclides of Interest and Action Levels

Table 2.1 presents the radionuclides that may be used to determine the sediment concentrations of radionuclides at Area IV; Table 2.2 presents this information for groundwater and surface water. Note that certain radionuclides may be added or removed during the course of the project; therefore, Tables 2.1 and 2.2 are considered generic. The reader should refer to Section 3.1 of the FSP for radionuclide lists associated with specific sampling events, locations, and media.

The radionuclides in Table 2.2 are grouped by the general analytical principle that was used to analyze samples for the Background Study; however, specific analytical methods will be determined upon selection of subcontracted laboratories and are presented in the laboratory-specific addenda to this QAPP. The action level associated with each radionuclide of interest is also presented in this table. Note that although an MCL has been promulgated for total uranium, one of the assumptions incorporated into the calculation of this MCL is that the isotopic distribution of uranium is that which would be expected to be found in public water systems; that is, the isotope ratios will correspond to the natural isotopic distribution. Since it has not been determined whether this will be true for water samples collected at SSFL, the tap water PRGs have been retained as the action level for the individual uranium isotopes.

2.2.7.4 Measurement Quality Objectives

The MQO that will control decision errors with the specified α and β of 0.05 is to establish a required relative method uncertainty (ϕ_{MR}) for each target radionuclide at no more than 10 percent when the measured activity is at or above the action level. The activity at which ϕ_{MR} for a radionuclide is equal to 10 percent corresponds to the MQC as defined in Multi-Agency Radiological Laboratory Analytical Protocols (MARLAP) Manual (USEPA, 2004). When sample activity for an isotope is less than the action level, the required absolute method uncertainty (u_{MR}) is not to exceed 10 percent of the action level. Setting ϕ_{MR} and u_{MR} at these

values allows for the variability from field sampling and the analytical system. Many of the action levels presented in Tables 2.1 and 2.2 are below the quantification capabilities of available analytical technology. In these cases, the laboratory will be required to propose alternate activity levels at which the requirements for ϕ_{MR} and u_{MR} can be achieved. These alternate activity levels, which may be considered practical limits to the action levels, must be approved by USEPA, HGL, and the project stakeholders.

For this project, the failure to detect and report a radionuclide of interest when it is present in the environment is a more severe error than to detect and report a radionuclide with elevated levels of uncertainty at the action level. To minimize the risk of such detection errors, and to optimize the assessment of inherent variability in the analytical methods, additional MQOs for project sensitivity are based on the CVs and MDCs that are associated with analytical methods meeting the ϕ_{MR} and u_{MR} requirements described above. CVs and MDCs associated with ϕ_{MR} and u_{MR} at the specified action level will be approved by USEPA, HGL, and the stakeholders and sample analyses will be evaluated against those CVs and MDCs, in addition to the ϕ_{MR} and u_{MR} requirements described above.

2.2.7.5 Laboratory-Specific Measurement Quality Objectives

Ultimately, the MQOs for this project will be performance-based for a majority of the target radionuclides and will consist of action levels, ϕ_{MR} and u_{MR} (and associated MQCs), CVs, and MDCs proposed and accepted by the selected laboratory contractor(s). The action levels provided by project laboratories and incorporated into the laboratory-specific Addenda represent the proposed action levels for sample analyses and will be accepted or rejected through the review process applied each QAPP Addendum. An isotope-specific evaluation of laboratory sensitivity performance that exceeds the preferred ϕ_{MR} and u_{MR} , CVs and MDCs at the action levels described in Section 2.2.6 are presented in each Addendum.

3.0 MEASUREMENT AND DATA ACQUISITION

3.1 SAMPLE PROCESS DESIGN

As discussed in Section 1.0, this QAPP is augmented by the sampling process designs conveyed in the FSP. The sampling processes presented in these planning documents are designed to meet the DQOs discussed in Section 2.2. The following subsections provide details related to sample collection to ensure the data are of known and acceptable quality.

3.2 SAMPLING METHOD REQUIREMENTS

Sampling will be conducted in accordance with prescribed methods detailed in USEPA and HGL SOPs to ensure that samples are collected in a standardized method and they represent actual site conditions. The SOPs that will be used for this project are appended to the FSP. The sampling method requirements discuss the sample container and collection requirements specific to each analytical laboratory where sample analysis will be performed.

3.2.1 Sampling Equipment and Preparation

Sampling equipment required for the field program (including environmental sampling, health and safety monitoring, equipment and personal decontamination, and general field operations) is listed in the FSP. Field preparatory activities will include:

- reviewing the FSP, QAPP, and pertinent SOPs by all HGL field personnel;
- holding a field planning meeting with HGL field personnel to discuss the content of the FSP, QAPP, SSHP, and general logistics related to implementation of the field program;
- procuring field equipment and supplies; and
- mobilizing subcontractors.

The sampling equipment that will be used for this project is listed in Section 4.0 of the FSP and the following SOPs:

- Sediment – SOP 2.15.
- Groundwater – SOP 2.02 and 2.23 (also SOP 2.32 for Domestic and Public Well Sampling).
- Seep samples and surface water samples – SOP 2.16.
- Equipment and material blank samples (Section 3.7.2.1) will be collected by direct filling of sample bottles. Equipment blanks will be collected from water poured over or through freshly decontaminated equipment.

3.2.2 Sample Containers

All sample containers will be pre-cleaned and traceable to the facility that performed the cleaning. Table 3.1 provides the sample containers, and holding times for the analyses that will be conducted. Containers (other than freezer bags) and coolers will be provided by the

laboratory. Any laboratory-specific container requirements will be included in the QAPP Addenda.

For sediment samples, most target analytes can be analyzed from sample aliquots collected in 1-gallon freezer bags that should not be filled over half-full to prevent bursting in transit. These samples will be dried and ground in entirety at the laboratory to create a homogenous solid matrix. There is concern that carbon-14, tritium (hydrogen-3), chlorine-36, iodine-129, and technetium-99 may volatilize during sample processing, and could potentially be lost before analysis. Due to this concern, separate sample aliquots will be collected for the analysis of these analytes. The laboratory SOPs for the analyses are required to address sample processing and preparation techniques for these analytes that will minimize losses due to volatilization. There will be some impact on sample homogeneity for the aliquots selected for the analyses of these isotopes; however, losses of target analytes during processing would represent a severe limitation to data usability.

3.2.3 Sample Collection for Off-Site Analysis

The sample collection procedures outlined in the FSP will be used to collect field samples and associated QC samples in the specified containers with appropriate preservatives as specified in Table 3.1. Documentation that will be delivered with samples includes sample labels and chain-of-custody forms as specified in the applicable SOPs and Section 3.3.

When possible, samples will be shipped to the laboratory daily via Federal Express or other overnight commercial carrier. Before shipping samples, the Sample Manager will contact the laboratory to confirm that laboratory personnel are available to receive the samples when they arrive. Where permissible by the prescribed method, if the samples must be held to accommodate the laboratory or field schedule, the samples will be stored under custody in a secure, temperature and humidity controlled environment.

3.2.4 Decontamination

Sampling equipment and other field items will be decontaminated in accordance with any requirements specifically addressed in individual sampling SOPs and the general requirements of HGL SOP 2.01 Cleaning and Decontaminating Sample Containers and Sampling Equipment.

- All sampling equipment will be thoroughly cleaned and decontaminated before starting field work each day and between sampling locations.
- Gamma scanning equipment will be thoroughly cleaned and decontaminated at the beginning of each day and before initiating work at a new location.
- Sample preparation equipment will be cleaned and decontaminated after processing each sample.

The efficacy of the decontamination process will be evaluated using equipment blanks and material blanks (Section 5.1.3).

3.3 SAMPLE HANDLING AND CUSTODY REQUIREMENTS

The following subsections describe the procedures that will be used to ensure that the integrity of the samples is maintained. Procedures to ensure the custody and integrity of the samples begin at the time of sampling and continue through transport, sample receipt, preparation, analysis, and storage. A discussion of corrections to documentation is also included.

Table 3.2 summarizes the Sample Handling System and personnel responsible for each task.

3.3.1 Field Sample Custody and Documentation

The purpose and description of the sample label and the chain-of-custody record are discussed in the following sections. All identification and tracking procedures for samples will follow information presented in Sections 5.4 and 5.5 of the FSP.

3.3.2 Sample Packaging and Shipping

Samples will be packaged and shipped promptly after collection. When sent by common carrier, packaging, labeling, and shipping of hazardous materials are regulated by the U.S. Department of Transportation under 49 CFR 172. Samples will be handled, packed, screened, and shipped in accordance Sections 5.4 and 5.5 of the FSP. Sample containers and sample shipment containers, sample radiological screening, and labeling must comply with the requirements of “Sample Collection Procedures for Radiochemical Analytes in Environmental Matrices” (USEPA, 2006b) and the requirements of 10 CFR 71 and 49 CFR 171-3. Key steps for packaging samples for shipment are outlined below:

- Screen all sample containers for radioactivity in accordance with the SSHP (HGL, 2010c).
- Wrap glass containers in bubble wrap to protect them during shipment. Enclose and seal labeled sample containers in appropriately sized plastic zip-top bags.
- Place a large plastic garbage bag into a sturdy cooler in good repair. Pour 2 to 4 inches of Styrofoam peanuts or bubble wrap into the plastic bag. Place the sample containers in the bag with sufficient space to allow for the addition of more packing material between the sample containers. Seal the top of the garbage bag with fiber or duct tape.
- Complete shipping/sample documentation including air bill shipment forms for each cooler. Seal the chain-of-custody forms inside a waterproof plastic bag and tape the bag inside the shipping container lid. Include a return address for the cooler.
- Close the shipping container, affix signed and dated custody seals, and seal the cooler with nylon fiber strapping tape.
- Apply any required Department of Transportation labeling to the exterior of the shipping cooler and complete any Department of Transportation-required manifests.

All samples will be shipped by an overnight delivery service to the designated laboratory. A copy of each air bill will be retained by HGL and the air bill number will be recorded in the field logbook so the cooler can be easily tracked if mishandled.

Note that although the shipping container is referred to as a “cooler”, no thermal preservation of samples is required. It is expected that coolers will be used as the routine shipping container because they are commercially available, rugged, are relatively water tight, and are easily decontaminated. Other shipping containers with performance properties appropriate for the shipped material will be acceptable for use.

3.3.3 Field Logbook(s) and Records

Procedures for completing daily field reports and field log books and for photographic documentation are presented in Sections 5.1, 5.2, and 5.3 of the FSP. The applicable SOPs are presented in Appendix A of the FSP.

3.3.4 Corrections to and Deviations from Documentation

The procedures for correcting erroneous field entries are described in HGL SOP 4.07, Use and Maintenance of Field Logbooks. If required, a single strikeout initialed and dated is required to document changes. The correct information should be entered in proximity to the erroneous entry. The same procedure will be used on field logbooks, field sheets, and chain-of-custody records.

Any deviations from the guidance documents (FSP, QAPP, SSHP, and SOPs) will be recorded in the appropriate field logbook. Significant deviations will additionally require approval by the USEPA Project Manager(s) before the deviation is implemented. Significant deviations from planned activities will be discussed in the field investigation report.

3.3.5 Laboratory Custody Procedures and Documentation

Upon receipt at the laboratory, each sample shipment will be inspected to assess the condition of the shipping cooler and the individual samples for container integrity and signs of damage or tampering. The pH of aqueous samples will be measured in accordance with the laboratory’s sample receipt SOPs. This measurement is made on each sample bottle to ensure that the samples were not preserved in the field. Samples received at a pH less than 2 require the laboratory to contact the project manager to verify that the samples were not preserved in the field in violation of the requirements of Section 3.3.6 and to confirm that sample preparation and analysis should continue as requested. The enclosed chain-of-custody records will be cross-referenced with all of the samples in the shipment. Laboratory personnel will then sign these chain-of-custody records; a copy of each signed record will be provided to HGL will be placed in the project file. The sample custodian will continue the chain-of-custody record process by assigning a unique laboratory number to each sample on receipt. This number will identify the sample through all further handling. It is the laboratory’s responsibility to maintain internal logbooks and records throughout sample preparation, analysis, data reporting, and disposal.

Correct identification of samples, extracts, and data is a critical element of laboratory performance. Errors in identifying samples and in associating extracts and data will invalidate all other QA and QC efforts and can lead directly to incorrect decisions about site conditions. Specific laboratory custody procedures and internal tracking procedures are provided in the

laboratory's QA Manual and in the applicable SOPs. Critical components of these SOPs include:

- sample receipt and inspection;
- sample login;
- documentation of discrepancies and corrective action;
- preservative verification;
- sample container identification;
- tracking custody for bulk sample containers and extracts;
- verification of manual and automated data entry;
- raw data reduction and reporting; and
- QA review and sign-off for login, custody and analytical logs, and other tracking documents.

3.3.6 Aqueous Sample Processing

The following steps will be used to collect and process aqueous samples in a manner that allows for accurate determination of dissolved and total radiological concentrations. **This procedure is not to be performed for the sample fraction submitted for tritium analysis.** Sample fractions submitted for tritium analysis will be collected in dedicated glass bottles. At the laboratory, these bottles will be transferred to the analyst for preparation and analysis in accordance with the laboratory's tritium SOP. **Performing these procedures on the tritium sample fraction will invalidate the subsequent analytical results.**

1. Aqueous samples collected for radiological analyses will be shipped unpreserved to the laboratory.
2. On receipt, the laboratory will determine whether the sample aliquots contain gross suspended material.
3. The laboratory will measure and record the volume of the sample as received to the nearest milliliter.
4. If gross suspended material is noted, the samples will be pre-filtered through a qualitative filter in order to prevent clogging of the 0.45 micron (μm) filter. Any filtered residue generated from this step will be retained for quantitative analysis.
5. The sample is filtered through a 0.45 μm membrane filter using a Büchner apparatus. Any filtered residue generated from this step will be combined with any residue from Step 3 above and retained for quantitative analysis. The graduated cylinder will be rinsed into the filter apparatus with a minimum volume of deionized water to facilitate full transfer of non-dissolved solids to the filter medium.
6. The filtrate will be transferred to a graduated cylinder and the Büchner apparatus will be rinsed with dilute (1 N) nitric acid to ensure complete transfer of dissolved material to the final filtrate. The rinsate will be added to the filtrate in the graduated cylinder.
7. The laboratory will measure and record the volume of the final filtrate to the nearest milliliter.

8. Each sample filtrate will be transferred back to the original sample bottle and acidified to $\text{pH} < 2$ with nitric acid.
9. A holding time of 48 hours will be imposed from the time of collection for processing unpreserved samples through all steps above.
10. In order to ensure that any dissolved material that plated out onto the sides of the sample container have sufficient time to re-dissolve in the acidified aliquot, processed sample filtrates will be held for a minimum of 16 hours after acidification before analysis begins.
11. The laboratory will perform all requested analyses on both the aqueous and residue fractions of each sample aliquot. The activities detected in the aqueous fraction will be used to calculate the dissolved concentration. The activities detected in the solid fraction will be used to calculate the concentration of the suspended phase, in picocuries per liter (pCi/L), using the volumetric information recorded by the laboratory in Steps 3 and 7 above. The dissolved and suspended concentrations will then be combined arithmetically to determine the total concentration.
12. The laboratory will report all results as ‘dissolved’ and ‘total’, in pCi/L.

This approach will minimize sample handling and processing in the field, where conditions are not as controlled as in a laboratory. There is potential impact associated with submitting samples unpreserved, as dissolved constituents may plate out onto the sides of the sample container. There is also a concern that dissolved constituents may precipitate out of solution due to changed oxidation-reduction and dissolved oxygen conditions in the sample container which are no longer representative of in situ conditions. These concerns are partially addressed by steps 8 and 10 above, which will re-dissolve any plated material. However, any dissolved material that precipitates out in particles greater than $0.45 \mu\text{m}$ will be counted as suspended activity rather than dissolved activity; the reported total concentration will not be affected, and any precipitate particles of less than $0.45 \mu\text{m}$ will be correctly counted in the dissolved fraction. The proposed procedure corresponds with what is currently allowed by USEPA for the submission of unpreserved metals samples for laboratory filtering (USEPA, 2005). USEPA guidance allows for a holding time of five days from collection for processing unpreserved metals samples; however, considering the level of analytical sensitivity required for this project and the expectation of low concentrations relative to analytical capabilities, 48 hours is proposed to minimize the time the sample is unpreserved but still allow for sufficient time for the laboratory to process the samples upon receipt.

3.4 ANALYTICAL METHODS REQUIREMENTS

Analytical testing will be subcontracted to qualified laboratories that do not have an unacceptable conflict of interest. Assumptions include the following:

- Multiple laboratories will be contracted to conduct all analyses, and will include a QA laboratory.
- Analytical services will be based on the radionuclide list presented in Tables 2.1 and 2.2, with associated sensitivity requirements. The project laboratory QA manuals and

relevant SOPs will be presented in an appendix to the laboratory-specific QAPP Addendum.

- Sediment sample milling and homogenization will be performed by the laboratories.
- Aqueous sample filtration and preservation will be performed by the laboratories (see Section 4.1.4 of the FSP and Section 3.3.6 above).
- Not all DQO-based sensitivity requirements are achievable.
- Data packages will be substantially equivalent to USEPA Level IV (full validation with raw data) standards.

3.4.1 Laboratory Quality Assurance Program

The laboratory(ies) will be required to hold accreditation through the National Environmental Laboratory Accreditation Program. The laboratory will adhere to all applicable QA/QC requirements stated in the applicable laboratory method SOP and the laboratory QA Plan. Applicable recommendations of the MARLAP (USEPA, 2004) and Evaluation of Radiochemical Data Usability (Department of Energy [DOE], 1997) will also be followed whenever practicable. Other QA elements associated with the laboratory analysis program include:

- At least one one-day audit of each laboratory will be performed during the analyses of project samples.
- All laboratory method SOPs and the laboratory QA manual will be reviewed to verify compliance with National Environmental Laboratory Accreditation Program and MARLAP requirements and for appropriate QA control over the analytical processes.
- An appropriate mass of customized performance evaluation sample will be purchased that contains as many of the radionuclides of interest as are commercially available.
- Blind performance evaluation samples will be submitted to each project laboratory for analysis by all analytical methods.
 - The laboratory will be required to report results for all project analytes, including those methods for which the target analytes were not spiked into the performance evaluation sample (the laboratory will not be informed of the identity of the suite of spiked radionuclides).
 - The performance evaluation sample will be submitted at the beginning of the project, prior to the analysis of project samples.
 - Performance evaluation samples will be evaluated by the procedures of Section 5.1.4.

3.4.2 Methods for Off-site Laboratory Analysis

The target radionuclides for project analyses are shown in Tables 2.1 (sediment) and 2.2 (groundwater and surface water); these tables also show the action levels for each radionuclide of interest in each medium. Although these radionuclides are grouped by anticipated analytical principle, this is not intended to be prescriptive. Sample analyses will be in accordance with standard USEPA and/or nationally accepted analytical procedures, where available. Some

radionuclides of interest do not have a widely accepted analytical procedure. In these cases, performance-based methods, including modifications of existing methods to include additional analytes will be allowed. All analytical methods proposed for project analyses will be required to be validated and demonstrate capability to successfully analyze all target radionuclides reported by that method, at the appropriate MQOs. The specific analytical principles and methods that will be used by project laboratories will be presented in laboratory-specific Addenda.

3.5 INSTRUMENT CALIBRATION PROCEDURES AND FREQUENCY

All field and laboratory instrumentation will be calibrated prior to and during continued use. The calibration and maintenance history of the project-specific field and laboratory instrumentation is an important aspect of the project's overall QC program. Consequently, all initial and continuing calibration procedures will be implemented and overseen by trained personnel following the manufacturer's instructions and method requirements. This will ensure that the equipment is functioning within the tolerances established by the manufacturer and the method-specific analytical requirements.

3.5.1 Field Equipment

Field instrumentation will be calibrated and maintained per manufacturers' operating instructions and the SOPs presented in Appendix A of the FSP. The calibration and general maintenance of field instrumentation will be the responsibility of the Field Team Leader and SSHO. All documentation pertaining to the calibration and maintenance of field equipment will be maintained in an active field logbook.

Entries made into the logbook will follow the requirements of Section 5.2 of the FSP and HGL SOP 4.07.

Equipment that fails calibration or becomes otherwise inoperable during the field investigation will be removed from service and segregated to prevent inadvertent use. Potentially affected data acquired on such equipment will be identified and evaluated for usability and potential impact on data quality. Such equipment will be properly tagged to indicate that it should not be used until the problem can be corrected. Equipment requiring repair or recalibration must be approved for use by the Field Team Leader or SSHO before being placed back into service. Equipment that cannot be repaired or recalibrated will be replaced.

3.5.2 Laboratory Equipment

Calibration of all analytical instrumentation is required to ensure that the analytical system is operating correctly and functioning at the required sensitivity to meet project-specific DQOs. Each radiation detection instrument will be calibrated with standard sources appropriate to the instrument and analytical method in accordance with the published analytical methods. Equipment such as thermometers, flow meters, and Geiger counters should be routinely checked and maintained in accordance with laboratory SOPs. Calibration of laboratory instruments should incorporate the guidance presented in American Society for Testing and

Materials (ASTM) Standard D7282-06, Standard Practice for Set-up, Calibration, and Quality Control of Instruments Used for Radioactivity Measurements (ASTM, 2010).

Calibration of laboratory equipment will be based on written procedures approved by laboratory management and included in the laboratory QA manual which is located in the QAPP Addendum. Instruments and equipment will be initially calibrated and the calibration will be subsequently verified at approved intervals, as specified by either the manufacturer or more frequent requirements (e.g., methodology requirements). Calibration standards used as reference standards will be traceable to the National Institute of Standards and Technology or another nationally recognized reference standard source. Calibration and spike standard preparation and traceability information must be presented in the laboratory data reports to allow for review and evaluation during the data validation process.

Records of initial calibration, continuing calibration and verification, repair, and replacement will be maintained by the laboratory where the work is performed in accordance with the requirements in the laboratory QA Manual. Laboratory calibration performance requirements and associated evaluation protocols are presented in Table 3.3.

3.6 ANALYTICAL SENSITIVITY AND UNCERTAINTY

To establish MQOs that meet the DQOs presented in Section 2.2, analytical sensitivity and uncertainty parameters must be defined in order to provide the basis for establishing criteria and to ensure comparability between results reported by multiple laboratories.

Formulas are provided below for the calculation of CV and MDC. It is recognized that some vendor-supplied proprietary software may use variants of the formulas described below, and that the laboratory may not have control over the exact formulas used. In these cases, the laboratory will provide documentation as to the formulas being used by the software. If a variety of formulas are available in such a proprietary software application, the laboratory will select the formula that most closely matches the ones described above. Alternative methods for calculation of CV and MDC will be subject to review and approval by HGL on a case-by-case basis.

3.6.1 Critical Value

The CV is the lowest reportable concentration for which the probability is 5 percent that this reported concentration is actually attributable to instrument noise. In terms of limiting error in detection decisions, the CV is the lowest concentration where the probability of the Type I error, α , is 0.05 or 5 percent.

The preferred formula used to calculate the critical value is presented below:

$$CV = \frac{1.65 \sqrt{R_b * \left(\frac{1}{T_S} + \frac{1}{T_B} \right)}}{k}$$

where:

- R_b = the instrument background count rate
- T_s = the sample count duration
- T_b = the background determination count duration
- K = the standard denominator

Additional discussion of the calculation of CV is discussed in MARLAP Section 20.4.1 and 20A.2 (Attachment 20A)(USEPA, 2004).

3.6.2 Minimum Detectable Concentration

The detection capability of an analytical measurement process, or its ability to distinguish small positive amounts of analyte from zero, is defined in terms of the probability of a Type II error. For this project, the measure of detection capability is the MDC, which equals the smallest true concentration of an analyte at which the probability of a Type II error does not exceed a specified value, β . In other words, the MDC is the smallest true value of the analyte that has a specified probability, $1 - \beta$, of generating an instrument signal greater than the CV. For this project, the value of β , like that of α , has been chosen to be 0.05, or 5 percent.

The preferred formula that is used to calculate MDCs is presented below:

$$M = \frac{3.2 \sqrt{R_b * \left(\frac{1}{T_s} + \frac{1}{T_b} \right)} + 3 * \left(\frac{1}{T_s} + \frac{1}{T_b} \right)}{k}$$

where:

- R_b = the instrument background count rate
- T_s = the sample count duration
- T_b = the background determination count duration
- K = the standard denominator

Additional discussion of the calculation of MDCs is discussed in MARLAP Section 20.4.2 and 20A.3 (Attachment 20A)(USEPA, 2004).

3.6.3 Combined Standard Uncertainty

The uncertainty of a measured value that is associated with the statistically random nature of radioactive decay is typically expressed as an estimated standard deviation, called a standard uncertainty (or one-sigma uncertainty). Standard uncertainty is sometimes referred to as ‘counting uncertainty’. The overall uncertainty of a calculated result usually is obtained by propagating the standard uncertainty with a number of other systematic contributions to uncertainty in the measured values. This overall uncertainty is called the CSU, and is expressed as one standard deviation (1σ or “1 sigma” CSU); this value may be multiplied by a specified factor called a coverage factor (e.g., 2 or 3) to obtain an expanded combined uncertainty (a 2σ or 3σ uncertainty), which describes an interval about the result that can be

expected to contain the true value with a specified probability. The estimates of uncertainty are incorporated into evaluation of the probability of making decision decisions.

For this project, the CSU is the value used for ϕ_{MR} and UMR in Section 2.2.7.4 above. The measurement quality objective is that the 1σ CSU should not exceed 10 percent at activity levels at or above the action level, and should not exceed 10 percent of the action level at activity levels below the action level.

Additional discussion of the estimation of uncertainty and the use of uncertainty information are presented in Section 19 of MARLAP (USEPA, 2004). The methods, terms, and symbols recommended by MARLAP for evaluating and expressing measurement uncertainty are described in the Guide to the Expression of Uncertainty in Measurement, published by the International Organization for Standardization (ISO) in 1993 and corrected and reprinted in 1995 (ISO, 1995).

3.6.4 Minimum Quantifiable Concentration

The CV and the MDC are used to evaluate ongoing method sensitivity performance. Once an analyte result is determined to meet those method sensitivity requirements, decision errors are possible based on the uncertainty associated with the quantification of the result. The MQC is defined as the concentration at which the CSU at 1σ does not exceed a project-specific ϕ_{MR} of 10 percent. For this project the MQC is equal to the action level (see Section 2.2.7.4). At the level of the MQC, reported analytical results will have a quantitative uncertainty that is small relative to the reported value, and will allow for control of decision errors even though the sampling uncertainty (which is generally assumed to be approximately three times the analytical uncertainty) is not quantified and incorporated into the reported results.

3.7 QUALITY CONTROL REQUIREMENTS

3.7.1 Field Measurements

The field measurements that will be taken during the investigative activities addressed by this QAPP include groundwater stabilization parameters, depth to water, and GPS location of samples. Field measurement equipment will be maintained and calibrated in accordance with Sections 5.6 and 5.7 of the FSP; GPS surveying equipment will be used and maintained in accordance with Section 6.0 of the FSP. The applicable SOPs are presented in Appendix A of the FSP.

3.7.2 Field Quality Control Samples

Field QC samples will be used to gauge the accuracy and precision of field collection activities. QC samples will be submitted to the laboratory and include field duplicates, equipment rinsate blanks, and decontamination source water blanks. The FSPs provide information on the number and types of analyses that will be performed, along with the number of associated QC samples that will be collected.

3.7.2.1 Field Blanks

Two types of field blanks, equipment (rinsate) blanks and material (source water) blanks, will be collected in association with the investigations at the Area IV Study Area. Equipment blanks will consist of decontamination water poured over or through a freshly decontaminated piece of equipment used by that team during that day's sampling activities. Equipment blanks are not required if samples are collected using disposable equipment or dedicated equipment and do not contact any equipment that has also been in contact with other samples at any point in the collection process.

One equipment (rinse) blank will be collected each day by each field team, where applicable. Each day's set of equipment blanks collected for analysis will be submitted in conjunction with a sample of the decontamination source water collected directly from the source. Each equipment blank and source blank will consist of sufficient sample volume, including any preservation requirements, to perform all the analyses that are requested for the associated environmental samples. Each equipment blank and source water sample initially will be analyzed for uranium isotopes only and the results will be reported to HGL within 14 days of collection. Evaluation of equipment blank results, including criteria for determining if additional analyses need to be performed, is discussed in Section 5.1.3.

3.7.2.2 Field Duplicates

Field duplicate samples will be collected at a rate of one per 10 environmental samples collected for this project. The procedure for collection of field duplicate sediment samples is to perform a field homogenization of the sample and submit two aliquots as separate samples.

Field duplicate samples will be submitted to the laboratory as blind QC samples (with unique sample identifiers) to ensure that they are analyzed in the same manner as all other environmental samples. Field duplicate results will not be used in the data validation process to determine data qualifiers or assess usability. Field duplicate results will be available to data users to provide an estimate of overall precision of sample collection, field sample preparation, site homogeneity, and laboratory analysis (total measurement of sample variability).

3.7.3 Laboratory Quality Control Elements

Laboratory QC samples will include calibration verification checks, method blanks, laboratory control samples (LCS), carrier and tracer performance, matrix spike (MS) analyses, and laboratory duplicates as required by each analytical method. These QC elements are specific to each analytical method and will be described in general terms in the selected project laboratory QA manual in Appendix A and in more detail in method-specific SOPs. All laboratory SOPs will be subject to review and approval for technical appropriateness and ability to support project MQOs before use for project analyses. Discussion of the calculation of QC element performance is presented in Section 3.8.

The descriptions of the laboratory QC elements presented below are based on the descriptions presented in MARLAP (USEPA, 2004). The acceptance criteria (based on the rationales provided below), corrective action, and evaluation protocols associated with these QC elements

are presented in Table 3.3. Laboratory-specific information on technical approaches to complying with the QC element requirements of this section is presented in the laboratory-specific QAPP addenda.

3.7.3.1 Calibration Verification

Radiation detectors and nuclear instrumentation, such as spectrometry systems, should be calibrated and maintained according to protocols and procedures documented in the laboratory's SOPs and quality manual. The important calibration parameters, the performance criteria used to monitor these calibration parameters, and the frequency of recalibrations should be addressed in these documents. At a minimum, sample counting efficiency and instrument background count rates are required calibration parameters, as well as peak location and resolution for spectroscopic analyses.

Calibration verifications serve as instrument performance checks to ensure that an instrument response during a sample analysis is consistent with the periodic calibration. Source calibration verification is performed using a pre-defined and reusable source and is independent of the sample preparation process; the only variability that will affect the results from these checks are due to instrument response. A sample counting efficiency control limit of a percent difference (%D) less than 3 percent limits the sample analysis uncertainty contributed by the instrumentation, which supports the MQOs. Other acceptance criteria for instrument performance checks should support the lab's ability to achieve the required MQOs and will be subject to approval before analytical work is begun.

3.7.3.2 Method Blanks

A method blank is a sample of a matrix as similar as practical to the associated samples that is free from the analytes (radionuclides) of interest to the extent possible. The method blank is processed simultaneously with, and under the same conditions as, samples through all steps of the analytical procedures. For the purposes of this project, the terms 'method blank' and 'reagent blank' are considered synonymous, and are referred to simply as 'blanks'. Blank samples are used to determine whether any radionuclide contamination is introduced by the measurement process. They assist in the control of any contamination introduced by the laboratory.

Ideally, no target analytes should be present in the blank at detectable concentrations. If that is not possible (e.g., for naturally occurring radionuclides), those radionuclides should be extremely well-characterized and tracked. Control charts can be used to track these radionuclide levels in blanks. Using X charts, the laboratory can establish a program that evaluates the levels and trends of radionuclides in the different laboratory blanks. The techniques for establishing such a control chart program are described in Attachment 18A of MARLAP (USEPA, 2004).

Acceptance criteria for method blanks are described in Table 3.3 and are designed to support the MQOs specific to this project.

3.7.3.3 Laboratory Control Samples

An LCS is a QC sample of known composition (reference material) or an artificial sample created by fortifying a clean material, similar in nature to the environmental sample, with a known, measurable amount of the analyte of interest. LCSs are prepared and analyzed in the same manner as the associated environmental samples. An important performance indicator is the ability to ensure that the analytical methods employed obtain data that are representative of the true activity in a sample, i.e., the analysis produces data that are accurate. The routine analysis of spiked samples provides data for an evaluation of the laboratory's reported measurement uncertainty and allow for the determination of the existence and direction of biases affecting the associated sample results.

Upon completion of the analysis, the results are compared to the known or accepted value, and the agreement is evaluated using a predetermined criterion. The range of sample types assayed in a laboratory may require the preparation of spikes using several sample media.

For this project, LCSs will be spiked at a concentration approximately 4 to 10 times the MDC intended to be supported by this QC check. Spiking at this level should limit the ϕ_{MR} for LCS results to 10 percent or less at the 1σ confidence level. To support the project MQOs, warning limits are set at 2σ and control limits are set at 3σ , as described in Table 3.3.

3.7.3.4 Carriers and Tracers

Some methods require that radionuclides should be separated chemically from their sample matrix and purified before measurement. During chemical processing, some of the analyte radionuclide will be lost due to sample spillage, evaporation, incomplete chemical reactions (e.g., precipitation or extraction). While these losses may correlate with a group of samples of similar chemical composition or from the same sampling area, they can be sample specific. For quantitative analysis, it is necessary to correct observed instrument responses for these losses for each analytical sample. Corrections are made using compounds that are stable (carriers) or radioactive (tracers). An inappropriate method for determining chemical yield may result in an analytical bias. Carrier/tracer performance is used to correct analytical results, and as such may impact the reliability of the sample MQOs when that performance is not within expected limits. Consequently, analytical performance criteria have been established and are presented in Table 3.3.

3.7.3.5 Matrix Spike Samples

An MS is typically an aliquant of a sample fortified (spiked) with known quantities of target radionuclides and subjected to the entire analytical procedure to establish if the method or procedure is appropriate for the analysis of a particular matrix. MS results are used by some radiological methods to assess the potential for matrix interferences to affect reported sample concentrations. Generally, MS analyses are required for analytical methods that do not use a chemical carrier or tracer or other laboratory-applied method for assessing matrix effects. MS analyses are not required for gamma spectroscopy analyses, due to the large volumes of radioactive waste that would be created and other limiting technical considerations. In many

cases, MS analyses will require the collection of extra sample material in order to perform multiple analyses.

Where required by the method, MS analyses will be prepared and analyzed on the basis of each preparation batch (not to exceed 20 samples). HGL will coordinate with the laboratories to ensure that as many preparation batches as possible will include a project-specific QC sample. For those preparation batches that do not contain a project-specific MS, the laboratory may report these results for non-project samples to fulfill batch QC requirements.

Acceptance criteria for matrix spikes are described in Table 3.3 and are designed to support the MQOs specific to this project.

3.7.3.6 Laboratory Duplicates

Radiological methods use laboratory duplicates to assess the potential for variability contributed by sample homogenization, subsampling, matrix effects, and instrument effects. In many cases, laboratory duplicate analyses will require the collection of extra sample material in order to perform multiple analyses.

Laboratory duplicate analyses will be prepared and analyzed on the basis of each preparation batch (not to exceed 20 samples). HGL will coordinate with the laboratories in order to ensure that as many preparation batches as possible will include a project-specific QC sample. For those preparation batches that do not contain a project-specific laboratory duplicate, the laboratory may report these results for non-project samples in order to fulfill batch QC requirements.

Acceptance criteria for laboratory duplicates are described in Table 3.3 and are designed to support the MQOs specific to this project by limiting the variability among the duplicate analyses to that which may be statistically expected, based on the required method uncertainties. Note that Table 3.3 is intended to present a general approach to addressing data quality requirements. Additional information on method-specific and laboratory-specific QC approaches will be incorporated into the laboratory-specific QAPP Addenda.

3.8 CALCULATION OF QUALITY CONTROL PERFORMANCE

The QC elements associated with laboratory operations associated with this project are presented in Table 3.3. These tables also include the data quality evaluation criteria associated with each QC element. The data qualifiers presented in Table 3.3 are defined in Table 3.4.

3.8.1 Z-Score

The Z-score is also known as the normalized difference. A Z-score for two results is calculated using the following general formula:

$$Z = \frac{X_1 - X_2}{\sqrt{CSU_{X_1}^2 + CSU_{X_2}^2}}$$

where:

- X1 = value of the first measured result;
- X2 = value of the second measured result; and,
- CSU = reported combined standard uncertainty (at 1σ) associated with X1 and X2

The Z-score for a measured parameter is used to evaluate the significance of the difference between the two results. When X1 represents a measured value and X2 represents the expected value, a positive value for a Z-score indicates a high bias and a negative value for a Z-score indicates a negative bias. When the Z-score is used to compare two results with no expected value for either result, the absolute value of the numerator is used in the calculation and the Z-score measures precision.

The null hypothesis for the evaluating Z-score is that X1 and X2 do not differ. A Z-score of 1.96 represents a 5 percent chance of incorrectly rejecting the null hypothesis and a Z-score of 2.58 represents a 1 percent chance of incorrectly rejecting the null hypothesis. These values of 1.96 and 2.58 are incorporated into several QC element evaluation procedures presented in Table 3.3.

Note that for MS evaluation, the X1 and CSU_{X1}^2 terms have two components. The X1 term consists of the parent sample result plus the spike amount; the CSU_{X1}^2 term consists of the CSU^2 for the parent sample result summed in quadrature with the CSU^2 for the spike amount.

3.8.2 Percent Difference

The %D between two results is calculated by the following formula:

$$\%D = \frac{M-E}{E} \times 100$$

where:

- M = value of the measured result
- E = value of the expected result

3.8.3 Percent Recovery

The percent recovery (%R) is calculated by the following formula:

$$\%R = \frac{M}{E} \times 100$$

where:

- M = value of the measured result
- E = value of the expected result

%R results below the lower acceptance limit are indications of potential low bias in the associated results; conversely, %R results above the upper acceptance limit are indications of potential high bias in the associated results.

3.9 EQUIPMENT MAINTENANCE PROCEDURES

To ensure that analytical data generated project activities are reliable, all equipment and instruments will have an established routine testing, inspection, and maintenance schedule. Preventive maintenance will be performed and documented by qualified project personnel.

3.9.1 Field Equipment

All field instrumentation, sampling equipment, and accessories will be maintained in accordance with the manufacturer's recommendations and specifications and Sections 5.6 and 5.7 of the FSP. All maintenance will be performed by qualified project personnel and will be documented by the appointed equipment manager or his designee under the direction of the equipment manager.

Each sampling team will be responsible for the condition of the equipment that is issued to them. The sampling team will be responsible for verifying that all equipment is clean and in good working order prior to use. Malfunctioning or damaged equipment must be repaired/replaced as soon as this condition becomes identified. All inspection and maintenance activities must be recorded in the field logbook. Any equipment removed from service for non-routine maintenance/repair will have a tag affixed to it indicating that the equipment is out of service and unsuitable for use. If the instrument is repaired onsite, the Field Team Leader or SSHO will approve returning the instrument to service only after it undergoes a series of tests to verify that proper operating status has been restored. If the equipment cannot be repaired on site, a replacement will be obtained.

The Field Team Leader and SSHO will review inspection and maintenance records on a regular basis to ensure that required maintenance is occurring. These activities will be recorded in the field logbook or dedicated maintenance log to document that established maintenance procedures have been followed. Field instruments will be checked and calibrated before use on site, and batteries will be charged and checked daily where applicable. For many field instruments, the calibration procedure is the principal maintenance activity associated with that instrument; more information related to field instrument maintenance and calibration activities are presented in Section 3.5.1.

3.9.2 Laboratory Equipment

The laboratory is responsible for the maintenance of laboratory equipment. Preventive maintenance will be provided on a scheduled basis to minimize down time and the potential interruption of analytical work. All instruments will be maintained in accordance with manufacturer's recommendations, the laboratory's SOPs, and good laboratory practices. Maintenance of laboratory instruments should incorporate the guidance presented in American Society for Testing and Materials standard D7282-06, Standard Practice for Set-up,

Calibration, and Quality Control of Instruments Used for Radioactivity Measurements (ASTM, 2010).

Designated laboratory personnel will be trained in routine maintenance procedures for all major instrumentation. When repairs become necessary, they will be performed by either trained staff or trained service engineers/technicians employed by the instrument manufacturer. The laboratory will have multiple instruments to serve as backup to minimize the potential for down time. All maintenance will be documented and kept in permanent logs. These logs will be available for review by auditing personnel. Both scheduled maintenance and unscheduled maintenance required by operational failures will be recorded in instrument-specific logbooks. The designated laboratory operations coordinator will review maintenance records on a regular basis to ensure that required maintenance is occurring.

Laboratory maintenance procedures are presented in the laboratory QA manuals included in the laboratory-specific QAPP addenda.

3.10 ACCEPTANCE REQUIREMENTS FOR SUPPLIES

Prior to acceptance, all supplies and consumables will be inspected to ensure that they are in satisfactory condition and free of defects. If defects are noted, the item will be replaced. The Field Team Leader or designated HGL personnel will inspect all supplies and consumables provided by subcontractors.

3.11 NON-DIRECT MEASUREMENT DATA ACQUISITION REQUIREMENTS

Non-direct measurements include information from logbooks, site documents, photographs, and data from other studies that can be used to augment the data set collected under this project and assist in decision-making. All logbooks, data sheets, and photographs generated by HGL during field activities will be documented and maintained in accordance with the requirements of Section 3.3.3. Information from external sources will be evaluated for any limitations on data use and will be incorporated into project decisions only with concurrence from the USEPA. These sources will be identified in any project reporting documents and these documents will include relevant information on any such sources, including the original generator, associated QC, and limitations on use.

4.0 ASSESSMENT AND OVERSIGHT

Project performance will be monitored by conducting assessment activities at predetermined intervals. Assessment activities can be associated with project planning, sample collection, analysis, data manipulation, and data reporting phases. These activities include routine QA/QC surveillance, management system reviews, and readiness reviews. These assessment activities will be ongoing and will often produce routine documentation such as hand-corrected printouts, editorial comments, and emailed memoranda. These ongoing assessment activities can be supplemented by audits of one or more of the data collection phases. These audits can be internal, performed by a team of HGL management and QA/QC personnel, or can be external, performed by a USEPA team or a subcontractor. The Project QC Manager, the HGL Project Manager, and the Program Manager all have the authority and the responsibility to issue a “stop work” notice if critical QA/QC deficiencies are observed at any time.

4.1 PROJECT PLANNING ASSESSMENT

During the project planning phase, a variety of documents will be produced, including the QAPP and FSP. An internal draft version of all planning documents will be reviewed by project-level technical personnel who have expertise in the processes described by each document (for example, a Project Geologist will review the FSP; a Project Chemist will review the QAPP). The results of the technical review will be transmitted to the document author or the document coordinator for action. Following the resolution of the technical review, each document will be reviewed by the HGL Project QA Manager or designee. The Project QA Manager review will ensure that all project documents are correct, internally consistent, and address the data acquisition needs that are provided in the project scope of work. Problems identified by the Project QA Manager will be communicated to the document coordinator if they are editorial in nature. If more significant issues are identified or the documents are unsatisfactory as written, the Project QA Manager will initiate communication with the Project Manager to correct all deficiencies. The Project QA Manager will also forward an assessment report to the Program Manager detailing the deficiencies in the documents, the corrective action that was taken, and the preventative measures that will be put in place to prevent a recurrence. The assessment report and its resolution will become part of the project file.

4.2 SAMPLE COLLECTION/FIELD ACTIVITY ASSESSMENT

The Field Team Leader will report to the Project Manager on a daily basis regarding progress of the fieldwork and QC issues associated with field activities. The Field Team Leader will review all field team logbooks. Any deficiencies identified by the Field Team Leader during the logbook review process will be communicated to the individual field teams. If these deficiencies are severe (sample condition was compromised, information not properly recorded), the Field Team Leader will communicate these deficiencies to the HGL Project Manager for follow-up. These follow-up activities can include retraining or institution of procedural modifications.

If, during field assessment activities, site subcontractor (e.g., an excavation or drilling firm) performance deficiencies are identified, these deficiencies will be addressed with the

subcontractor before allowing any further site work to be performed and a discrepancy report will be transmitted to the HGL Project Manager.

4.3 ANALYSIS ASSESSMENT

Project analytical processes will be assessed internally at the laboratory by the procedures described in the laboratory QA manuals. In addition to the routine assessment procedures, audits will be performed in accordance with Section 3.4.1 and data validation will be performed in accordance with Sections 4.6 and 5.0.

4.4 DATA MANIPULATION ASSESSMENT

Database deliverables will be assessed under the direction of the Database Manager. The procedures are discussed in Section 5.0 of this QAPP and presented in more detail in Section 5.0 of the SMP (HGL, 2010a). Routine corrections will be made and records of all edits to the database will be maintained. If greater problems in the database (e.g., improper file format, inaccurate results, or data gaps) are identified, the HGL Project Manager will be notified in writing. The HGL Project Manager will contact the laboratory to ensure that the deficiencies in the electronic database deliverable (EDD) are corrected and a new EDD submitted in a timely manner. The HGL Project Manager may, at his or her discretion, assign this task to the Database Manager, Project Chemist, or other technically competent personnel.

4.5 DATA REPORTING ASSESSMENT

Data tables and database queries that will support data reporting processes will be checked as described in Section 5.0 of the SMP (HGL, 2010a) to verify that all data extracted from the database are complete and appropriate to the data evaluation being performed.

4.6 AUDITS

At the discretion of HGL's Division QA Manager, any stage of the data collection process can undergo an audit. These audits can be in response to a specific incident, or can be part of the overall corporate QA/QC program. The HGL Project Manager or Program Manager may also request that an audit be initiated if concerns over quality arise. Examples of audits that can be performed include sample collection or health and safety audits performed in the field; audits of project management and scheduling; audits of laboratory or field analytical systems; and audits of data tracking and manipulation processes. All audits will be documented, and the audit findings and resulting corrective actions will be entered into the project file. If an audit is initiated in response to USEPA concerns, a report will be provided to the USEPA for review, comment, and corrective action. Additional reporting requirements are discussed in Section 4.8.

4.7 PLANNED ASSESSMENTS AND RESPONSE ACTIONS

Assessment activities planned for this project are outlined in Table 4.1, and procedures for handling project deviations are outlined in Table 4.2. The frequency of the audits presented in Table 4.1 represents minimum frequencies. The frequency of any planned audit activity can be

increased at the discretion of the project team in response to concerns raised by stakeholders or HGL, or if there is a need to evaluate the success of corrective actions.

The HGL project management team will conduct an audit during the initial stages of this project to ensure that the procedures of this QAPP, the FSP, the SSHP, and field SOPs are being performed. The HGL audit team will identify items requiring immediate corrective action and verify that the corrective action has been performed to address any deficiencies. The team will produce a report that will document findings and corrective actions.

At the discretion of USEPA Region 9, USEPA will perform an oversight audit to verify that all agreed-upon procedures are being followed and that no QA discrepancies will affect the results of the investigation. Any discrepancies found will be addressed as they are identified.

4.8 REPORTS TO MANAGEMENT

Reports will be generated for all QA audits that are conducted and provided to the HGL QA Manager. Reports will include deficiencies that were noted during the audit and corrective actions that were planned or implemented.

The USEPA Remedial Project Manager will receive QA reports whenever major quality problems cannot be immediately corrected. A QA summary of major quality problems and their resolution will be also be provided to the USEPA Remedial Project Manager in a timely manner.

A data evaluation summary will be provided after data validation is complete. This QA summary will detail any quality issues that cause data to be provisionally rejected pending USEPA review and approval (Section 5.2.1). A second summary will be provided after statistical evaluation of the data sets and will include all results provisionally rejected as outliers.

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5.0 DATA VALIDATION REQUIREMENTS AND USABILITY

5.1 QUALITY CHECK OF RADIOLOGICAL DATA

Analytical data packages will be received from the laboratory in both hard copy and EDD format for uploading into the project database. The project manager or designee will perform a quality check of the laboratory results by reviewing sample numbers versus chain-of-custody's and field sheets for consistency and completeness. HGL will subcontract data verification and validation services. The Project Chemist or designee will review any qualifiers added by the validator to determine usability of the results.

5.1.1 Data Validation Protocols

The data validation contractor will validate radiological analysis results. Data validation will be performed in accordance with DOE document Evaluation of Radiochemical Data Usability (DOE, 1997) and MARLAP (USEPA, 2004). The data validation will be the equivalent of an USEPA full validation (Level IV) and will include examination of raw data and recalculation of results. Each data validator will be required to be a radiochemist with at least two years of experience in radiochemical separations and measurement.

Table 3.3 shows data qualification conventions for QC elements associated with the project analyses. These conventions are general, and will be supplemented by method-specific QC elements where appropriate. When analytical results are reported in association with QC results that do not meet the performance criteria, the validator will apply the appropriate qualifier as presented in Table 3.3. Alternative qualification approaches that contradict the requirements of Table 3.3 are allowed if, in the validator's judgment, the alternative is appropriate for a specific QC issue. Each instance of application of an alternative protocol must be documented in the corresponding data validation report to allow for USEPA review and final approval.

5.1.2 Data Verification and Validation

In addition to the laboratory QC elements and qualification conventions described in Table 3.3, the data verification and validation process will also include a review of the following elements:

- sample receipt, condition, and preservation;
- chain-of-custody;
- sample preparation documentation;
- standard preparation and traceability;
- required MDCs;
- field (equipment) blank performance;
- field duplicate performance;
- examination of raw data to verify laboratory and instrument performance;
- holding times;
- nuclide identification and interferences;
- detection decisions;

- sample aliquot representativeness; and
- data comparison between parent compounds and daughter products and gross screening results.

The validator will also be responsible for checking selected results for transcription errors from raw data to summary forms (both for representative sample and QC results) and for performing recalculation of selected reported sample and QC analysis results.

5.1.3 Equipment Blank Data Review

Equipment blanks will consist of decontamination water poured over or through a freshly decontaminated piece of equipment used by that team during that day's sampling activities. Equipment blanks are not required if samples are collected using disposable equipment or dedicated equipment and do not contact any equipment that has also been in contact with other samples at any point in the collection process.

One equipment (rinse) blank will be collected each day by each field team, where applicable. Each day's set of equipment blanks collected for analysis will be submitted in conjunction with a sample of the decontamination source water collected directly from the source. Each equipment blank and source water sample will be analyzed for uranium isotopes and tritium only and the results will be reported to HGL within 14 days of collection.

HGL will compare the initial uranium and tritium results of each rinse blank to the corresponding source water results to determine if there are substantial differences at the 99 percent confidence level (Z -score >2.58 ; see Section 3.8.1). If substantial differences are not noted (i.e., Z -score ≤ 2.58), the decontamination procedures will be considered to be effective and no additional analyses will be required for that specific rinse blank. If substantial differences are noted, it is possible that incomplete decontamination procedures could affect results by cross-contamination. The project team leader will initiate an investigation into the source of the problem and take corrective action. HGL will also instruct the laboratory to analyze the affected rinse blank and source water sample for all project parameters. In these cases, the full set of results for the equipment blank and source water blank will be required to be included in the same data report as the soil samples collected on the same day.

Validators will evaluate each rinse blank that was analyzed for the full set of parameters. For each such rinse blank, those analytes that show a substantial difference (at 99 percent confidence) from the corresponding source water sample will be treated as contamination and will be compared to the associated environmental sample results (with adjustment for matrix differences). Environmental sample results that do not differ from the corresponding rinse blank result at 99 percent confidence will be considered potential cross-contamination artifacts and qualified B.

5.1.4 Performance Evaluation Sample Review

All project laboratories will be required to analyze project-specific performance evaluation samples. Performance evaluation sample results will be evaluated against the certified values

provided by the manufacturer. The Z-score for each reported analyte will be calculated as follows:

$$Z = \frac{|R - C|}{\sqrt{u_R^2 + u_C^2}}$$

where:

- R = analysis result
- u_R = 1 σ CSU for the analysis result
- C = analyte certified value
- u_C = 1 σ uncertainty in the certified value

Performance evaluation sample results that have a Z-score ≤ 2.58 will be considered to be in compliance. Performance evaluation sample results will not be evaluated for naturally occurring radionuclides whose activity values are not certified. Performance evaluation sample results for anthropogenic radionuclides whose values are not certified will be evaluated on the assumption that $C = 0$ with the same acceptance criteria used to evaluate method blank performance (Section 3.7.3.2 and Table 3.3).

5.2 RECONCILIATION WITH USER REQUIREMENTS

5.2.1 Data Quality Objectives Reconciliation

After the data quality reviews and validation are complete as discussed in Section 5.1, HGL will determine which data are usable for their intended purposes based on the DQOs that have been established for this project. Reconciliation with the DQOs and overall project objectives will be discussed in the data quality assessment report produced in accordance with the guidance in MARLAP (USEPA, 2004). Rejection of any data, whether due to a discrepancy identified in the validation process or as the result of the application of statistical tests, requires explicit USEPA Region 9 concurrence. Summary reports of all data provisionally rejected for decision-making and rationale for rejection will be provided to USEPA for USEPA's final determination of data usability (Section 4.8).

5.2.2 Data Reduction and Tabulation

Data reduction and tabulation will be performed using the various data that have been uploaded into a project database during the course of the project as described in Section 6.2.

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6.0 DATA MANAGEMENT AND VISUALIZATION

6.1 INTRODUCTION

Data management encompasses the methodologies that will be employed during project execution to link the various data management tools, including software packages, to ensure that the various data and information types to be collected are systematically obtained and managed. The data management procedures for this project are discussed below and presented in more detail in Appendix D of the SMP (HGL, 2010a).

6.1.1 Objectives of Data Management Program

The sample activities to be conducted at this site will generate fixed laboratory data from the analysis of samples from multiple media, field measurements, and other site-derived information. The resulting data will be entered into a site-specific database that will be established to store field data, laboratory data and other electronic data, as necessary. This will ensure consistency in tracking samples; storing and retrieving data; evaluating analytical results; visualizing data; and generating data tables and reports. Successful data management results from coordinating data collection, control, storage, access, reduction, evaluation and reporting.

The specific objectives of the data management program are to:

- Standardize and facilitate the collection, formatting, and transfer of project data into the data management system and components;
- Provide a structured data system that will support the end uses of the data;
- Minimize the uncertainties associated with the data, data-derived products, and interpretation of results through defined QC measures and documented processes, assumptions and practices; and,
- Provide data that are adequately documented with descriptive information for technical defensibility and legal admissibility of the data.

6.1.2 Data Management Team

A Data Management Team has been established for the site. Project technical personnel assigned to database tasks will perform those tasks under the direction of the Database Manager. The Database Manager will coordinate with the Project Chemist, Project Manager, and the Laboratory Database Manager. The Database Manager will oversee the database and will be responsible for loading data received from the laboratory and the field teams. The Database Manager will ensure that only authorized personnel have access to the database and control any updates to the data. The Database Manager will work with the laboratory to ensure that the data provided are in the correct format for upload into the database.

6.1.3 Data Management Process

The data management process is presented in Appendix D of the SMP (HGL, 2010a).

6.2 DATABASE DEVELOPMENT AND MANAGEMENT

HGL will create and maintain the project database, and will ensure that the database is organized in a fashion that can be queried to support project data reporting needs. Validated analytical data will be uploaded into the project database only after a series of QC checks have established that all appropriate qualifiers have been applied and the EDD content is complete and accurate.

6.2.1 Electronic Database Deliverables

All analytical sample data will be received from each laboratory following sample analysis as an EDD for inclusion in the database. Before field efforts commence, the subcontracted laboratories will coordinate with HGL's Database Manager to develop an acceptable format for EDDs. All EDDs transmitting project data will be in the agreed-upon format. As results may change during data validation, all validated data will supersede the 'as-delivered' (unvalidated) results in the project database.

6.2.1.1 Data Tracking Sheets

Once data have been collected, sample result packages will be checked by the Project Data Coordinator for completeness and entered onto a sample tracking sheet. A sample tracking sheet will inventory samples collected and determine which results have not been received from the laboratory. If data are missing, the Database Manager will contact the appropriate laboratory coordinator to obtain electronic/hard copies of the missing data.

6.2.1.2 Database Log

During the data manipulation process, the Database Manager will maintain a database log updated with project-specific assumptions and changes made.

6.2.2 Pre-Processing Non-Analytical Data

All data not received as an EDD will be entered into a separate Excel spreadsheet to be loaded into the site database, rather than directly keyed into the database through the user interface. This is preformed so that the loading quality checks are uniformly applied, and to assure that all data pass through the same QC process. Data included in this step are sample collection information, field parameters, soil boring and well construction logs, survey information, and investigation-derived waste information. All hand-entered data will receive a 100 percent QC check before being loaded into the database.

6.2.3 Processing Analytical Electronic Database Deliverables

Each EDD will be loaded into the Excel database by the Database Manager using the data loading tools provided in the software. Analytical data will be provided by the data validation subcontractor in Excel format and will not require revision to apply qualifiers determined by the data validation process.

6.2.4 Post-Processing

Data will be exported from the Excel database to Environmental System Research Institute's ArcView geographic information system for analysis and visualization. Database queries in support of the geographic information system will be conducted when analytical data has been validated and entered into the database.

6.2.5 Reporting

Following sampling events, tables of results of sample analysis, population characteristics, and population comparisons will be generated from the database after the sampling effort is completed and validated analytical results have been received.

At conclusion of project, the entire project database will be provided to USEPA Region 9 without limitations. This database will be in a format that is usable with commercially available software; no proprietary software will be required for database access.

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7.0 REFERENCES

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- U.S. Environmental Protection Agency, 2006a. Guidance on Systematic Planning Using the Data Quality Objectives Process, USEPA QA/G4. February.
- U.S. Environmental Protection Agency, 2006b. Sample Collection Procedures for Radiochemical Analytes in Environmental Matrices. Publication No. EPA/600/S-07/001. December.

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TABLES

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**Table 1.1
Personnel Responsibilities**

Name	Organization/Contact Information	Responsibility
Nicole Moutoux	USEPA Region IX 75 Hawthorne Street (SFD-8-2) San Francisco, CA 94105 (415) 972-3012	Remedial Project Manager
Mary Aycock	USEPA Region IX 75 Hawthorne Street (SFD-8-2) San Francisco, CA 94105 (415) 972-3289	Remedial Project Manager
Craig Cooper	USEPA Region IX 75 Hawthorne Street (SFD-8-2) San Francisco, CA 94105 (415) 947-4148	Remedial Project Manager
Gregg Dempsey	Center for Environmental Restoration, Monitoring and Emergency Response Radiation and Indoor Environments National Laboratory P.O. Box 98517 Las Vegas, Nevada 89193-8517 (702) 784-8232	Technical Lead
Don Bandur	USEPA Region IX 75 Hawthorne Street (SFD-8-2) San Francisco, CA 94105 (415) 972-3721	EPA Region IX Alternate Contract Officer
Bob Overfelt, R.G., CHMM	HGL 6430 Glenwood, Suite 200, Building 7 Overland Park, KS 66202 (913) 317-8860	Program Manager
Eric Evans, PMP	HGL Northway 10 Executive Park, 313 Ushers Road Ballston Lake, NY 12019 Phone: (518) 877-0390	Project Manager
T. Stewart Williford	HGL 5023 North Parkway Calabasas Calabasas, CA (818) 876-9631	Head Geologist
Ken Rapuano, CHMM	HGL 11107 Sunset Hills Road, Suite 400 Reston, VA 20190 (703) 478-5186	Project Chemist

Name	Organization/Contact Information	Responsibility
Jeff Martin	HGL 11107 Sunset Hills Road, Suite 400 Reston, VA 20190 (703) 478-5186	Database Manager
To Be Determined (TBD)	This position will be filled at a later time, local to the onsite office.	Project QA/QC Officer
Mark McGowan, CIH, CSP	HGL 11107 Sunset Hills Road, Suite 400 Reston, VA 20190 (703) 478-5186	Corporate Health and Safety Director
Carl Palladino	TPC 720 Fillmore Street San Francisco, CA 94117 (415) 861-1945	Radiological Services
Richard Thurman	HGL 4745 S. Zeno Street Aurora, CO 80015 (303) 693-3785	Radiochemistry Expert
David C. Burns	TPC PO Box 976 Fort Collins, CO 80522 (970) 980-9792	Radiochemistry Expert
TBD	Project Laboratory - TBD	Laboratory Project Manager
TBD	Project Laboratory - TBD	Laboratory QA Officer
TBD	Project Laboratory - TBD	Laboratory Radiochemistry Section Manager
TBD	Project Laboratory - TBD	Laboratory Database Manager
TBD	Data Validation Firm - TBD	Data Validator

**Table 1.2
Communication Pathways**

Communication Drivers	Responsible Entity	Name	Phone Number	Procedure (Timing, Pathways, etc.)
Corporate project oversight and resource allocation	HGL Program Manager	Bob Overfelt, R.G., CHMM	(913) 317-8860	Evaluate project support requirements at periodic program staff meetings and at request of Project Manager.
Manages all project phases	HGL Project Manager	Eric Evans, PMP	(518) 877-0390	Interact with the Program Manager, HGL personnel, subcontractors, EPA Region 9, and stakeholders.
				Notify Region 9 RPMs of field-related problems by phone, e-mail, or fax by close of business (COB) the next business day.
				Approves all real-time changes to the QAPP and coordinates obtaining EPA Region 9 RPM approval for QAPP non-time critical QAPP modifications.
				Transmit all project deliverables (including revisions) to EPA Region 9 and stakeholders.
Field sampling	Head Geologist	T. Stewart Williford, PG	(818) 876-9631	Prepare daily progress reports and fax or e-mail to HGL's Project Manager.
				Coordinate field activities with on-site contractors and HGL personnel.
				Inform Project Manager and/or QA/QC Officer of field issues requiring resolution.
				Notify Project Manager immediately if work stopped due to technical or health and safety (H&S) issues.
				Alerts PM or Project Chemist of need for real-time modification of QAPP (with EPA Region 9 RPM approval) if field conditions warrant.

**Table 1.2 (Continued)
Communication Pathways**

Communication Drivers	Responsible Entity	Name	Phone Number	Procedure (Timing, Pathways, etc.)
Analytical program oversight	HGL Project Chemist	Ken Rapuano, CHMM	(703) 736-4546	Provide guidance through memoranda, e-mail, or phone to HGL field staff, laboratory subcontractors, and data validation staff to ensure that data of required quality is obtained.
				Approves validated data for release for project use.
				Identify QAPP non-conformances and recommends corrective action to the Project Manager.
				Informs Project Manager whether real-time deviations from the QAPP can be considered single-instance or require QAPP modification (with EPA Region 9 RPM approval).
Overall project QA	HGL Project QA/QC Officer	Shannon Thompson, PhD - Radiological Data Jeff Hodge – Field Operations		Communicate program QA/QC requirements to the HGL Project Manager and Project Chemist.
				Determine need to develop procedural changes to address QA/QC deficiencies.
Laboratory project management	Subcontract Laboratory	TBD	TBD	Approve transmittal of analytical reports to the HGL Project Manager.
				Inform HGL Project Manager and/or Project Chemist of QC issues by COB next business day.
				Alert HGL Project Manager and/or Project Chemist of need to modify QAPP (with EPA Region 9 RPM approval) based on analytical conditions.
				Coordinate interaction of the laboratory manager, laboratory QA manager, and analytical staff with HGL management as needed to resolve QA/QC issues.

**Table 1.3
Project Documents and Records**

Sample Collection Documents and Records	On-site Analysis Documents and Records	Off-site Analysis Documents and Records	Data Assessment Documents and Records	Other
Field notes (bound logbook)	Equipment calibration logs	Sample receipt, custody, and tracking records	Data validation reports	Project planning documents
Daily Quality Control Reports	Equipment maintenance, testing, and inspection logs	Standard traceability logs	Automated data review reports	Project deliverables
Chain-of-custody records	Field sampling data sheets	Equipment calibration logs	Database QC Spreadsheets	Telephone logs, e-mails, faxes, and correspondence
Air bills	Waste disposal records	Sample preparation logs	Telephone logs, e-mails, faxes, and correspondence	Permits
Custody seals		Analytical run logs		Site maps
Telephone logs, e-mails, faxes, and correspondence		Equipment maintenance, testing, and inspection logs		
Corrective action forms		Analytical discrepancy forms		
Photographs		Reported analytical results		
		Reported results for standards, QC checks, and QC samples		
		Data package completeness checklists		
		Sample disposal records		
		Extraction and cleanup records		
		Raw data (stored electronically)		
		Telephone logs, e-mails, faxes, and correspondence		

**Table 2.1
Radionuclides of Interest, Sediment**

Symbol	Radionuclide	Method ¹	Half-Life	Units	AL (pCi/g)	MQC ¹ (pCi/g)	AL Met? ¹
<i>Alpha Spectroscopy</i>							
Am-241	americium-241	TBD	432.6	Years	0.0132	TBD	TBD
Am-243	americium-243	TBD	7,370	Years	0.0111 (+D)	TBD	TBD
Cm-243	curium-243	TBD	29.1	Years	0.127	TBD	TBD
Cm-244	curium-244	TBD	18.1	Years	0.304	TBD	TBD
Cm-245	curium-245	TBD	8,500	Years	0.0922	TBD	TBD
Cm-246	curium-246	TBD	4,760	Years	0.129	TBD	TBD
Cm-248	curium-248	TBD	348,000	Years	0.00143	TBD	TBD
Np-237	neptunium-237	TBD	2.144E+06	Years	0.000448 (+D)	TBD	TBD
Po-210	polonium-210	TBD	138.376	Days	19.4	TBD	TBD
Pu-236	plutonium-236	TBD	2.585	Years	0.104	TBD	TBD
Pu-238	plutonium-238	TBD	87.7	Years	0.00731	TBD	TBD
Pu-239	plutonium-239	TBD	24,110	Years	0.00609	TBD	TBD
Pu-240	plutonium-240	TBD	6,563	Years	0.0061	TBD	TBD
Pu-242	plutonium-242	TBD	375,000	Years	0.00642	TBD	TBD
Pu-244	plutonium-244	TBD	8.00E+07	Years	0.00506 (+D)	TBD	TBD
Th-228	thorium-228	TBD	1.9116	Years	0.0338 (+D)	TBD	TBD
Th-229	thorium-229	TBD	7,880	Years	0.00171 (+D)	TBD	TBD
Th-230	thorium-230	TBD	75,400	Years	0.0105	TBD	TBD
Th-232	thorium-232	TBD	1.405E+10	Years	0.00942	TBD	TBD
U-232	uranium-232	TBD	68.9	Years	0.00059	TBD	TBD
U-233	uranium-233	TBD	1.592E+05	Years	0.00184	TBD	TBD
U-234	uranium-234	TBD	245,500	Years	0.00187	TBD	TBD
U-235	uranium-235	TBD	7.040E+08	Years	0.00181 (+D)	TBD	TBD
U-236	uranium-236	TBD	2.3420E+07	Years	0.00198	TBD	TBD
U-238	uranium-238	TBD	4.468E+09	Years	0.00147 (+D)	TBD	TBD
U-240	uranium-240	TBD	14.1	Hours	298	TBD	TBD

Table 2.1 (Continued)
Radionuclides of Interest, Sediment

Symbol	Radionuclide	Method ¹	Half-Life	Units	AL (pCi/g)	MQC ¹ (pCi/g)	AL Met? ¹
<i>Gas Flow Proportional Counting</i>							
Bi-210	bismuth-210	TBD	5.012	Days	1340	TBD	TBD
Pb-210	lead-210	TBD	22.20	Years	0.0000642 (+D)	TBD	TBD
Sr-90	strontium-90	TBD	28.8	Years	0.00139 (+D)	TBD	TBD
Y-90	yttrium-90	TBD	64.053	Hours	9630	TBD	TBD
<i>Gamma Spectroscopy²</i>							
Ac-227	actinium-227	TBD	21.772	Years	0.0831 (+D)	TBD	TBD
Ac-228	actinium-228	TBD	6.15	Hours	731	TBD	TBD
Ag-108	silver-108	TBD	2.37	Minutes	6010000	TBD	TBD
Ag-108m	silver 108m	TBD	418	Years	0.00629	TBD	TBD
Ba-133	barium-133	TBD	10.5	Years	0.161	TBD	TBD
Ba-137m	barium-137m	TBD	2.552	Minutes	178000	TBD	TBD
Bi-212	bismuth-212	TBD	60.55	Minutes	22400	TBD	TBD
Bi-214	bismuth-214	TBD	19.9	Minutes	8190	TBD	TBD
Cd-113m	cadmium-113m	TBD	14.1	Years	0.00526	TBD	TBD
Cf-249	californium-249	TBD	351	Years	0.0613	TBD	TBD
Co-60	cobalt-60	TBD	5.275	Years	0.000901	TBD	TBD
Cs-134	cesium-134	TBD	2.0652	Years	0.00747	TBD	TBD
Cs-137	cesium-137	TBD	30.08	Years	0.0012 (+D)	TBD	TBD
Eu-152	europium-152	TBD	13.537	Years	0.0376	TBD	TBD
Eu-154	europium-154	TBD	8.593	Years	0.0472	TBD	TBD
Eu-155	europium-155	TBD	4.753	Years	3.74	TBD	TBD
Ho-166m	holmium-166m	TBD	1,230	Years	0.011	TBD	TBD
I-129	iodine-129	TBD	1.57E+07	Years	0.0000276	TBD	TBD
K-40	potassium-40	TBD	1.248E+09	Years	0.0445	TBD	TBD
Na-22	sodium-22	TBD	2.6027	Years	0.0852	TBD	TBD

Table 2.1 (Continued)
Radionuclides of Interest, Sediment

Symbol	Radionuclide	Method ¹	Half-Life	Units	AL (pCi/g)	MQC ¹ (pCi/g)	AL Met? ¹
<i>Gamma Spectroscopy² (Continued)</i>							
Nb-94	niobium-94	TBD	2.03E+04	Years	0.0115	TBD	TBD
Np-236	neptunium-236a	TBD	1.53E+05	Years	0.00281	TBD	TBD
Np-239	neptunium-239	TBD	2.356	Days	22.6	TBD	TBD
Pa-231	protactinium-231	TBD	32,760	Years	0.21	TBD	TBD
Pb-212	lead-212	TBD	10.64	Days	80	TBD	TBD
Pb-214	lead-214	TBD	26.8	Minutes	34900	TBD	TBD
Ra-226	radium-226	TBD	1,600	Years	0.000632 (+D)	TBD	TBD
Ra-228	radium-228	TBD	5.75	Years	0.00116 (+D)	TBD	TBD
Rn-220	radon-220	TBD	55.6	Seconds	774000000	TBD	TBD
Rn-222	radon-222	TBD	3.8235	Days	127000 (+D)	TBD	TBD
Sb-125	antimony-125	TBD	2.7586	Years	0.46 (+D)	TBD	TBD
Sn-126	tin-126	TBD	2.30E+05	Years	0.711	TBD	TBD
Te-125m	tellurium-125m	TBD	57.40	Days	32	TBD	TBD
Th-231	thorium-231	TBD	25.52	Hours	3310	TBD	TBD
Th-234	thorium-234	TBD	24.1	Days	15.3	TBD	TBD
Tl-208	thallium-208	TBD	3.053	Minutes	22600	TBD	TBD
Tm-171	thulium-171	TBD	1.92	Years	1250	TBD	TBD
<i>Liquid Scintillation</i>							
C-14	carbon-14	TBD	5,700	Years	0.0000563	TBD	TBD
Fe-55	iron-55	TBD	2.737	Years	0.821	TBD	TBD
H-3	tritium (hydrogen-3), inorganic	TBD	12.32	Years	144	TBD	TBD
H-3	tritium (hydrogen-3), organic	TBD	12.32	Years	0.16	TBD	TBD
Ni-59	nickel-59	TBD	76,000	Years	2.15	TBD	TBD
Ni-63	nickel-63	TBD	100.1	Years	1.01	TBD	TBD

**Table 2.1 (Continued)
Radionuclides of Interest, Sediment**

Symbol	Radionuclide	Method ¹	Half-Life	Units	AL (pCi/g)	MQC ¹ (pCi/g)	AL Met? ¹
<i>Liquid Scintillation (Continued)</i>							
Pu-241	plutonium-241	TBD	14.290	Years	1.05	TBD	TBD
Tc-99	technetium-99	TBD	211,100	Years	0.00557	TBD	TBD
<i>To Be Determined</i>							
Cl-36	chlorine-36	TBD	3.01E+05	Years	0.0102	TBD	TBD
Pm-147	promethium-147	TBD	2.6234	Years	669	TBD	TBD
Se-79	selenium-79	TBD	2.95E+05	Years	0.132	TBD	TBD

Notes:

¹The information in these columns will be provided in the laboratory-specific Quality Assurance Project Plan Addenda.

⁽²⁾ In addition to the target analytes listed in this table, non-target radionuclides detected by gamma spectroscopy will be added to the data library and be reported with or without an applicable MQC.

AL - action level (for sediment, the Agricultural PRG)

(+D) - PRG calculated for target isotope plus additional daughters

NA - not applicable

MQC - minimum quantifiable concentration

pCi/g - picocuries per gram

TBD - to be determined

Table 2.2
Radionuclides of Interest in Groundwater and Surface Water

Symbol	Radionuclide	Method ¹	Half-Life	Units	AL (pCi/L) ²	MQC ¹ (pCi/L)	PRG Met? ¹
<i>Gross Radiation</i>							
NA	gross alpha	SW-846 9310	NA	NA	15 pCi/L	TBD	TBD
NA	gross beta	SW-846 9310	NA	NA	4 mrem/y	TBD	TBD
<i>Alpha Spectroscopy</i>							
Am-241	americium-241	TBD	432.6	Years	0.458	TBD	TBD
Am-243	americium-243	TBD	7,370	Years	0.441 (+D)	TBD	TBD
Cm-243	curium-243	TBD	29.1	Years	0.503	TBD	TBD
Cm-244	curium-244	TBD	18.1	Years	0.57	TBD	TBD
Cm-245	curium-245	TBD	8,500	Years	0.458	TBD	TBD
Cm-246	curium-246	TBD	4,760	Years	0.467	TBD	TBD
Cm-248	curium-248	TBD	348,000	Years	0.005	TBD	TBD
Np-237	neptunium-237	TBD	2.144E+06	Years	0.707 (+D)	TBD	TBD
Po-210	polonium-210	TBD	138.376	Days	0.126	TBD	TBD
Pu-236	plutonium-236	TBD	2.585	Years	0.637	TBD	TBD
Pu-238	plutonium-238	TBD	87.7	Years	0.364	TBD	TBD
Pu-239	plutonium-239	TBD	24,110	Years	0.353	TBD	TBD
Pu-240	plutonium-240	TBD	6,563	Years	0.353	TBD	TBD
Pu-242	plutonium-242	TBD	375,000	Years	0.372	TBD	TBD
Pu-244	plutonium-244	TBD	8.00E+07	Years	0.331 (+D)	TBD	TBD
Th-228	thorium-228	TBD	1.9116	Years	0.159 (+D)	TBD	TBD
Th-229	thorium-229	TBD	7,880	Years	0.0902 (+D)	TBD	TBD
Th-230	thorium-230	TBD	75,400	Years	0.523	TBD	TBD
Th-232	thorium-232	TBD	1.405E+10	Years	0.471	TBD	TBD
U-232	uranium-232	TBD	68.9	Years	0.163	TBD	TBD

Table 2.2 (Continued)
Radionuclides of Interest in Groundwater and Surface Water

Symbol	Radionuclide	Method ¹	Half-Life	Units	AL (pCi/L) ²	MQC ¹ (pCi/L)	PRG Met? ¹
<i>Alpha Spectroscopy (Continued)</i>							
U-233	uranium-233	TBD	1.592E+05	Years	0.663	TBD	TBD
U-234	uranium-234	TBD	245,500	Years	0.674	TBD	TBD
U-235	uranium-235	TBD	7.040E+08	Years	0.663 (+D)	TBD	TBD
U-236	uranium-236	TBD	2.3420E+07	Years	0.711	TBD	TBD
U-238	uranium-238	TBD	4.468E+09	Years	0.547 (+D)	TBD	TBD
U-240	uranium-240	TBD	14.1	Hours	6.77	TBD	TBD
<i>Gas Flow Proportional Counting</i>							
Bi-210	bismuth-210	TBD	5.012	Days	5.34	TBD	TBD
Pb-210	lead-210	TBD	22.20	Years	0.0375 (+D)	TBD	TBD
Sr-90	strontium-90	TBD	28.8	Years	0.644 (+D)	TBD	TBD
Y-90	yttrium-90	TBD	64.053	Hours	2.63	TBD	TBD
<i>Gamma Spectroscopy³</i>							
Ac-227	actinium-227	TBD	21.772	Years	0.098 (+D)	TBD	TBD
Ac-228	actinium-228	TBD	6.15	Hours	23.9	TBD	TBD
Ag-108	silver-108	TBD	2.37	Minutes	Not established	TBD	TBD
Ag-108m	silver 108m	TBD	418	Years	5.85	TBD	TBD
Ba-133	barium-133	TBD	10.5	Years	6.99	TBD	TBD
Ba-137m	barium-137m	TBD	2.552	Minutes	Not established	TBD	TBD
Bi-212	bismuth-212	TBD	60.55	Minutes	67.1	TBD	TBD
Bi-214	bismuth-214	TBD	19.9	Minutes	248	TBD	TBD
Cd-113m	cadmium-113m	TBD	14.1	Years	1.66	TBD	TBD
Cf-249	californium-249	TBD	351	Years	0.375	TBD	TBD
Co-60	cobalt-60	TBD	5.275	Years	3.03	TBD	TBD

Table 2.2 (Continued)
Radionuclides of Interest in Groundwater and Surface Water

Symbol	Radionuclide	Method ¹	Half-Life	Units	AL (pCi/L) ²	MQC ¹ (pCi/L)	PRG Met? ¹
<i>Gamma Spectroscopy³ (Continued)</i>							
Cs-134	cesium-134	TBD	2.0652	Years	1.13	TBD	TBD
Cs-137	cesium-137	TBD	30.08	Years	1.57 (+D)	TBD	TBD
Eu-152	europium-152	TBD	13.537	Years	7.84	TBD	TBD
Eu-154	europium-154	TBD	8.593	Years	4.62	TBD	TBD
Eu-155	europium-155	TBD	4.753	Years	25.1	TBD	TBD
Ho-166m	holmium-166m	TBD	1,230	Years	5.93	TBD	TBD
I-129	iodine-129	TBD	1.57E+07	Years	0.322	TBD	TBD
K-40	potassium-40	TBD	1.248E+09	Years	1.93	TBD	TBD
Na-22	sodium-22	TBD	2.6027	Years	4.95	TBD	TBD
Nb-94	niobium-94	TBD	2.03E+04	Years	6.13	TBD	TBD
Np-236	neptunium-236a	TBD	1.53E+05	Years	4.54	TBD	TBD
Np-239	neptunium-239	TBD	2.356	Days	9.26	TBD	TBD
Pa-231	protactinium-231	TBD	32,760	Years	0.275	TBD	TBD
Pb-212	lead-212	TBD	10.64	Days	1.9	TBD	TBD
Pb-214	lead-214	TBD	26.8	Minutes	138	TBD	TBD
Ra-226	radium-226	TBD	1,600	Years	5.0 ⁽⁴⁾	TBD	TBD
Ra-228	radium-228	TBD	5.75	Years	5.0 ⁽⁴⁾	TBD	TBD
Rn-220	radon-220	TBD	55.6	Seconds	Not established	TBD	TBD
Rn-222	radon-222	TBD	3.8235	Days	Not established	TBD	TBD
Sb-125	antimony-125	TBD	2.7586	Years	9.28 (+D)	TBD	TBD
Sn-126	tin-126	TBD	2.30E+05	Years	1.86	TBD	TBD
Te-125m	tellurium-125m	TBD	57.40	Days	14.3	TBD	TBD
Th-231	thorium-231	TBD	25.52	Hours	21.5	TBD	TBD

Table 2.2 (Continued)
Radionuclides of Interest in Groundwater and Surface Water

Symbol	Radionuclide	Method ¹	Half-Life	Units	AL (pCi/L) ²	MQC ¹ (pCi/L)	PRG Met? ¹
<i>Gamma Spectroscopy³ (Continued)</i>							
Th-234	thorium-234	TBD	24.1	Days	2.06	TBD	TBD
Tl-208	thallium-208	TBD	3.053	Minutes	Not established	TBD	TBD
Tm-171	thulium-171	TBD	1.92	Years	68.1	TBD	TBD
<i>Liquid Scintillation</i>							
C-14	carbon-14	TBD	5,700	Years	1.29	TBD	TBD
Fe-55	iron-55	TBD	2.737	Years	55.2	TBD	TBD
H-3	tritium (hydrogen-3), inorganic	TBD	12.32	Years	144	TBD	TBD
H-3	tritium (hydrogen-3), organic	TBD	12.32	Years	144	TBD	TBD
Ni-59	nickel-59	TBD	76,000	Years	174	TBD	TBD
Ni-63	nickel-63	TBD	100.1	Years	71.1	TBD	TBD
Pu-241	plutonium-241	TBD	14,290	Years	27.1	TBD	TBD
Tc-99	technetium-99	TBD	211,100	Years	17.3	TBD	TBD
<i>To Be Determined</i>							
Cl-36	chlorine-36	TBD	3.01E+05	Years	14.4	TBD	TBD
Pm-147	promethium-147	TBD	2.6234	Years	28.2	TBD	TBD
Se-79	selenium-79	TBD	2.95E+05	Years	6.53	TBD	TBD

Notes:

¹The information in these columns will be provided in laboratory-specific QAPP Addenda.

²The Action Level is established at the PRG for tap water; the ALs for gross alpha and gross beta, radium-226, and radium-228 are the Maximum Contaminant Levels (MCLs) established by the Safe Drinking Water Act.

³In addition to the target analytes listed in this table, non-target radionuclides detected by gamma spectroscopy will be added to the data library and be reported with or without an applicable MQC.

⁴The MCL of 5 pCi/L for radium-226 and radium-228 is for the total of the two isotopes.

AL - Action Level

(+D) - PRG calculated for target isotope plus additional daughters

MQC - minimum quantifiable concentration (see Section 3.6.4)

mrem/y - millirem per year

NA - not applicable

pCi/L - picocuries per liter

PRG - Preliminary Remediation Goal

TBD - to be determined

Table 3.1
Summary of Sample Containers, Preservatives,
Sample Volumes, and Holding Time Requirements

Analyte Group	Container	Minimum Sample Volume ¹	Preservative	Holding Time ²
Groundwater (Priority 1)				
Gamma Spectroscopy ³	Plastic container	4 L	None	5 Days
Gross Alpha ⁴	Plastic container	500 mL	None	5 Days
Gross Beta ⁴	Plastic container	250 mL	None	5 Days
Isotopic Uranium	Plastic container	1 L	None	5 Days
Strontium-90	Plastic container	2 L	None	5 Days
Tritium ⁴	Glass	250 mL	None	5 Days
Extra Volume	Plastic container	2 L	None	5 Days
Groundwater (Priority 2)				
Carbon-14 ⁴	Glass	250 mL	None	5 Days
Iodine-129	Plastic container	2 L	None	5 Days
Isotopic Americium/Curium	Plastic container	3 L	None	5 Days
Isotopic Plutonium	Plastic container	1 L	None	5 Days
Neptunium-237	Plastic container	1 L	None	5 Days
Radium-226	Plastic container	1 L	None	5 Days
Technetium-99	Plastic container	1 L	None	5 Days
Extra Volume	Plastic container	3 L	None	5 Days

Notes:

¹When collecting a field duplicate water sample the sample volume should be doubled for all parameters. When collecting a duplicate for laboratory QC use, the sample volume should be doubled except for the gamma spectroscopy analysis.

²Holding Time for all unpreserved parameters is 5 days. The samples will be preserved after they have been laboratory-filtered as described in Section 4.1.4 of the Phase I FSP.

³Do not collect a duplicate volume for the gamma spectroscopy analysis when providing a duplicate for laboratory QC use; when collecting a field duplicate sample, an extra volume should be collected.

⁴Only these tests require the collection of an extra volume for a matrix spike analysis.

L – liters

mL – milliliters

Table 3.2
Sample Handling System

<i>Sample Collection, Packaging, and Shipment</i>
Sample Collection (Personnel/Organization): Site staff/HGL
Coordination of Shipment (Personnel/Organization): Site Supervisor/HGL and Courier Supervisor/Project Laboratories
Type of Shipment/Carrier: Commercial Overnight Delivery Service
<i>Sample Receipt and Analysis</i>
Sample Receipt (Personnel/Organization): Sample Management Staff/Project Laboratories
Sample Custody and Storage (Personnel/Organization): Sample Management Staff/Project Laboratories
Sample Preparation (Personnel/Organization): Sample Preparation Staff; Bench Chemists/Project Laboratories
Sample Determinative Analysis (Personnel/Organization): Bench Chemists/Project Laboratories
<i>Sample Disposal</i>
Personnel/Organization: Sample management staff/Project Laboratories
Number of Days: 30 from report release

Table 3.3
General Laboratory Quality Control Procedures for Radiological Methods¹

QC Check	Minimum Frequency	Acceptance Criteria	Corrective Action	Validator Qualification Criteria ²
Initial calibration	Initial calibration prior to sample analysis.	Method-specific criteria; see guidance presented in MARLAP Section 18.5.6 or ADSTM D7282.	Bring system back under control; recalibrate as required by analytical method and instrument manufacturer instructions.	Validator judgment; J or R for detected results and UJ or R for non-detected results.
Background	At the method-specific frequency presented in MARLAP Section 18.5.6.	Method-specific criteria; see guidance presented in MARLAP Section 18.5.6 or ADSTM D7282.	Bring system back under control; perform initial calibration as required by analytical method and instrument manufacturer instructions.	Validator judgment; J or R for detected results and UJ or R for non-detected results.
Continuing calibration verification	At the method-specific frequency presented in MARLAP Section 18.5.6; at minimum, daily prior to sample analysis.	Within 3% of the expected value of the control chart.	Recount; if still out of tolerance, correct problem and then repeat initial calibration. If in control, recount again. If in control a second time, proceed with analysis, otherwise, treat as a failure.	Validator judgment; J or R for detected results and UJ or R for non-detected results.

Table 3.3 (Continued)
General Laboratory Quality Control Procedures for Radiological Methods

QC Check	Minimum Frequency	Acceptance Criteria	Corrective Action	Validator Qualification Criteria ²
LCS for all analytes ³	One per preparation batch	Z between -1.96 and +1.96.	Correct problem then reanalyze the LCS; if the LCS is still out of tolerance, re-prepare and reanalyze the LCS and all samples in the affected batch.	For all affected analytes in associated samples: If $Z > 1.96$, qualify affected detected results K. If $Z > 2.58$, examine other QC elements to determine if detected results require qualification of R If $Z < -1.96$, qualify detected results L and non-detected results UL. If $Z < -2.58$, examine other QC elements to determine if detected results require qualification of R; qualify non-detected results R.
Laboratory duplicate	One per preparation batch	$ Z < 1.96$	Correct problem then reanalyze the laboratory duplicate; if the laboratory duplicate is still out of tolerance, re-prepare and reanalyze the laboratory duplicate and all samples in the affected batch.	For all affected analytes in associated samples: If $ Z > 1.96$, qualify detected results J and non-detected results UJ. If $ Z > 2.58$, examine other QC elements to determine if results require qualification of R. [Note, qualification criteria also apply to field duplicate results; see Table 1.7]

Table 3.3 (Continued)
General Laboratory Quality Control Procedures for Radiological Methods

QC Check	Minimum Frequency	Acceptance Criteria	Corrective Action	Validator Qualification Criteria ²
MS	One per preparation batch	Z between -1.96 and +1.96.	Correct problem then reanalyze the MS; if still out of tolerance, re-prepare and reanalyze the MS and all samples in the affected batch.	For all affected analytes in associated samples with similar matrix properties: If $Z > 1.96$, qualify affected detected results K. If $Z > 2.58$, examine other QC elements to determine if detected results require qualification of R. If $Z < -1.96$, qualify detected results L and non-detected results UL. If $Z < -2.58$, examine other QC elements to determine if detected results require qualification of R; qualify non-detected results R.
Method blank	One per preparation batch	Positive blank results: $Z_{\text{blank}} < 2.58$ $[Z_{\text{blank}} = \text{concentration}/1 \sigma \text{ CSU}]$	Calculate Z_{DER} for each affected analyte in each associated sample. If $Z_{\text{DER}} < 2.58$, correct problem then re-prepare and reanalyze the method blank and all associated samples with affected analyte detections.	For affected analytes in associated samples: If $Z_{\text{DER}} > 2.58$, no qualification required. If $Z_{\text{DER}} < 2.58$, qualify affected detected results K. If $Z_{\text{DER}} < 1.96$, qualify affected detected results B.

Table 3.3 (Continued)
General Laboratory Quality Control Procedures for Radiological Methods

QC Check	Minimum Frequency	Acceptance Criteria	Corrective Action	Validator Qualification Criteria ²
		Negative blank results: $ Z_{\text{blank}} < 2.58$	Calculate Z_{DER} for each affected analyte in each associated sample. If $Z_{\text{DER}} < 2.58$, correct problem then re-prepare and reanalyze the method blank and all associated samples with affected analyte detections.	For affected analytes in associated samples: If $Z_{\text{DER}} > 2.58$, no qualification required. If $Z_{\text{DER}} < 2.58$, qualify affected detected results L and affected non-detected results UL. If $Z_{\text{DER}} < 1.96$, qualify affected detected results L and affected non-detected results R.
Chemical yield	Each sample, as required by individual analytical methods	Chemical yield within laboratory control limits (as established by control charts), but not less than 40% for methods that employ a stable carrier or 20% for methods that employ a radioactive tracer (provided that the 1S counting uncertainty does not exceed 5% (400 counts).	Examine system and evaluate whether it is in control; correct any system problems and reanalyze affected samples.	For affected analytes in each sample: If the yield is above the upper limit, qualify detected results L and non-detected results UL. If the yield is below the lower limit, qualify detected results K. If the yield is grossly above or below the control range, evaluate the data to determine if affected results require qualification of R.
		1 σ counting uncertainty < 5% (400 counts) for radioactive tracers.	Examine system and evaluate whether it is in control; correct any system problems and reanalyze affected samples.	1 σ CU in radioactive tracer < 5%: If the result is greater than the MQC, qualify J. If the result is less than the critical value, qualify UJ.

Table 3.3 (Continued)
General Laboratory Quality Control Procedures for Radiological Methods

QC Check	Minimum Frequency	Acceptance Criteria	Corrective Action	Validator Qualification Criteria ²
Analyte quantitation	NA	None	None	If a result is reported greater than the critical value but less than the MQC, consider the result detected, qualify J; if a result is reported less than the critical value, qualify U.
Negative results	None	No analytes with absolute value of negative result greater than the critical value.	Reanalyze sample, evaluate system for negative drift or problems with background correction.	For affected analytes in each sample: If the absolute value is between the critical value and the MDC, UL. If the absolute value is greater than the MDC, qualify R.

Notes:

¹The requirements presented in this table are general and may not support all analytical methods proposed by individual laboratories or methods. Additional information will be presented in laboratory-specific QAPP Addenda.

²When more than one qualifier is applicable to a sample result, the priority of qualifiers for detected results is: X > R > B > J > K or L > no qualifier; a result with both a K and L applied will have a final qualifier of J; the priority of qualifiers for results considered non-detected is: X > R > UJ > UL > U. Qualifiers are defined in Table 3.4.

³LCSs will be processed and counted to yield the same target MDCs as in associated environmental samples in order to minimize uncertainty in these QC samples and provide appropriately rigorous control.

CSU = combined standard uncertainty

CU = counting uncertainty

LCL = lower control limit

LCS = laboratory control sample

LCSD = laboratory control sample duplicate

MARLAP = Multi-Agency Radiological Laboratory Analytical Protocols Manual

MDA = minimum detectable activity

MDC = minimum detectable concentration

MQC = minimum quantifiable concentration

MS = matrix spike

QC = quality control

%R = percent recovery

CSU = total propagated uncertainty

UCL = upper control limit

Z = Z-score (normalized difference)

Table 3.4
Definitions of Data Validation Qualifiers

Qualifier	Definition
No qualifier	Confirmed identification. The analyte was positively identified at the reported value. The reported concentration is within the calibrated range of the instrument and the result is not affected by any deficiencies in the associated quality control criteria.
B	Analyte present, but not detected substantially above the level reported in laboratory or field blanks.
J	The analyte was detected at the reported concentration; the quantitation is an estimate.
K	Analyte present. Reported value may be biased high. Actual value is expected to be lower.
L	Analyte present. Reported value may be biased low. Actual value is expected to be higher.
R	The result is rejected due to serious deficiencies in the ability to analyze the sample and meet quality control criteria.
U	Not considered detected. The associated number is the reported concentration.
UJ	Not considered detected. The associated number is the reported concentration, which may be inaccurate.
UL	Not considered detected. The associated number is the reported concentration, which may be inaccurate due to a low bias.
X	Excluded. The data point is associated with reanalyses or diluted analyses and is excluded because another result has been selected as the definitive result for the analyte.

**Table 4.1
Planned Project Assessments**

Assessment Type	Frequency	Internal or External	Organization Performing Assessment	Person(s) Responsible for Performing Assessment	Person(s) Responsible for Responding to Assessment Findings	Person(s) Responsible for Identifying and Implementing CA	Person(s) Responsible for Monitoring Effectiveness of CA
Field Audit	Once	Internal	HGL	HGL Project QA/QC officer	HGL Project Manager	HGL Field Team Leader and Project Manager	HGL QA Officer
Interim Field Audit	At USEPA Discretion	External	USEPA Region 9	EPA Region 9 QA Department	TBD	TBD	TBD (EPA); QA Officer (HGL)
Pre-Contract Award Laboratory Audit	Once – prior to analysis of samples	External	TPC	TPC Radiochemist	HGL Project Manager	HGL Project Manager	HGL QA Officer
Interim Laboratory Audit	Once per Year	External	TPC	TPC Radiochemist	HGL Project Manager	HGL Project Manager	HGL QA Officer
Close-Out Laboratory Audit	(Optional) Once – at conclusion of project	External	TPC	TPC Radiochemist	HGL Project Manager	HGL Project Manager	HGL QA Officer
Technical Reviews (Data Verification)	Each Data Report	Internal	HGL	HGL Technical Reviewer, TBD	HGL Project Manager	HGL Project Manager	Technical Reviewer

Table 4.1 (Continued)
Planned Project Assessments

Assessment Type	Frequency	Internal or External	Organization Performing Assessment	Person(s) Responsible for Performing Assessment	Person(s) Responsible for Responding to Assessment Findings	Person(s) Responsible for Identifying and Implementing CA	Person(s) Responsible for Monitoring Effectiveness of CA
Data Validation	Each Sampling Event	External	Subcontracted Data Validation Firm, TBD	Data Validator, TBD	Radiological Laboratory Project Manager or HGL Project Manager	Radiological Laboratory Manager or HGL Project Manager	Laboratory Director or HGL Program Manager
Provisionally Rejected Data Summary	After data validation completed and after statistical evaluation completed	Internal	HGL	HGL Project Chemist or HGL Project QA/QC officer	Region 9 Project Team	HGL Project Manager	Technical Reviewer
Data Quality Assessment	Each Sampling Event	Internal	HGL	HGL Project Chemist	Radiological Laboratory Project Manager or HGL Project Manager	Radiological Laboratory Manager or HGL Project Manager	Laboratory Director or HGL Program Manager

Notes:

CA - corrective actions
HGL - HydroGeoLogic, Inc.
QA - quality assurance
QC - quality control
RPM - Remedial Project Manager
TBD - to be determined
TPC - The Palladino Company, Inc.

Table 4.2
Assessment Findings and Corrective Action Responses

Assessment Type	Nature of Deficiencies Documentation	Individual(s) Notified of Findings (Name, Title, Org.)	Contact Information	Timeframe of Notification	Nature of Corrective Action Response Documentation	Individual(s) Receiving Corrective Action Response (Name, Title, Org.)	Contact Information	Timeframe for Response
Field Audit	Written audit report	HGL Project Manager	TBD	5 business days after audit	Memo	HGL QA Officer, TBD	TBD	Field actions immediately implemented, 10 business days to address other concerns in report
Pre-Contract Award Laboratory Audit	Written audit report	HGL Project Manager	TBD	5 business days after audit	Memo	HGL QA Officer, TBD	TBD	5 business days
Laboratory Audit	Written audit report	HGL Project Manager	TBD	5 business days after audit	Memo	HGL QA Officer, TBD	TBD	5 business days
Technical Review (Data Verification)	Memo	HGL Project Manager, HGL Project Chemist	TBD	5 business days after report receipt	Memo	HGL Project Manager, HGL Project Chemist	TBD	5 business days
Data Validation	Memo	HGL Project Manager, HGL Project Chemist	TBD	15 business days after report receipt	Memo	HGL Project Manager, HGL Project Chemist	TBD	5 business days

Table 4.2 (Continued)
Assessment Findings and Corrective Action Responses

Assessment Type	Nature of Deficiencies Documentation	Individual(s) Notified of Findings (Name, Title, Org.)	Contact Information	Timeframe of Notification	Nature of Corrective Action Response Documentation	Individual(s) Receiving Corrective Action Response (Name, Title, Org.)	Contact Information	Timeframe for Response
Provisionally Rejected Data Summary	Memo	Region 9 RPM	TBD	10 business days after validation completed and after statistical evaluation completed	Memo	HGL Project Manager	TBD	15 business days
Data Quality Assessment	Report section	HGL Project Manager and QA Officer	TBD	Per project report schedule	Report section	HGL Project Manager and QA Officer	TBD	5 business days

Notes:

QA - quality assurance

RPM - Remedial Project Manager

TBD - to be determined

APPENDIX A

**STATISTICAL METHODS TO DETERMINE RADIOLOGICALLY
AFFECTED MEDIA AT THE AREA IV STUDY AREA**

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Statistical Methods to Address Stakeholders' Concerns and Statistical Issues Described in Sampling and Analysis Plan for Santa Susana Field Laboratory

This document describes statistical methods that will be used to address stakeholders' concerns as discussed during the April 30, 2009 meeting held in Chatsworth, California. A brief description of the robust statistical methods is also included in this document to address some specific concerns of Mr. D. Hirsch raised by him during a conference call held on July 28, 2009. Specifically, this document describes statistical methods which will be used to analyze and evaluate radiological background reference area (RBRA) data sets (from Santa Susana and Chatsworth geological formations) and distance test locations (DTLs) data set collected during the Radiological Background Study (RBS) to be conducted for the SSFL Site. As described in the SAP, it is planned to analyze 20 samples from the DTLs; and 50 surface and 20 subsurface background reference samples will be collected and analyzed from the Santa Susana formation. Two RBRA data sets will be used from the Chatsworth formation; and 25 surface and 10 subsurface samples will be collected from each of the two RBRA data sets from the Chatsworth formation, for a total of 50 surface samples and 20 subsurface samples from the Chatsworth formation. The RBRA and DTL data sets will be used to compare the concentrations of the radionuclides of concern (RNCs) of the two geological formations with the RNC concentrations of DTLs.

The representativeness of the RBRA data sets from the Chatsworth formation will be established first. Specifically, each of the two RBRA data sets from Chatsworth formation will be compared with the DTL data set. The statistical tests as described in Section 1.2 of this document will be used to perform these comparisons. If the two RBRA data sets from the Chatsworth formation represent non-impacted radiological background reference area locations (in comparison with the RNC concentrations of DTLs), statistical tests will be performed to compare the RNC concentrations of the two RBRA data sets collected from the Chatsworth formation. If there are significant differences between the RNC concentrations of the two RBRA data sets, additional 25 surface and 10 subsurface samples will be collected to complete the RBRA data set from the Chatsworth formation. Once the RBRA data sets from the two formations have been validated and established, statistical tests will be used to compare RNC concentrations of the two formations. Both univariate (one radionuclide at a time) and multivariate (several radionuclides simultaneously) methods supplemented with formal graphical tests and displays will be used to address stakeholders concerns and various other statistical issues of the RBS evaluations as described in the Sampling and Analysis Plan (SAP) for the SSFL site.

Univariate (analyzing one radionuclide at a time) statistical methods used and described in MARSSIM (2000) and EPA guidance documents (e.g., EPA 1989, EPA 1992, EPA 2002a, EPA 2002b, and EPA 2006) will be used to address statistical issues of the evaluation studies of the RBS. Additionally, robust and resistant (to outliers) and formalized graphical methods will be used to effectively address specific concerns of stakeholders. All statistical analyses for

the RBS evaluations as described in the SAP/QAPP/FSP for the SSFL site will be performed using peer-reviewed EPA software packages (developed by Lockheed Martin for ORD, NERL-EPA, Las Vegas, NV): Scout 2008, Version 1.00.01 and ProUCL 4.00.04. These beta tested and peer-reviewed software packages are equipped with most of the statistical methods as described in MARSSIM and other EPA guidance documents listed above. These software packages offer classical, robust and resistant, and graphical methods to analyze univariate and multivariate (e.g., analyzing multiple radionuclides simultaneously) data sets with and without the nondetect (ND) or below detection limit (BDL) observations. Specifically, univariate two sample parametric t-test, nonparametric Wilcoxon Rank Sum (WRS) or Wilcoxon Mann-Whitney (WMW) test, Quantile test, and Gehan test will be used to compare: RNC concentrations of the two RBRA data sets, and RNC concentrations of RBRA (individually or combined) data sets with the DTL data set. Furthermore, since many contaminants will be analyzed and compared, it is also planned to use multivariate methods to compare concentrations of the multiple radionuclides of the two RBRA; and of RBRA (individually or merged) and DTLs.

For verification of results and conclusions, more than one statistical method may be used on the same data set. Most statistical methods and tests will be supplemented with formalized graphical displays. Graphical displays provide added insight (e.g., presence of outliers, data distributions and patterns, mixture populations, visual comparison of two or more groups) into data sets that is not possible to visualize and understand simply by reviewing the estimates and test statistics such as Dixon and Rosner outlier test statistics, upper confidence limits (UCLs), upper tolerance limits (UTLs), upper prediction limit (UPL), t-test and WRS test statistics. Hypotheses testing approaches will be used to compare RBRA and DTL concentrations; upper percentiles, UPLs and/or UTLs will be used to establish background level contaminant concentrations also known as background threshold values (BTVs) or trigger values. Additionally, in order to address stakeholders' concerns, formalized classical and robust graphical displays will be used to compare on-site observations (single, multiple, or entire data set) with the entire RBRA data set (as a comparison to comparing on-site observations with robust upper limits such as upper percentiles, UTLs).

Outliers (if any) will be identified in the original raw scale (non-transformed data set) as the remediation and cleanup decisions need to be made using data and statistics (e.g., averages, prediction limits) in the original scale. Often, the use of a log-transformation tends to hide contamination by accommodating outlying observations (e.g., Singh, Singh, and Engelhardt, 1997, Chapter 7, ProUCL 4.00.04 Tech Guide) as part of the data set. For an example, an outlier in the raw scale may not be an outlier in the transformed space (e.g., log-scale). This does not imply that the outlier (e.g., an elevated RBRA concentration in the original scale) identified in the original scale represents a clean unimpacted location and can be included in the computation of a BTV, estimated by a UPL/UTL. Furthermore, since environmental decisions need be made based upon the values of statistics (e.g., UCL, UPL, t-test, WRS test statistic) in the original scale, all transformed test statistics computed using log-transformation need to be back-transformed in the original scale. The transformation and back-transformation process yields statistics which suffer from an unknown amount of transformation bias. It is

also well known (Singh, Singh, and Engelhardt (1997)) that the use of a lognormal distribution often yields unrealistic and unstable values of upper limits such as 95% UCL, 95% UPL, 95%-90th UTLs. Therefore, in order to compute reliable statistics, derive defensible and correct conclusions, the use of lognormal distribution will be avoided, and all statistical tests including outlier tests, two sample hypotheses tests, and estimation of BTVs will be performed in the original raw scale. Some drawbacks and pitfalls of using lognormal distribution are summarized in Appendix D of this document.

Once the data sets become available from RBRAs and DTLs, those data sets will be screened for potential outliers. Outlying observations will not be included in hypotheses testing and estimation of the background level radiological concentrations. The presence of even a few (single, a couple) outliers in a background reference data set can yield distorted/inflated estimates of the BTVs and hypothesis testing statistics. The use of those distorted/inflated statistics (e.g., upper prediction limit, t-test statistic) may yield incorrect and misleading results and conclusions. Robust statistical methods will be used to identify all potential outliers (e.g., Rousseeuw and van Zomeren (1990); Singh and Nocerino (1995)). A brief description of outlier identification procedures is given in Appendix B. Scout 2008 Version 1.00.01 software will be used to identify potential outliers present in RBRA and DTL data sets.

Statistically rigorous hypotheses testing and estimation methods (and not simple ad hoc substitution methods) will be used on data sets consisting of ND and BDL observations. The details of those methods can be found in ProUCL 4.00.04 Technical Guide (EPA, 2009), Helsel (2005), and Singh, Lee, and Maichle (2006). A brief description of statistical methods to deal with data sets consisting of nondetects is given in Appendix C.

One main disadvantage of using univariate statistical methods on multivariate data sets is that they do not take the potential correlation structure existing among the multiple contaminants (e.g., metals, radionuclides) into account. Moreover, it is hard to control the specified Type I error rate, as an error rate (e.g., = 0.1) is used for each radionuclide, which results in a cumulative error rate (for all analytes combined) much different from the specified error rate of 0.1. Due to some of these reasons, it is always desirable to use multivariate methods (e.g., Johnson and Wichern, 2002) on multivariate (consisting of multiple correlated radionuclides) data sets. The main drawback of multivariate statistical methods is that they are relatively complex to use and proper statistical training in multivariate statistics is required to adequately use them and interpret them. However, the use of multivariate robust methods often produce more accurate results leading to defensible conclusions by minimizing error rates (false positives and false negatives) that are protective of human health and the environment. Whenever applicable and appropriate (and agreed by all concerned parties), it is planned to use multivariate methods to address stakeholders concerns and statistical issues related to RBS evaluations. However, it should be pointed out that univariate methods (widely used and commonly accepted) will be used to address all statistical issues and concerns, and multivariate methods will be used to supplement and verify the results/conclusions derived using univariate methods.

1.0 Evaluations Based Upon Univariate Methods

Univariate methods that will be used to address stakeholders concerns and to analyze RBRAs and DTL data sets collected during RBS evaluations are briefly described in this Section 1.0.

1.1 Goodness-of-Fit Tests to Evaluate Data Distributions

Before using parametric statistical methods on data sets generated during the RBS, normality of data sets will be assessed using Shapiro-Wilk (S-W) and Lilliefors goodness-of-fit (GOF) tests. Anderson-Darling and Kolmogorov-Smirnov GOF tests will be used to determine if a data set follows a gamma distribution, a statistical probability model. A Gamma distribution is better (than lognormal distribution) suited to model positively skewed data sets originating from environmental applications (Singh, Singh, and Iaci, 2002). Another advantage of using a gamma distribution is that the gamma model can be used on the original untransformed data sets. Depending upon the data distribution, the Gamma distribution may be used to estimate BTVs. All of these GOF tests are available in EPA software packages: ProUCL 4.00.04 and Scout 2008.

1.2 Establishing Radiological Background Reference Area (RBRA) Data Sets

Three RBRA (one from the Santa Susana formation and two from the Chatsworth formation) data sets will be collected. The two RBRA data sets from the Chatsworth formation will be considered as coming from a single Chatsworth reference area population. In other words, the two RBRA data sets from the Chatsworth formation will be combined together to make a single Chatsworth RBRA data set. However, if deemed necessary, the RNC concentrations of the two Chatsworth RBRAs can also be compared using the statistical methods as described in this document.

In order to verify that the three RBRAs are not impacted by the site activities, a radiological background data set will be obtained from DTLs, over 10 miles away from the SSFL site. The main objective of this evaluation is to establish representative and defensible RBRA data sets unimpacted by the site activities. Univariate two sample hypotheses testing approaches (e.g., t-test, WRS test) supplemented with graphical displays (e.g., side-by-side boxplots, multiple Q-Q plots, histograms, formal control-chart-type graphical displays) will be used to address this objective. Background module of ProUCL 4.00.04 will be used to address some of these objectives. A brief description of the Background module of ProUCL 4.00.04 is given in Appendix A.

The following two sample parametric and nonparametric hypotheses tests (supplemented with graphical displays) will be used to compare RNC concentrations of the two RBRAs with DTL RNC concentrations; and also to compare RNC concentrations of the two RBRAs collected from Santa Susana and Chatsworth formations

Two Sample Parametric Student's t-Test: This test will be used when the RBRA data sets and DTL data set all follow normal distributions, and no nondetects are present in either of the two RBRA data sets and DTL data set. Normality of a data set will be tested using Shapiro-Wilk (S-W) test and/or Lilliefors GOF test supplemented with a normal Q-Q plot.

Due to the reasons described above (and described in Appendix D), no attempt will be made to use log-transformation (or some other transformation) to achieve normality of the two RBRA data sets and DTL data set. If all of the data sets do not follow normal distributions, nonparametric approaches supplemented with graphical displays will be used. The use of graphical displays (e.g., boxplots, multiple Q-Q plots (EPA 2002a), and histograms) will provide added insight about the data distributions (e.g., skewness, tails, outliers) of the RNCs from the three RBRA and DTLs.

Two Sample Nonparametric WRS (equivalently WMW) Test: When at least one of the RBRA data sets and/or DTL data set for a certain RNC do not follow normal distributions, WRS (WMW) test will be used to compare the concentrations of RNCs of the two RBRA; and also to compare RNC concentrations of RBRA versus DTL. This test will also be used when RBRA data sets and/or DTL data set consist of BDL observations with a single reporting limit or detection limit (DL). No ad hoc substitution methods such as replacing NDs by DL/2, DL, or estimates obtained using regression on order statistics (ROS) methods will be used in hypotheses testing process.

Two Sample Nonparametric Quantile Test: Since WRS test compares the medians (and not the mean) of two populations (e.g., two RBRA, DTL versus RBRA), Quantile test will also be used to compare the distributions (tails) of two RBRA data sets (e.g., EPA 2006), and to compare the distributions of RBRA and DTLs. In other words, for defensible conclusions, both WRS test and the Quantile test will be used on the same data sets to properly determine the potential differences between the distributions of two populations (e.g., RBRA versus RBRA, and RBRA versus DTL). Concentrations of a RNC at the two formations will be considered statistically similar (comparable) if both tests lead to the conclusion that RNC concentrations of the two data sets are comparable (null hypothesis not rejected).

Two Sample Nonparametric Gehan Test: This test is used when data sets consist of BDL observations with multiple reporting or detection limits (DLs). Again, no ad hoc substitution methods such as replacing NDs by DL/2, DL, or estimates obtained using ROS method will be used in hypotheses testing process.

1.2.1 Comparing RNC Concentrations of RBRA with DTL RNC Concentrations

First, it will be determined if any of the two RBRA (Santa Susana and Chatsworth) are impacted by the site activities. Univariate two sample hypothesis testing approaches (e.g., WRS test, t-test) described above will be used to compare RNC concentrations of each of the two RBRA with those of the DTL. Background Hypothesis Test Form 2 (EPA, 2002a, ProUCL 4.00.04) will be used to compare concentrations of RBRA versus DTLs. These

statistical comparisons will be performed separately for each of the two RBRA.

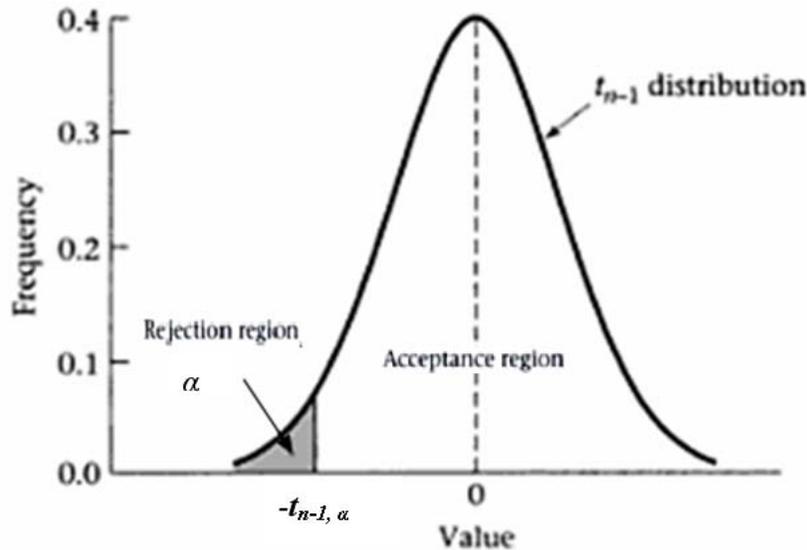
Let μ_1 represent the mean/median of a certain radionuclide at a RBRA (e.g., Santa Susana Formation), and μ_2 be the mean/median concentration of the same radionuclide at DTLs. The following null and alternative hypotheses will be considered. The allowable Type I ($=\alpha$) and Type II ($=\beta$) errors can both be fixed at 0.1. If deemed necessary, other levels of false positive and false negatives error rates may also be considered. Background Form 2 (with substantial difference, $S=0$) null and alternative (left- sided, left -tailed) hypotheses are defined as follows.

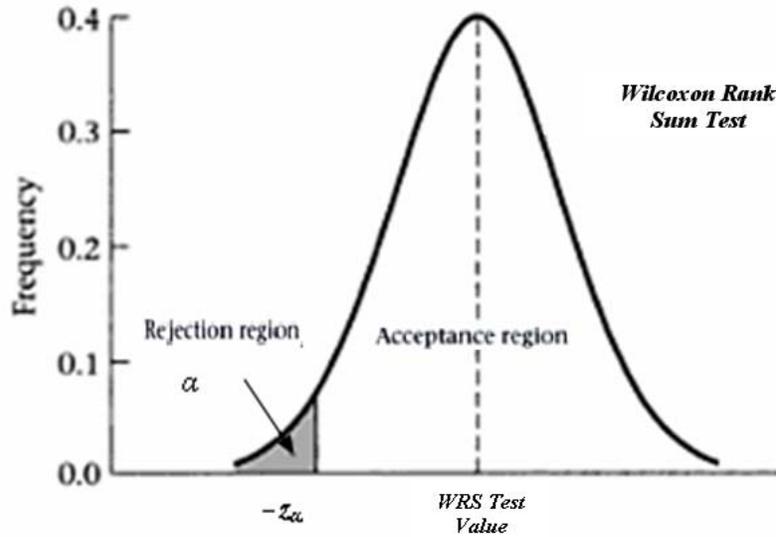
1.2.1.1 Form 2 Background Hypothesis with Substantial Difference, $S=0$

Null Hypothesis, H_0 : Mean/median, $\mu_1 \geq$ Mean/median, μ_2 , versus the left-tailed (sided)

Alternative hypothesis, H_1 : Mean/median, $\mu_1 <$ Mean/median, μ_2

Based upon the collected data, the null hypothesis will be tested against the left-sided alternative hypothesis. These hypotheses will be tested for each RNC. Depending upon the level of significance, α (Type I error rate), and the test statistic used (e.g., t-test, WRS test), an acceptance region and a rejection region (left-tailed) for the null hypothesis will be established. For specified level of significance, α , the acceptance and rejection regions are graphically shown in the following figures for t-test and WRS test.





The conclusion regarding the acceptance or rejection of the null hypothesis is based upon the value of the test statistic (e.g., WRS test value) lying within the acceptance region or rejection region represented by intervals (and not by a single point) as shown in the above figures. If the value of the test statistic (e.g., t-test, or WRS test) falls within the acceptance region, the null hypothesis that the mean/median concentration of a RNC at that RBRA is greater than or equal to the mean/median concentration of that RNC at DTL will be accepted, otherwise the null hypothesis will be rejected. This conclusion may also be supplemented with graphical displays such as side-by-side boxplots and Q-Q plots for further clarification and verification.

1.2.1.2 Form 2 Background Hypothesis with substantial difference, $S > 0$

Moreover, in order to determine the degree of separation between the RNC concentrations of RBRA and DTL, if deemed necessary, Form 2 Background Hypothesis with substantial difference, $S > 0$ may also be used (EPA, 2002a). The appropriate values of substantial differences, S associated with various RNCs will be determined by site and radiological experts; and all parties involved such as the project management, regulators, and stakeholders. Form 2 null and alternative hypotheses are stated as follows.

Null Hypothesis, H_0 : Mean/median, $\mu_1 \geq \text{Mean/median, } \mu_2 + S$, versus the left-tailed (sided)
 Alternative hypothesis, H_1 : Mean/median, $\mu_1 < \text{Mean/median, } \mu_2 + S$, where $S > 0$

Same statistical approaches and tests (e.g., t-test, WRS test) as described above (when $S=0$) will be used to perform Background Form 2 hypotheses with substantial difference, $S > 0$. ProUCL 4.00.04 will be used to perform these hypotheses tests.

1.2.1.3 Conclusions of RBRA versus DTL RNC Concentration Comparisons

Based upon the hypotheses test statistics and associated graphical displays, if it is concluded that the concentrations of RNCs at RBRA are not higher than those found at DTLs (Form 2 null hypothesis rejected based upon sampled data) , then it would be concluded that the two RBRA are not impacted by the site activities. The three data sets (two from Chatsworth and one from Santa Susana) consisting of unimpacted locations exhibiting concentrations comparable (not statistically significantly different) to DTL concentrations will be used as RBRA data sets for all future evaluations. In this case, the RNC concentrations of the two RBRA will be compared (as described below) to determine if the two RBRA data sets can be merged together to form a single combined radiological background reference data set for all future Site versus Background comparisons. It should be noted that if RNC concentrations of the two RBRA are comparable (e.g., with respect to mean, median, spread, and data distribution), and can be considered as coming from a single statistical population of RNC concentrations, it is desirable and recommended to compute a single estimate of the background threshold value (BTV) for that RNC.

The process of merging the two RBRA data sets (when applicable based upon statistical and graphical tests) and computing a single BTV (one for each RNC) for the two formations will result in representative and defensible estimates of the BTVs, especially when BTVs are estimated using robust and resistant methods. The use of BTV estimates computed using the merged (when applicable) RBRA data set will result in a lesser number of statistical comparisons with more manageable decision errors.

It is a common practice to merge two comparable data sets which can be considered as coming from a single statistical population. Statistics computed (e.g., BTVs) based upon the merged RBRA data sets will be statistically more robust.

However, if any of the RBRA exhibits concentrations higher than those of the DTLs (Form 2 null hypothesis not rejected), then it would be concluded that the RBRA (s) is impacted by the site activities. The RBRA locations exhibiting RNC concentrations higher than the RNC concentrations of DTLs will be identified using formal graphical displays as described in this document. Those potentially impacted RBRA locations will not be included in establishing radiological background reference data sets for the SSFL site. It should be noted that the RBRA locations exhibiting concentrations higher than those of the DTLs can be identified using formal graphical displays as used in Examples 1 and 2 below (e.g., Figure3 and Figure4) of Section 1.2.1.4.

1.2.1.4 Graphical Comparisons of RNC Concentrations: RBRA versus DTL

In addition to statistical two sample tests described above, formal graphical Control-Chart-Type displays will also be used to compare individual observations (e.g., single or multiple on-site observations) with the entire data set (and not the average, or some upper limit of the RBRA data set). These graphical displays will be helpful to address specific concerns of

stakeholders as discussed during April 30th meeting and in a conference call held on July 28th, 2009. The QA/QC module of Scout 2008 offers both univariate and multivariate formal graphical tests to compare individual (single or multiple) observations of one group (e.g., RBRA, on-site, test set) with all observations of another group (e.g., DTL, background, training set). A couple of examples illustrating these issues are discussed next.

Example 1. A three-dimensional (lead, manganese, iron) real data set consisting of on-site and offsite background concentration data from a Superfund site has been considered to illustrate the use of graphical methods to perform comparisons of two or more groups. This data set is used again in Example 8 of Section 2 dealing with multivariate methods. Simple side-by-side boxplots and multiple Q-Q plots (EPA, 2002a) for background lead (“Lead (1)”) and on-site lead (“Lead (2)”) concentrations are respectively given in Figures 1 and 2.

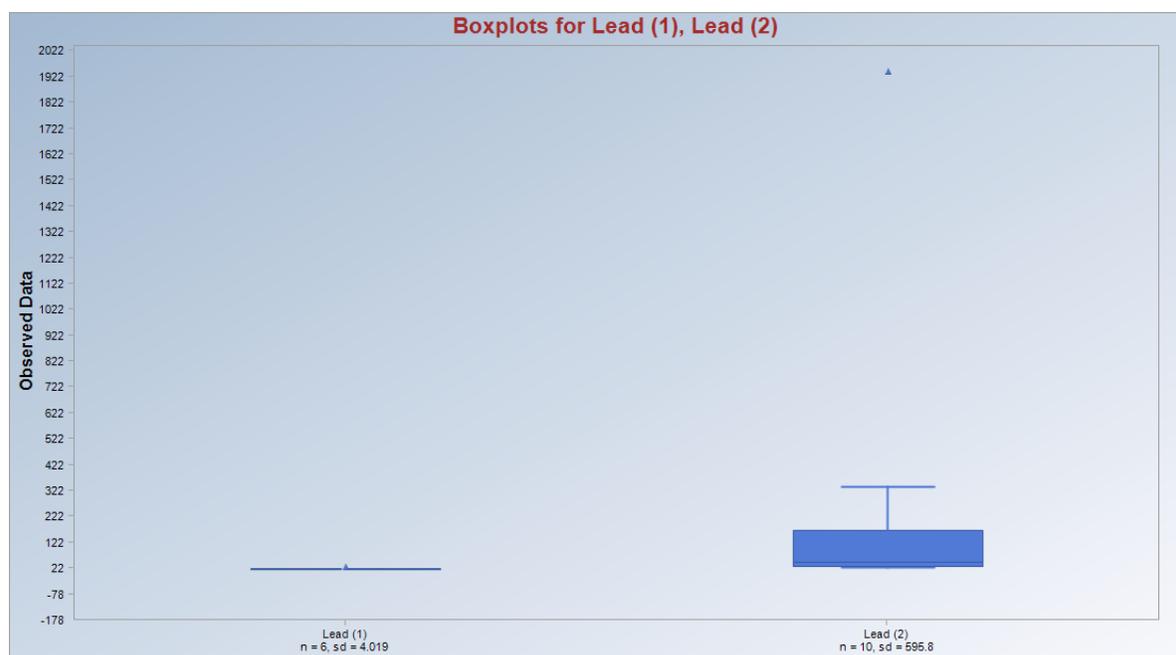


Figure 1. Side-by-side Boxplots Comparing On-site and Background Lead Concentrations

A quick look at the boxplots for lead shown in Figure 1 suggests that the on-site “Lead (2)” concentrations are significantly higher than the “Lead (1)” concentrations found at background locations. A similar conclusion that on-site lead concentrations are higher than background lead concentrations can be derived from the multiple Q-Q plot graph shown in Figure 2. It should be noted that univariate two sample t-test and WRS test (results not included in this report), and graphical displays, all lead to the conclusion that the lead concentrations of the two groups (populations) are significantly different, and on-site lead concentrations are significantly higher than the background lead concentrations. Since three analytes (lead, manganese, and iron) are present in the data set, univariate analyses will be conducted for each of the three contaminants separately.

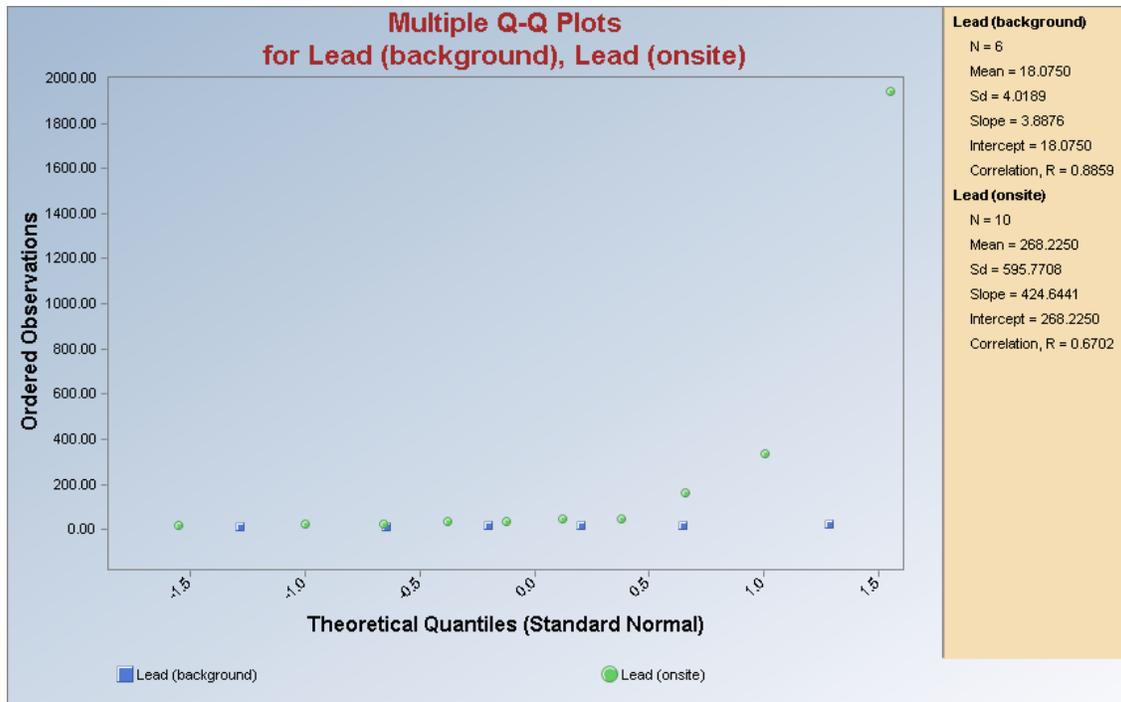


Figure 2. Multiple Q-Q Plots Comparing On-site and Background Lead Concentrations

Next, on-site and background manganese concentrations are being compared using the following *formal* graphical display.

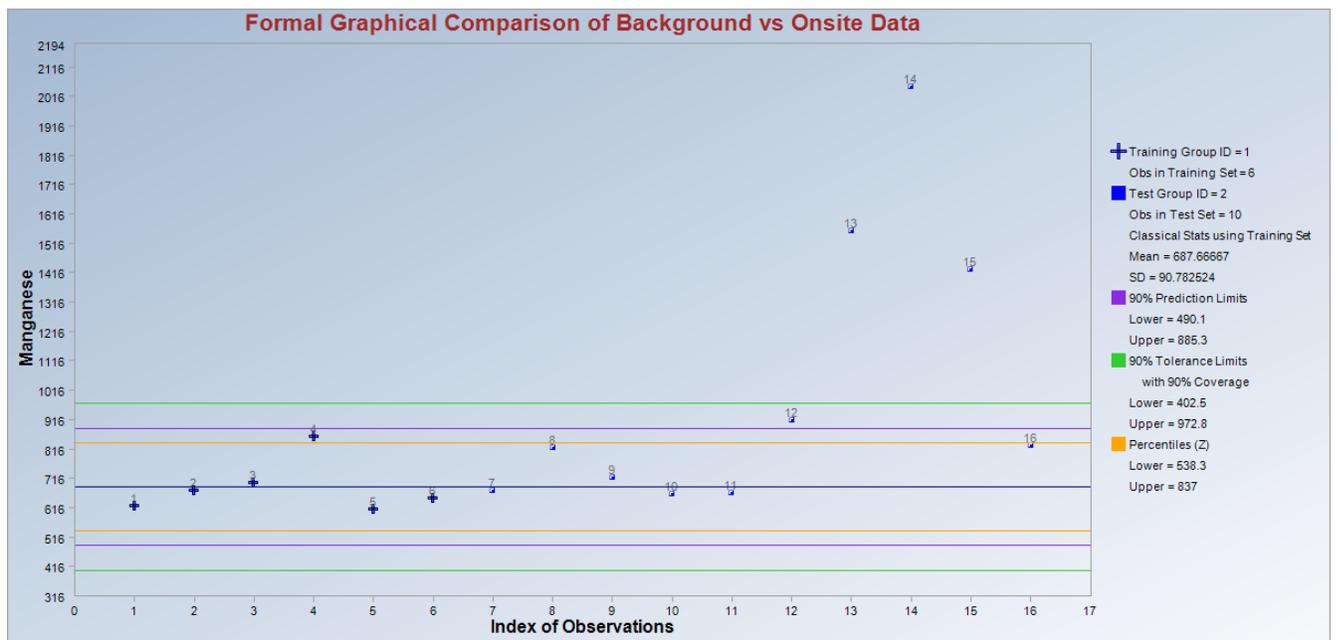


Figure 3. Formal Graphical Test to Compare Mn Concentrations of Two Populations

From Figure3, one can easily determine that the concentrations of the two groups (background data denoted by bold ‘+’, and on-site data denoted by ‘square’) are significantly different. Additionally, the graphical display shown in Figure3 identifies on-site contaminated (e.g., # 13, 14, and 15) locations, which a typical test statistic such as t-test or WRS test cannot identify.

Example 2. The graphical tests can also be used to compare two data sets (e.g., on-site vs background) consisting of nondetect observations. A four (4) dimensional data set consisting of 4 analytes has been considered. The nondetects are shown in red (Figure4). Using univariate methods, 4 different comparison graphs will be generated. One of those graphs is shown in the following Figure4.

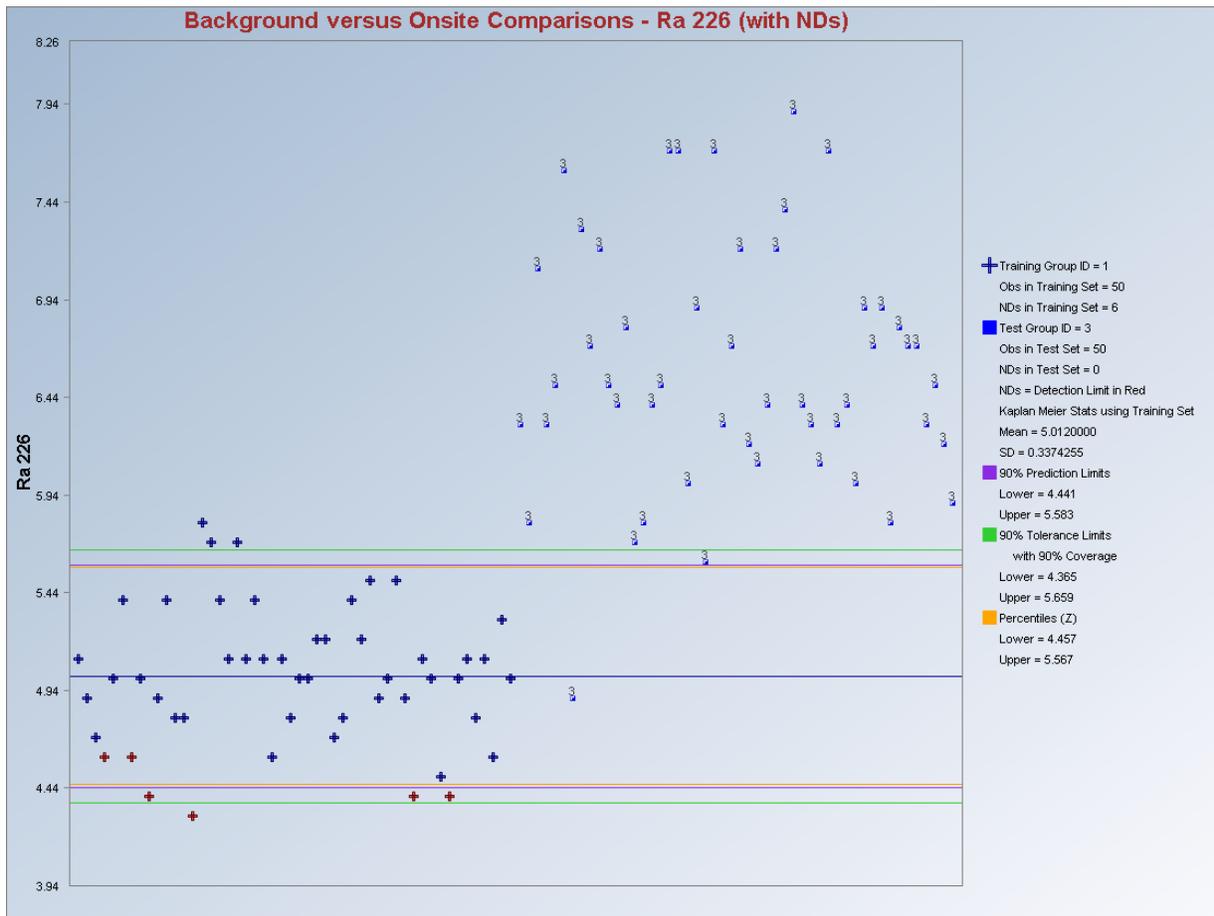


Figure 4. Graphical Test to Compare Ra 226 Concentrations of Two Groups, NDs shown in red

From Figure4, it is easy to see that concentrations of the analyte, Ra 226, in the two groups are significantly different. Moreover, this graph also identifies all on-site (“Test Group ID = 3”) locations labeled by ‘squares’ exhibiting significantly higher Ra 226 concentrations than those found in the background (“Training Group ID = 1”) data set, labeled by bold ‘+’. Since, the data set consists of four analytes; this test will have to be repeated four times for

each of the 4 variables. This data set is considered again in Example9 (Figure 16) of Section 2 to demonstrate the needs (and advantages) for using multivariate methods on multivariate data sets consisting of multiple contaminants.

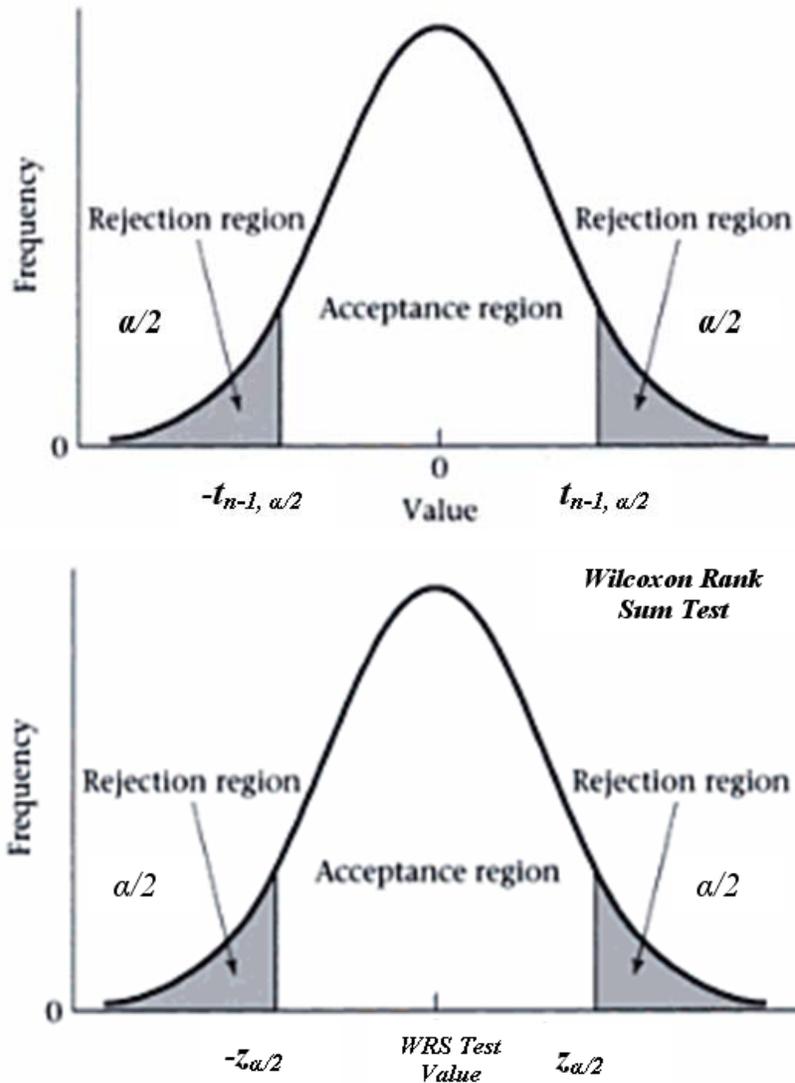
1.3 Comparing Concentrations of the two RBRA's

Once, RBRA data sets from the two formations have been established, the RNC concentrations of the two RBRA's will be compared. Statistical methods which will be used to compare RNC concentrations of the two RBRA's are described in this section. Since during this comparison, the objective is to determine if the concentrations of RNCs at the two geological formations are statistically similar, the use of two-sided alternative hypotheses described below will be most appropriate.

Let μ_1 represent the mean/median of a certain radionuclide at the Santa Susana RBRA, and μ_2 be the mean/median concentration of the same radionuclide at the Chatsworth RBRA (assume either the data from both Chatsworth RBRA's have been combined or one of the RBRA's selected as representative of Chatsworth background). The following null and alternative hypotheses will be considered. The allowable Type I ($=\alpha$) and Type II ($=\beta$) errors can both be fixed at 0.1. If deemed necessary, other levels of false positive and false negatives error rates will also be considered. The null and two-sided alternative hypotheses are stated as follows.

Null Hypothesis, H_0 : Mean/median, $\mu_1 =$ Mean/median, μ_2 , versus the two-sided (two-tailed) Alternative hypothesis, H_1 : Mean/median, $\mu_1 \neq$ Mean/median, μ_2

Based upon the collected data from the two formations, the null hypothesis will be tested against the alternative hypothesis. Depending upon level of significance, α (Type I error rate), and the test statistic used (e.g. t-test, WRS test), an acceptance region and a rejection region for the null hypothesis will be established. If the value of the test statistic (e.g., t-test, or WRS test) falls within the acceptance region, the null hypothesis that the mean/median concentrations of the two populations are similar (not statistically significantly different) will be accepted, otherwise the null hypothesis will be rejected. The acceptance and rejection regions with two sided alternative hypothesis are shown in the following figures. Note that since the alternative hypothesis is two tailed, the rejection region for the null hypothesis is also two tailed.



As mentioned before, the conclusions of hypotheses tests will be supplemented by information and patterns displayed in graphical displays (e.g., boxplots, Q-Q plots, histograms, control-chart-type displays). If hypotheses test results and graphical displays all lead to the conclusion that the RNC concentrations of the two RBRA are statistically comparable (similar), then the two RBRA data sets (Santa Susana and Chatsworth) may be merged together to make a single RBRA data set. All interested parties including site experts, project team, regulators, and stake holders will decide how the RBRA data sets will be used in future evaluation studies. Specifically the parties involved will determine if:

1. On-site RNC concentrations from the two formations (Santa Susana and Chatsworth) will be compared separately with their respective RBRA (Santa Susana and Chatsworth) data sets; or
2. On-site RNC concentrations from the two formations will be compared with concentrations

of the single merged RBRA data set, provided the statistical tests suggest that the RNC concentrations of the two RBRA data sets are not significantly different. In this case, the merged RBRA data set may be used as representative of the radiological background reference area for all future on-site versus background comparisons.

In any case, if the RBRA data sets (merged or individually) exhibit RNC concentrations comparable (not statistically significantly different) to those of DTL data set (perhaps after excluding potentially impacted RBRA locations), then those data sets will be used as background reference data sets for all future site investigations. In case the two RBRA data sets from the two formations (Santa Susana and Chatsworth) are significantly different in their RNC concentrations, then two separate reference data sets will be used in all future comparisons. Specifically, on-site versus background comparisons will be performed separately for the two geological formations of the SSFL site.

1.4 Establishing Background Level RNC Concentrations or Background Threshold Values (BTVs)

Procedures to estimate and determine the BTVs or trigger values will commence after successful completion of establishing defensible RBRA data sets. Once defensible RBRA data sets (combined RBRA data set, or two separate RBRA data sets, one for each formation) have been established, evaluations will be conducted using the procedures described in this section. The main objective of these evaluations is to identify statistical methods which will be used to compare on-site RNC concentrations (when they become available) with RNC concentrations of the RBRA data sets. Specifically, based upon the RBRA data sets, background level RNC concentrations, also known as BTVs will be computed. These BTVs may be used to compare on-site observations in future investigations. For an example, if an on-site observation exceeds a BTV, the corresponding on-site location may be considered impacted by the site activities requiring further investigations or cleanup.

Additionally, when comparing on-site concentrations with some upper limit (e.g., BTV, 90th percentile of RBRA data set) of the background data set, other formal graphical methods (e.g., shown in Figures 3 and 4) as discussed during the stakeholder meeting on April 30th will also be used to compare one or more on-site observations with the entire RBRA data set(s). Depending upon the statistical comparability of the two RBRA data sets (from two formations) and the decision made by all concerned parties: 1) on-site RNC concentrations may be compared with concentrations of the merged RBRA data set (when the two RBRA data sets exhibit statistically comparable concentrations, and decision makers agree to merge them); or 2) on-site RNC concentrations of the two formations will be compared separately with the RBRA concentration of their respective formations (when the two RBRA are significantly different or the decision makers decide not to merge them).

1.4.1 Estimation of Background Threshold Values (BTVs)

Once defensible and representative (e.g., representing site conditions before any of the site related activities) RBRA data sets (free of outliers) have been established, BTVs will be estimated by using the documented and well established statistical procedures available in the environmental statistical literature. Typically, BTVs are estimated by upper percentiles (e.g., 90th) or upper tolerance limits (e.g., 90% upper confidence limit of the 90th percentile- 90%-90th UTL) computed based upon a pre-established reference data set (EPA 1989, 1992, 2002, Navy 1998, 2002, and ProUCL 4.00.01, 2009). Inclusion of outliers in a reference data set may yield inflated and non-representative estimates of background threshold values. As mentioned before, outliers will not be included in the computation of any of the decision making statistics including upper percentiles, upper prediction limits, and upper tolerance limits. In order to compute conservative and defensible estimates of BTVs/trigger values all statistics will be computed using original raw data set, and no log-transformation will be used. Additionally, robust and resistant methods will be used to compute upper limits based upon the RBRA data set(s). Robust estimation methods assign reduced or negligible weights to potential outlying observations (Singh (1993), Singh and Nocerino, (1995)).

The proposed robust statistical methods to estimate BTVs will provide double protection against outlying observations that potentially increase the variability of the RBRA data sets. First, the RBRA data set will be free of outliers, and second the robust and resistant methods will be used to compute the upper limits. Robust and resistant methods automatically assign reduced to negligible weights to outlying observations (e.g., Rousseeuw and van Zomeren (1990), Singh and Nocerino (1997)). Estimates of BTVs thus obtained will be undoubtedly protective of human health and the environment.

1.4.1.1 Not to Use Reference Area Average to Estimate BTVs

It is recommended not to use reference area average or its associated 95% upper confidence limit (UCL95) to estimate of a BTV. Since, individual on-site observations will be compared with a trigger value, the trigger value/BTV should represent a threshold level meant for comparison of individual concentrations (and not a mean concentration). Comparing individual on-site values with reference area average value is not desirable, as that comparison will result in a high percentage of false positives without providing additional protection to human health and the environment. The comparison of individual on-site observations with reference area average value would result in the further characterization, and potentially remediation, of unimpacted, clean site locations. This kind of comparison is not supported by statistical theory. This is further illustrated in Figure5 below based upon the data set of Example2.

Figure5 has the graphical display of the two-sided 90% confidence interval of the mean (showing 5% lower confidence limit and 95% upper confidence limit), the 5th and 95th percentiles, and the two-sided 90%-90th tolerance interval based on the *reference area* data set of Example 2. Since the confidence interval of the mean is meant to provide coverage for the mean (e.g., reference area mean, on-site area mean), several individual reference area values

lie above the reference area mean and its one-sided 95 % upper confidence limit (UCL95) shown in Figure5 below. If one assumes that a location with measurement lying above the reference area mean, which equals 5.012 in this example, or its UCL95, which equals 5.092 in this example, has been impacted by site-related contaminants, then several reference area locations lying above the UCL95 will also appear to be impacted by site-related contaminants. This is a fallacy because by definition contamination is always above background.

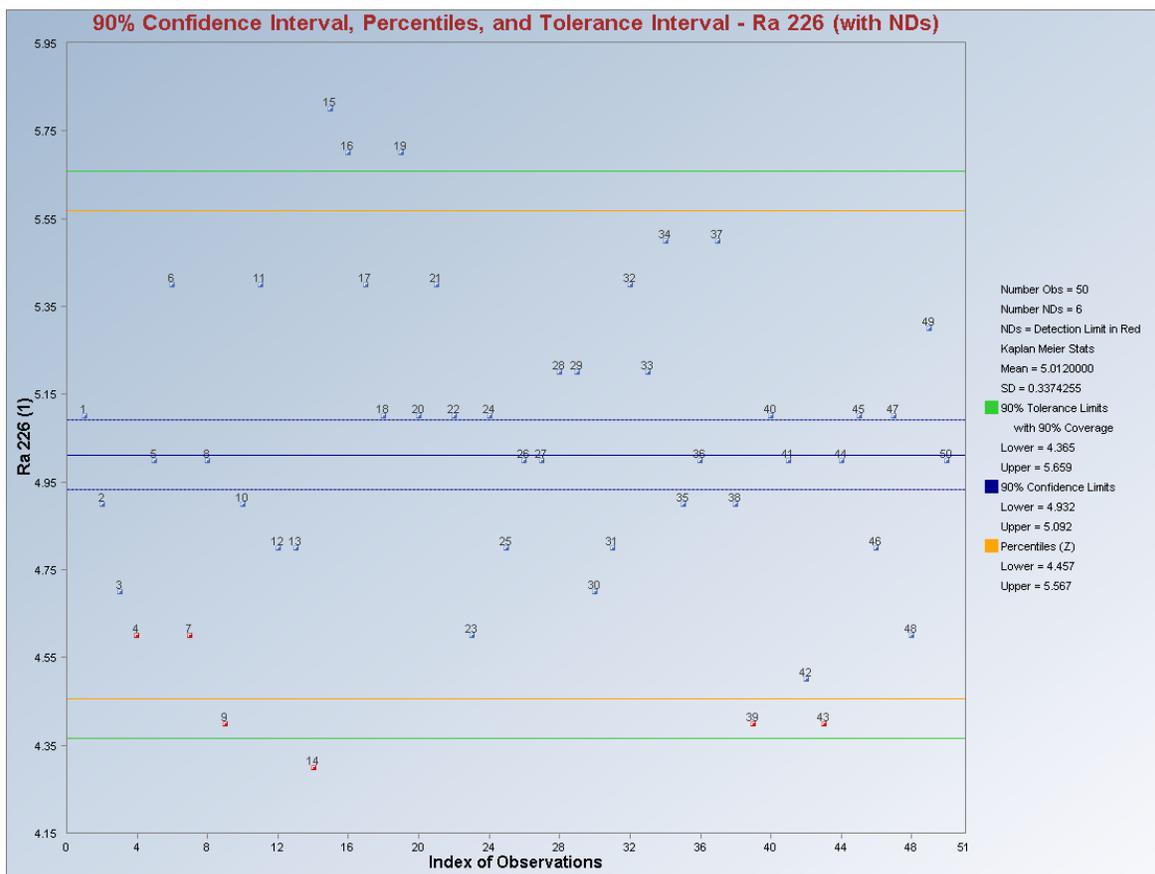


Figure 5. 90% Two-sided Confidence Interval for the Mean Computed Using Reference Data Set

It is, therefore recommended to use upper limits such as 90th percentiles or 90% -90th upper tolerance limits as estimates of BTVs/trigger values.

1.4.1.2 Computing Upper Limits to Estimate BTVs

This section briefly describes statistics which will be used to estimate BTVs. The BTVs are estimated by upper percentiles (e.g., 90th) or upper tolerance limits (e.g., 90% upper confidence limit of the 90th percentile- 90%-90th UTL) computed based upon a pre-established reference data set (EPA 1989, 1992, 2002, Navy 1998, 2002, and ProUCL 4.00.01, 2009).

The relationship between the values of the statistics often used to estimate the BTVs or trigger values is given as follows:

$$90^{\text{th}} \text{ percentile} \leq 90\% \text{ UPL} \leq 90\% \text{ UTL} - 90^{\text{th}} \text{ percentile} \quad (90\% - 90^{\text{th}} \text{ UTL}) \leq 95\% \text{ UTL} - 90^{\text{th}} \text{ percentile} \quad (95\% - 90^{\text{th}} \text{ UTL})$$

$$95^{\text{th}} \text{ percentile} \leq 95\% \text{ UPL} \leq 90\% \text{ UTL} - 95^{\text{th}} \text{ percentile} \quad (90\% - 95^{\text{th}} \text{ UTL}) \leq 95\% \text{ UTL} - 95^{\text{th}} \text{ percentile} \quad (95\% - 95^{\text{th}} \text{ UTL})$$

The values of these upper limits are illustrated by graphical displays shown in Example3. Furthermore, in order to illustrate how the use of robust and resistant methods yields conservative and defensible estimates of BTVs, both classical and robust estimates of BTVs are discussed in Example4.

Example 3. A reference data set of size 20 is used to graphically display upper limits used to estimate the BTVs/trigger values. The data set does not consist of any outliers (e.g., using Dixon test and other robust outlier identification methods). Figure6 illustrates the various classical statistics (90th percentile and 90% -90th UTL) used to estimate the BTVs; and Figure7 has the corresponding robust and resistant upper limits. Since no outliers are present in this data set, classical and robust estimates of BTVs are in complete agreement.

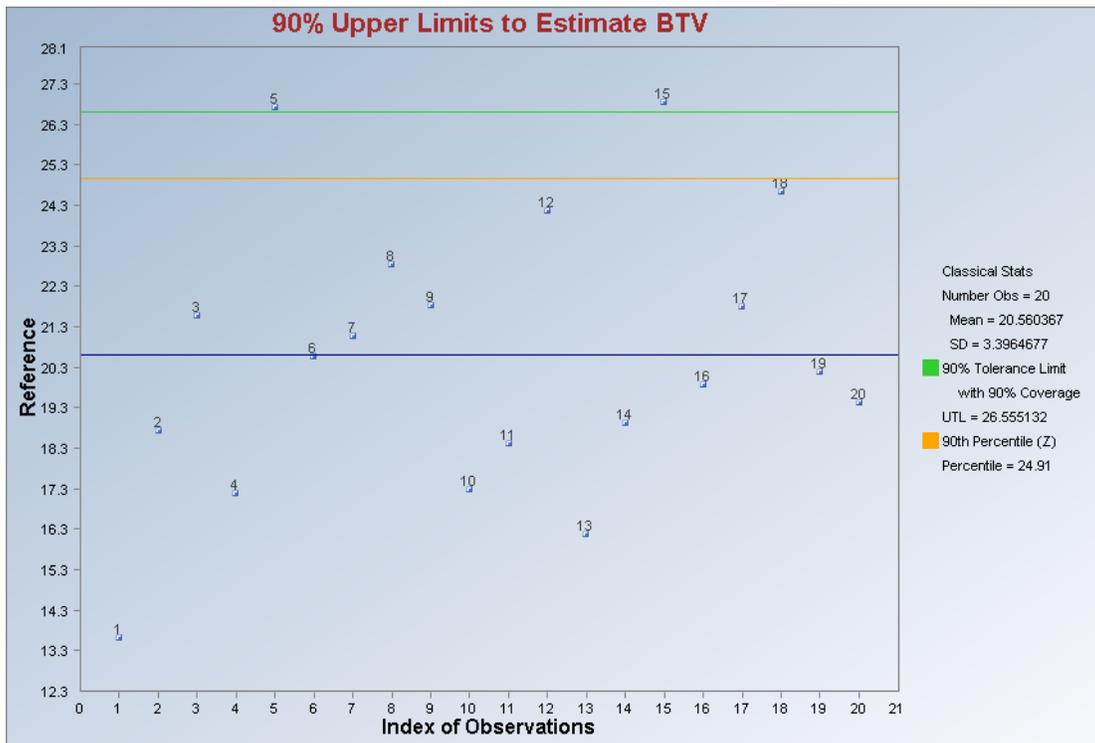


Figure 6. Graphical display of classical 90th percentile and 90% -90th UTL

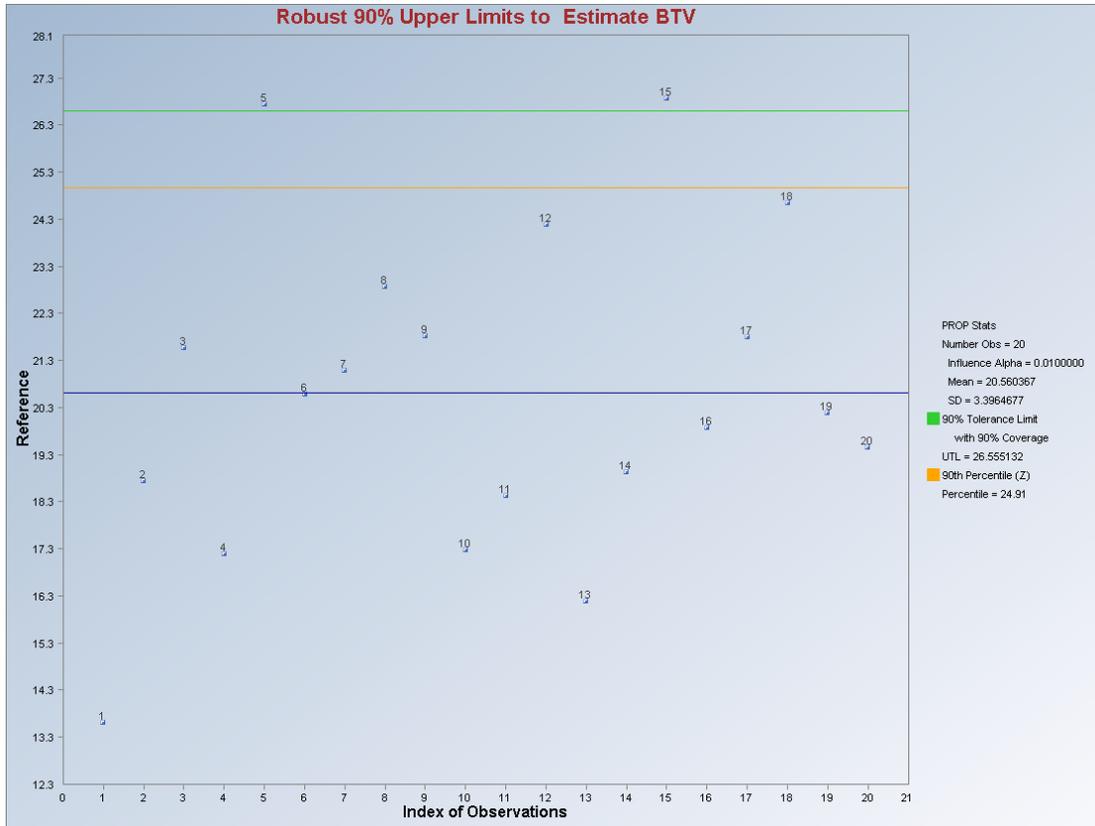


Figure 7. Graphical display of robust 90th percentile and 90% -90th UTL

This reference data set does not consist of any outliers. Therefore, both classical and robust 90th percentile and 90%-90th UTL of the reference area data set are in complete agreement. For this data set, parametric 90th percentile = 24.91 and one-sided 90%-90th UTL = 26.56. An on-site RNC observation belonging to the background population will lie at or below the 90th percentile with probability 0.90. The 90%-90th UTL represents a 90% upper confidence limit on the 90th percentile and provides coverage to the 90th percentile.

Example 4. This example uses a reference data set consisting of 9 measurements. The classical upper limits (90% percentile, 90%-90th UTL) are shown in Figure8. From Figure8, it appears that the observation number 4 (=67.72) represents a potential outlier. A simple outlier test (e.g., Dixon’s test) also suggests that observation number 4 = 67.72 indeed represents an outlier. Since the presence of outlier distorts classical statistics such as mean, standard deviation, percentiles, and UTLs, robust and resistant methods will be used to estimate the BTVs. The upper limits to estimate BTV based upon robust and resistant method are shown in Figure9 and the corresponding upper limits without the outlier (observation # 4 omitted) are shown in Figure10. It is noted that the robust limits and the limits obtained without the outlier are in close agreement (Figures 9 and 10). The values of the various limits are summarized in Table1.

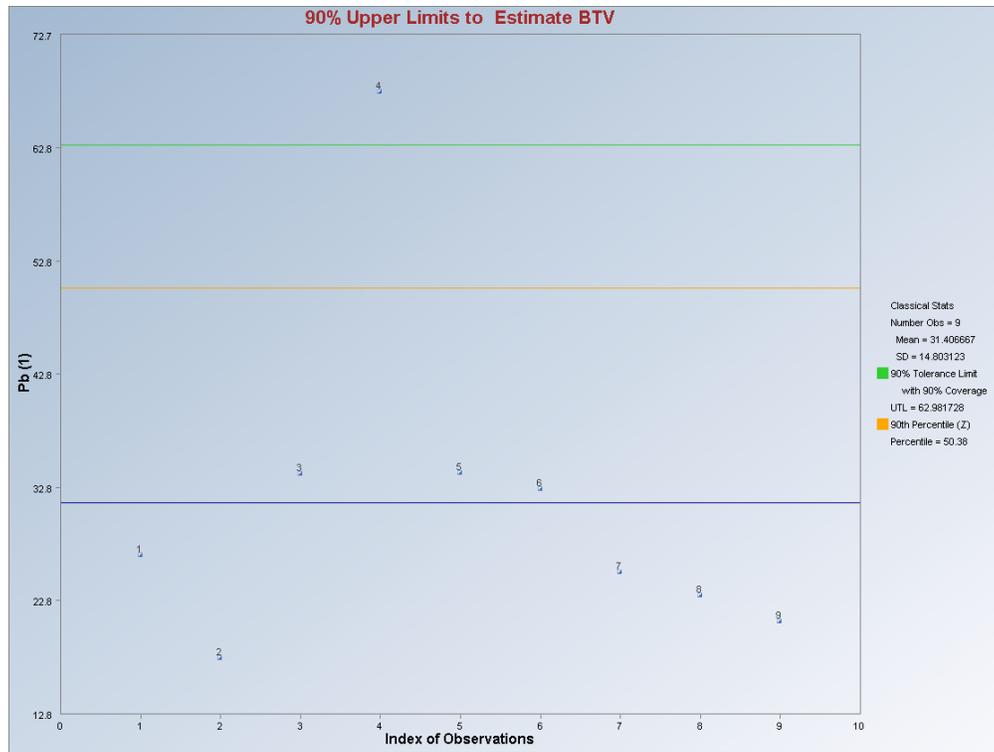


Figure 8. Graphical display of Classical 90th Percentile and 90% -90th UTL with Outlier (#4)

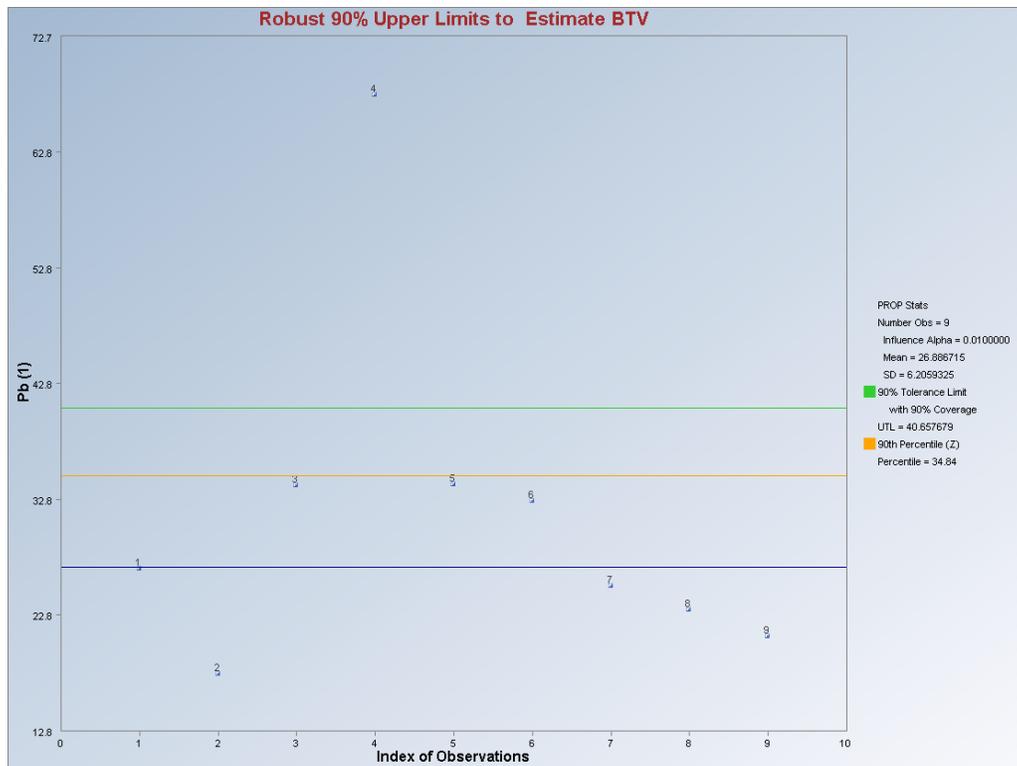


Figure 9. Graphical display of Robust 90th percentile and 90% -90th UTL with Outlier (#4)

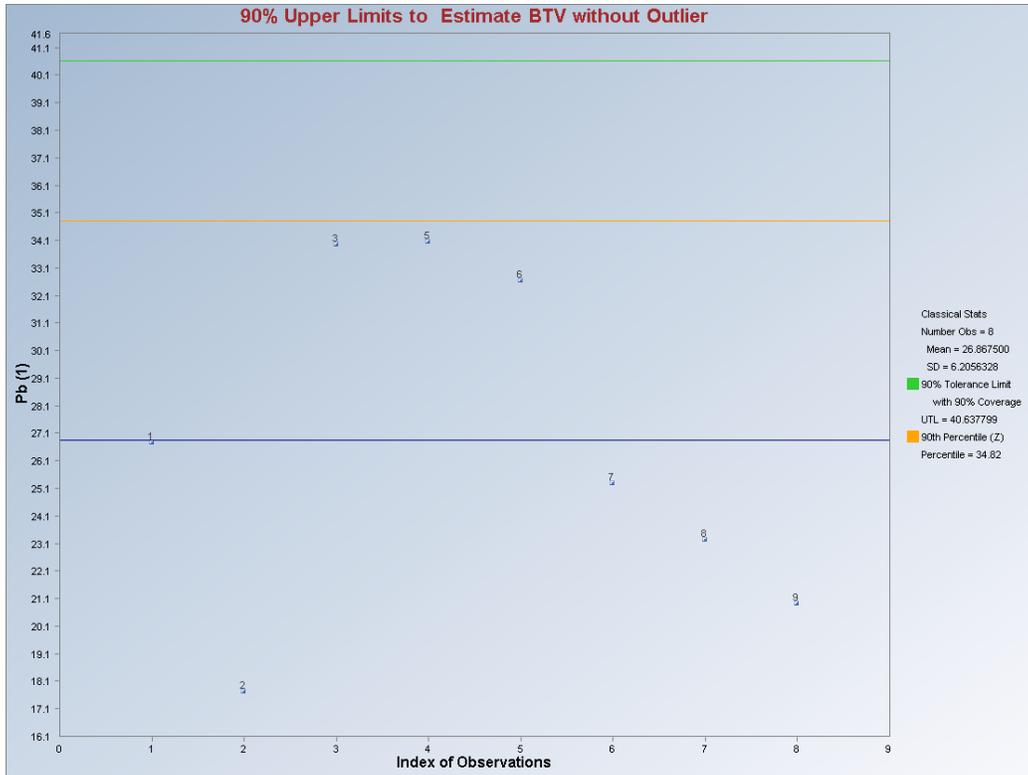


Figure 10. Display of classical 90th percentile and 90% -90th UTL without Outlier (#4)

Table 1. Upper Limits to Estimate BTV

Method	Mean	Sd	90 th percentile	90%-90 th UTL
Classical Method with Outlier	31.41	14.80	50.38	62.98
Robust/Resistant Method with Outlier	26.89	6.21	34.84	40.66
Classical Method without Outlier	26.87	6.21	34.82	40.64

From Figures 8-10, and Table1, it is easy to see outliers inflate the variability and distort all other statistics of interest (e.g., percentile, UTL). However, robust methods automatically assign reduced/negligible weights to outlying observations, therefore, robust and resistant (to outliers) methods yield statistics (BTVs) that are not inflated by outliers. The upper limits (to estimate BTVs) based upon the robust method (PROP influence function) and the classical method without the outlier are in close agreement.

It should be noted that RBRA data sets will be screened for outliers before computing estimates of BTVs. Outliers will not be included in RBRA data sets. All statistics will be computed using data in original scale without using a log-transformation. Furthermore, robust and resistant methods will be used to compute upper limits to estimate BTVs. The robust statistics thus obtained will be conservative and protective of human health and the environment.

A stepwise procedure based upon *robust and resistant estimates of BTVs* can be used to determine if an on-site observation is potentially impacted by the site activities.

- If an on-site measurement falls below the robust 90th percentile of the RBRA data set, then the location of that measurement will be considered unimpacted.
- If an on-site observation lies between the robust 90th percentile and the robust 90%-90th UTL, the project team will take a closer look at the location and determine whether the corresponding location should be further investigated.
- If an on-site location exceeds the robust 90%-90th UTL, the corresponding on-site location will be considered as potentially impacted by the site activities and further investigation/evaluation will be needed.

The stepwise procedure based upon robust estimates of BTVs described above will lead to conclusions that are statistically defensible and protective of human health and the environment.

1.4.2 Comparing On-site RNC Concentrations with Background Data Set (as a whole versus some upper limit such as UTL)

Other formal graphical displays will also be used to perform these comparisons. Specifically, one or more on-site observations will be graphically compared with the entire reference background data set. A couple of univariate graphical displays (Figures 11 and 12) illustrating these comparisons are given in Example 5.

Example 5. On-site and background chromium (Cr) concentration comparisons can also be made by using the following tolerance interval comparison graph shown in Figure 11

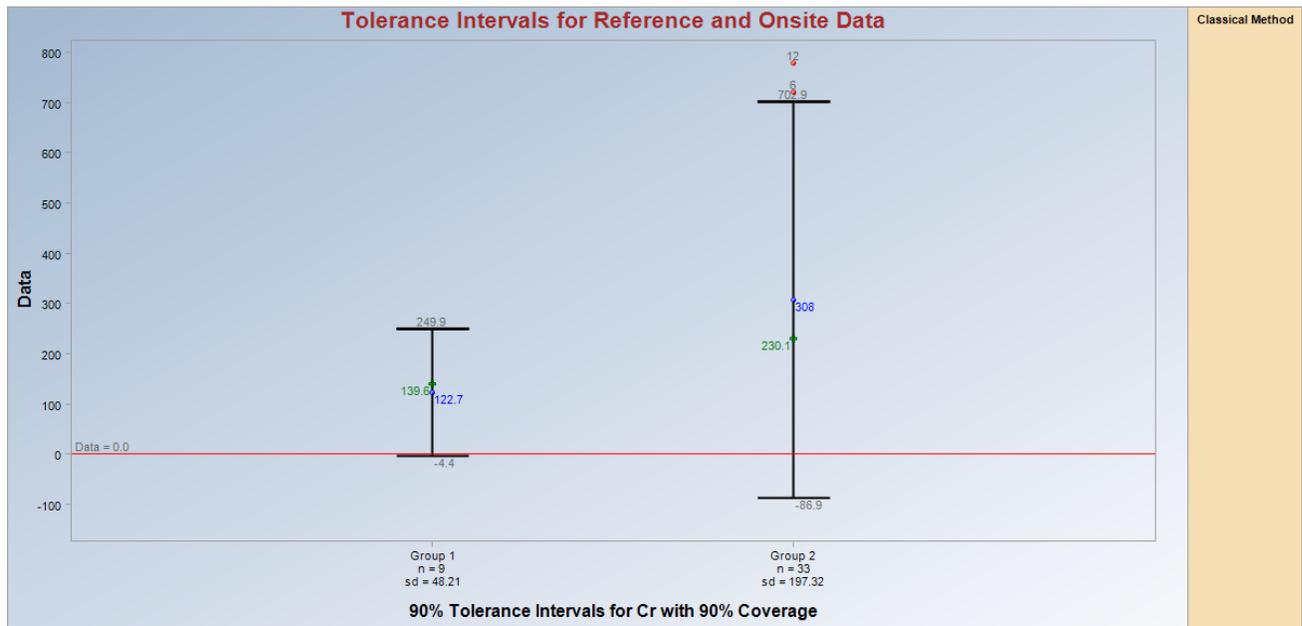


Figure 11. 90% Tolerance Intervals for Reference and On-site Chromium Concentrations

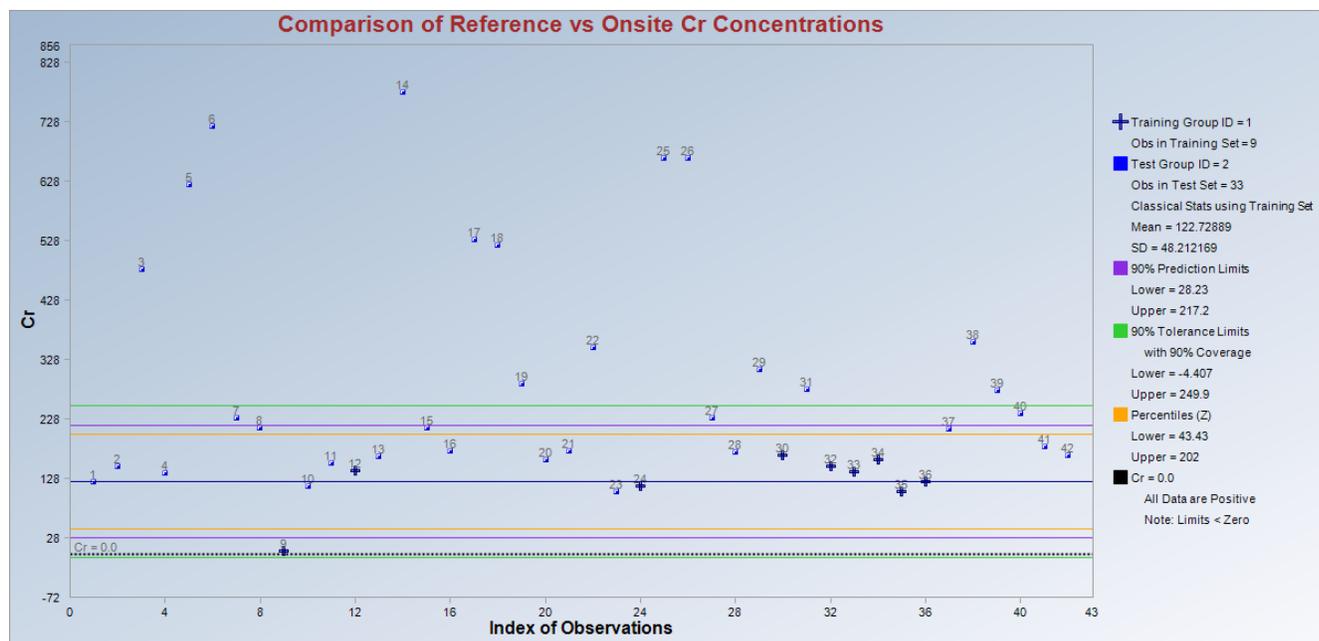


Figure 12. Formal Graphical Test to Compare Cr Concentrations of Two Populations

From Figures 11 and 12, one can easily determine that the concentrations of the two groups (Reference data (group ID=1) denoted by bold ‘+’, and On-site data (group ID=2) denoted by ‘square’) are significantly different. Actually these formal graphs demonstrate that on-site chromium concentrations are significantly higher than those of the reference are. The graphical display shown in Figure 12 identifies all on-site locations exhibiting chromium concentrations higher than BTVs (e.g., 95% UPL, 95th percentile, and 95%-90th UTL as shown in Figure 12). It should be noted that use of a typical t-test or WRS test can only provide the conclusion that the on-site locations exhibit concentrations significantly higher than the background locations.

2.0 Statistical Evaluations Based Upon Multivariate Methods

It is noted that many correlated constituents (e.g., radionuclides, and metals by DTSC) will be considered in RBS evaluations. Performing statistical analyses for each constituent separately can be tedious and time consuming. Furthermore, the use of univariate methods on multivariate data sets (multiple constituents) fail to control Type I and Type II error rates (false positives and false negatives) specified in the DQOs. Therefore, for multivariate data sets consisting of multiple radionuclides, appropriate multivariate methods may also be used to address stakeholders’ concerns and statistical issues of the RBS evaluations as described in the SAP. Multivariate methods as incorporated in Scout 2008 are based upon the peer-reviewed published research efforts of many researchers and academicians. Scout 2008 comes with a User Guide and many technical published journal articles used in the development of Scout 2008, Version 1.00.01. Multivariate robust methods (e.g., Johnson and Wichern, 2002, Rousseeuw and Leroy, 1987, Rousseeuw and van Zomeren, 1990, Singh 1993, Singh and Nocerino, 1995, 1997) are resistant to outliers and can successfully identify all potential

outliers that may be present in a data set. Theoretical details of the multivariate methods used in this document can be found in the cited references.

Robust and resistant (to outliers) statistical methods will be used to identify potential outliers in univariate and multivariate data sets; and formal multivariate (based upon Mahalanobis distances (MDs)) graphical test displays (e.g., Singh and Nocerino (1995, 1997)) available in the QA/QC module of Scout 2008 will be used to determine if concentrations of RNCs of the two groups (e.g., RBRA vs. DTL, On-site vs. RBRA) differ significantly. Additionally, multivariate graphical displays will be used to determine and identify on-site (test set) observations that do not belong to the background (training set) population.

It should be noted that statistics, MDs and maximum (MDs) are multivariate in nature and are computed using all selected analytes present in a data set. Therefore, in multivariate graphs (e.g., shown in Figures 13 through 18) based upon MDs, all selected analytes are being used and included even though they are not directly shown on the graphical displays. In addition to generating graphical displays, Scout 2008 also generates Excel output sheets summarizing details about the selected variables, statistical tests, and statistics. However, in this document, only graphical displays have been used. The effectiveness and some of the advantages of using multivariate methods on multivariate data sets is illustrated in the following examples.

Example 6. Consider a 6-dimensional (e.g., 6 radionuclides) data set consisting of $n=20$ observations (e.g., DTLs). For the sake of illustration, assume that the data set has 4 outliers. The univariate Rosner outlier test (USEPA, 2006, MARSSIM, 2000) cannot be used since $n < 25$. The univariate Dixon test could not identify any outliers. The Robust multivariate formal outlier test identified all 4 outliers as shown in the following Figure 13.

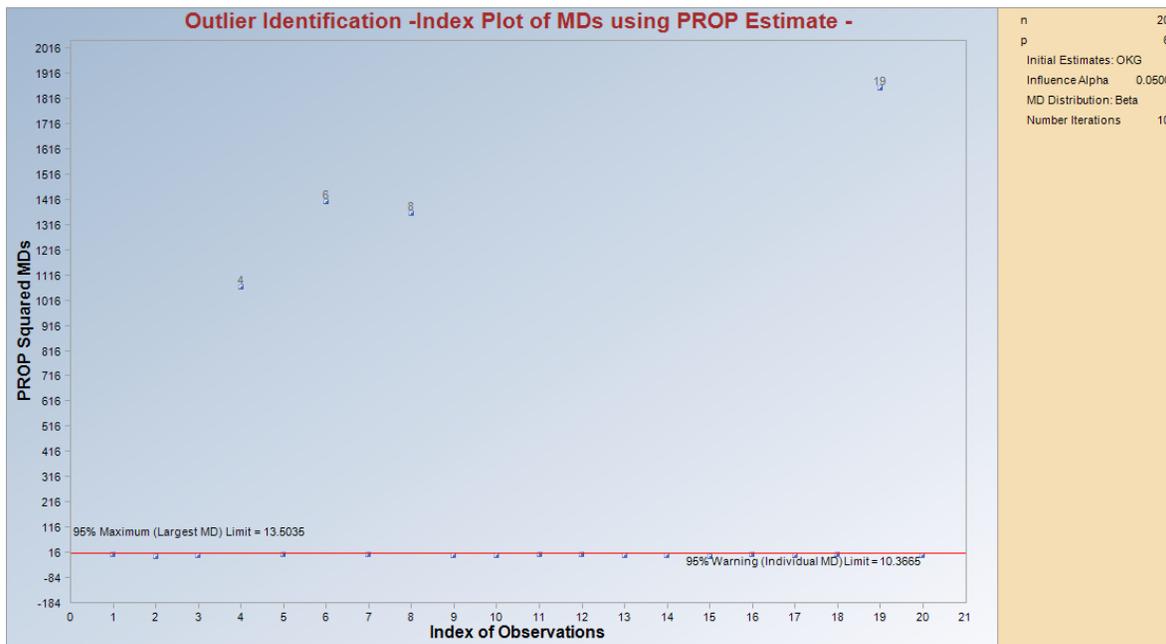


Figure 13. Identification of Outliers based upon Robust PROP Influence Function

Example 7. Effectiveness of multivariate robust outlier methods is shown by using another data set consisting of several outliers of varying degrees of extremeness. The graphical display based upon the robust outlier method not only identified all outliers successfully, but also revealed 4 extreme outliers (#11, 20, 30, and 34), 2 intermediate outliers (#7, 14), and 1 mild outlier as shown in Figure14 below.

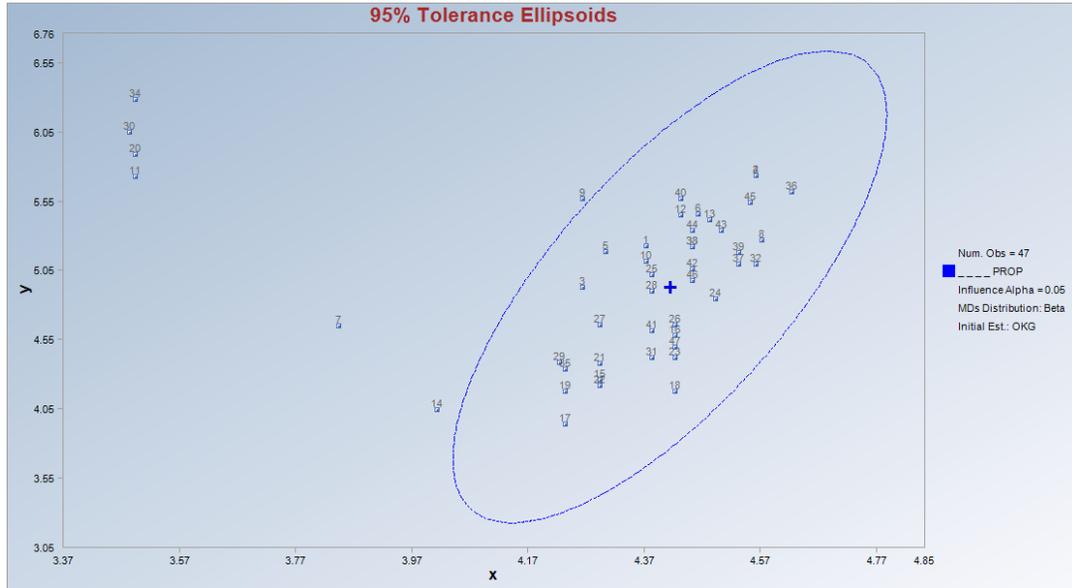


Figure 14. Identification of Outliers based upon the PROP Influence Function

Example 8. The three-dimensional (lead, manganese, iron) real data set (consisting of on-site and offsite background concentration data) from a Superfund site was used earlier in Example1, Section 1.0 to illustrate the use of univariate graphical methods. In this example, the data set is used to illustrate the effectiveness of multivariate graphical test to determine if the metal concentrations of two populations (background vs site) differ significantly. Using the multivariate graphical test based upon MDs (representing all 3 contaminants), one can not only determine that there are differences between two populations (site vs background) but can also determine which of the site (e.g., test set, group 2) observations do not belong to the background population (e.g., training set, group 1). Specifically, from Figure15, it can be determined that on-site locations 13, 14, and 15 do not belong to the background population (training set). Note that univariate manganese graphical test shown in Figure3 also identified the same three (3) on-site (test set) observations (13, 14, and 15) not belonging to the background (training set) population.

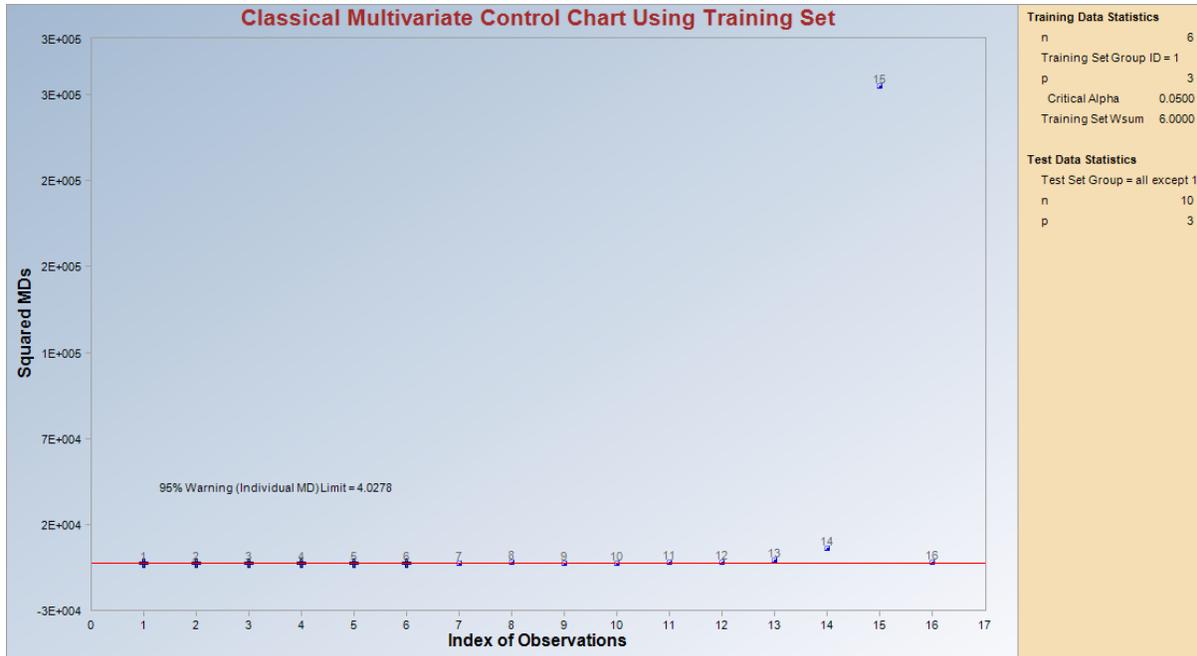


Figure 15. Multivariate (3 analytes) two-sample test supplemented with graphical display

Example 9. This four dimensional data set was considered earlier in Example 2. From the formal multivariate graphical test display shown in Figure 16, it is easy to conclude that the concentrations of the two groups (e.g., On-site vs Background, training set vs test set) are significantly different. No other univariate test (graphical or analytical) is needed to come to this conclusion, and the associated Type Error I rate indeed stays fixed at 0.05. Figure 16a has a similar graph comparing populations 2 and 3. Typically, on-site observations lying above the control limit (“95% Maximum (Largest MD) Limit”) on the control-chart-type index plot (Figure 16) of MDs may represent impacted site observations requiring further investigation.

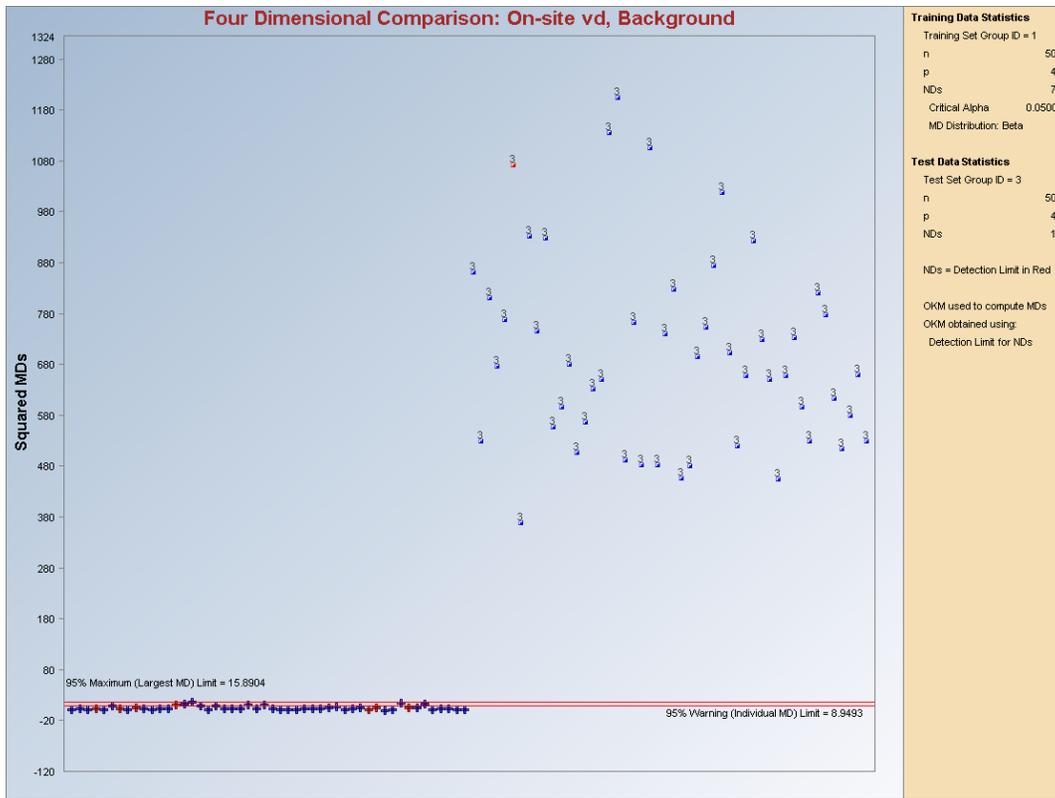


Figure 16. Multivariate (4 analytes) formal graphical two-sample test

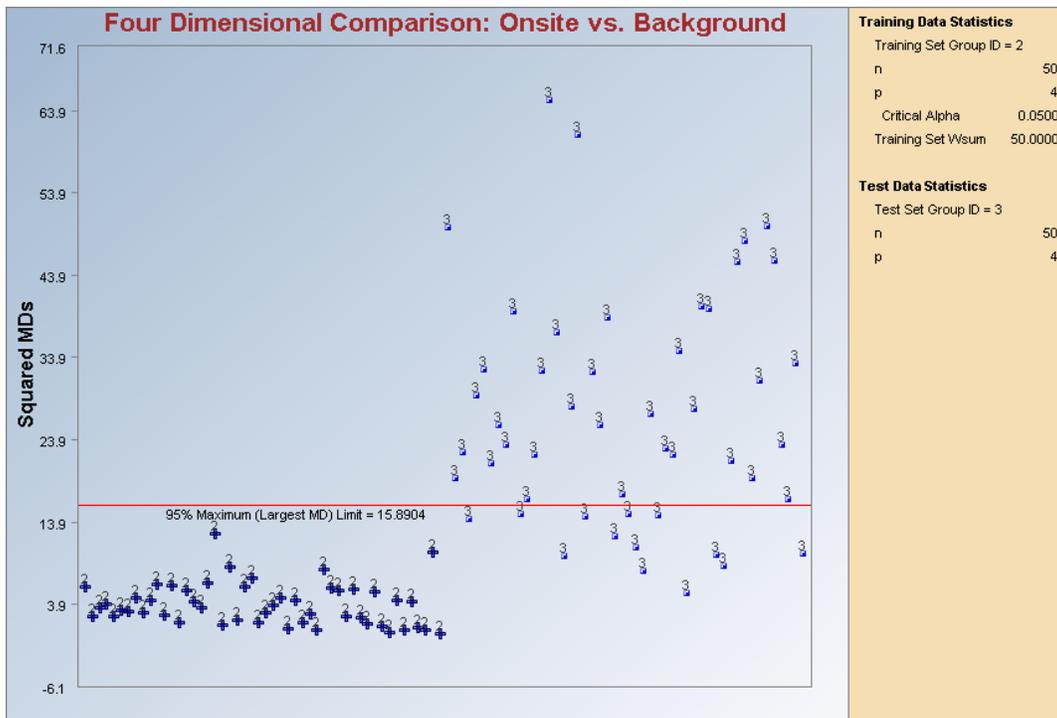


Figure 16a. Multivariate (4 analytes) formal graphical two-sample test

Example 10. Another five dimensional crude oil data set from two different populations is used to illustrate the use of multivariate methods to assess and test the differences between two groups (e.g., Background vs On-site, Group 1 vs Group 2). The graph shown below in Figure17 can be used to come to the conclusion that the bivariate (vanadium and beryllium) concentrations of the two groups (e.g., training set vs test set, group 1 vs group 2, RBRA vs DTL, On-site vs RBRA) differ significantly. Test set (Group 2) observations lying outside the tolerance ellipsoid shown in Figure17 may be considered as not belonging to the training set (Group 1) population (e.g., background population). Multivariate graph (Figure18) using all 5 metals quickly reveals that the metal concentrations of two groups are significantly different. Observations lying above the maximum limit shown on Figure18 can be considered as not belonging to the background (training set, group 1) population.

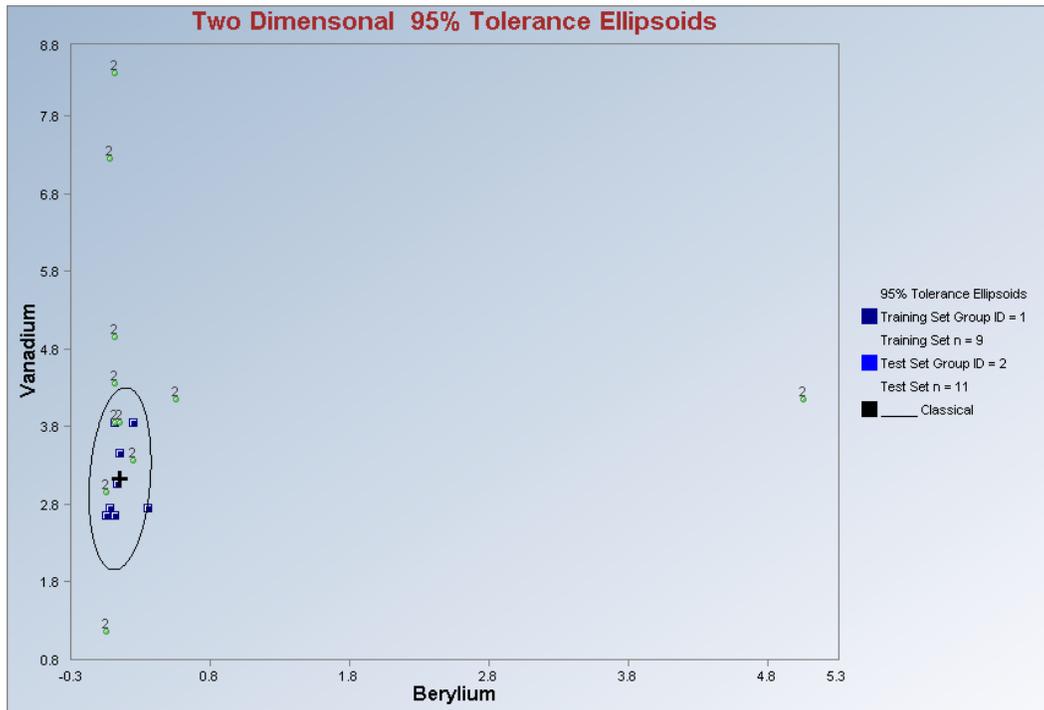


Figure 17. Bivariate formal graphical two-sample test

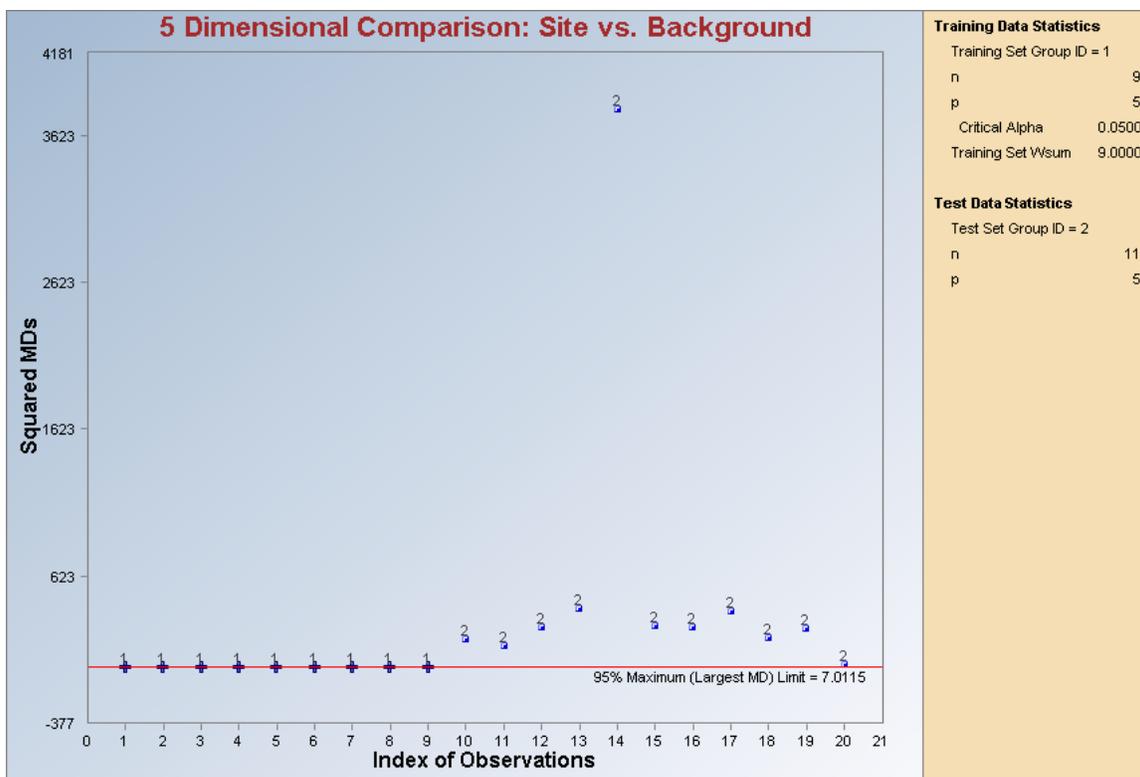


Figure 18. 5-Dimensional formal two-sample test: Site (group 2) vs Background (group 1)

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Attachment A

Background Module of ProUCL 4.00.04

The background module of ProUCL 4.00.04 will be used to address most of the objectives of evaluations. The background module of ProUCL 4.00.04 (and its earlier versions) was developed to: 1) compare site concentrations data distribution to background concentrations data distribution, 2) compare point-by-point site data to some pre-established screening level such as background threshold value (BTV) or not-to-exceed value, or 3) compute background upper threshold value (BTV) based upon site-specific background data. Specifically, while comparing site data to background data, one is interested in determining whether the site concentrations can be considered as coming from (site concentrations comparable to those of background) the background population. The main objective of performing background versus site concentrations comparison is to determine if site concentration data exceed some background threshold levels (e.g., upper prediction limit, upper tolerance limit) with high confidence. Typically, in such situations, background upper threshold is estimated by a 95% upper prediction limit (95UPL), 95% upper limit for 90th, or 95th percentile (95UTL90, or 95UTL95) provided enough (e.g., at least 8-10, more are desirable) background data are available. Thus a 95% UPL or UTL is computed based upon background data, and individual point-by-point site observations are compared with the BTVs. For details refer to ProUCL 4.00.04 technical guide, which can be downloaded from the EPA website.

References

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Attachment B

Identification of Outliers

It is noted that typically, in environmental applications (e.g., EPA, 2006), classical Rosner and Dixon outlier tests are used to identify outliers which often suffer from masking effects. However, it is well known (e.g., Singh, 1993) that classical univariate outlier tests (Dixon test, Rosner test) suffer from masking effects (e.g., extreme outliers may mask the occurrence of other intermediate outliers), it is therefore, suggested that for univariate data sets, these classical outlier tests be supplemented with graphical displays such as a box plot or a quantile-quantile (Q-Q) plot. Moreover, in order to use Rosner test, one needs to specify the number of suspected outliers, which is not known in advance. The user has to try many values (e.g., =1, 2, 3, 4,..., 10) for the number of suspected outliers. Therefore, it is always desirable to supplement analytical statistics (e.g., GOF test, Rosner test statistic) and results (as they may get inflated by outliers) with graphical displays. The use of UTLs inflated by outliers can result in inflated estimates of background threshold values (BTVs). The use of inflated BTVs is not protective of human health and the environment.

The use of robust and resistant outlier identification procedures (e.g., Singh, 1993, and Singh and Nocerino, 1995 and 1997) is recommended when multiple outliers may be present. Outliers (specifically high and extremely high values) in site data represent potentially polluted locations. These observations need to be identified using effective statistical methods. Outliers found in RBRAs and DTLs may represent observations not representative of representative background conditions. Such background locations representing outliers will not be included in statistical evaluations to address assessment objectives of the RBS. A defensible background data set should represent a “single” background population (e.g., representative of site conditions before any of the industrial site related activities) free of contaminating observations such as outliers. In a background data set, outliers may represent potentially contaminated observations from impacted site areas under study or possibly from other polluted site(s).

Furthermore, it needs to be emphasized that outliers (if any) need to be identified in the original raw scale as the remediation and cleanup decisions need to be made using data and statistics (e.g., UTL or UCL) in the original scale. An outlier in the raw scale may not be an outlier in the transformed space (e.g., log-scale). That does not imply that the elevated concentration in the original scale represents a clean location and may be included in the statistical computations such as estimation of a background threshold value (BTV). This topic has been discussed in greater detail in Chapter 7 of ProUCL 4.00.04 Technical Guide (EPA, 2009). It should be pointed out that the use of a log-transformation tends to hide contamination by accommodating outlying observations.

EPA software Scout 2008 offers many robust outlier identification and robust estimation procedures. Several of those methods will be used in evaluations of RBS data as described in the SAP for the SSFL site. The details of the robust outlier identification procedures can be

found in the references used in this brief write-up. Several worked out examples using robust methods can be found in Scout 2008 User Guide.

In order to establish that when dealing with multivariate data sets (consisting of multiple radionuclides), multivariate tests are more effective to address statistical issues and in controlling decision errors (false positives and false negatives), both univariate (as commonly used) and multivariate tests supplemented with graphical displays will be used on the same data set. Results based upon two approaches will be compared, and in case of discrepancies between the conclusions derived using the two approaches, the most conservative conclusion protective of human health will be used.

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Attachment C

Analyses of Data Sets with Nondetects (NDs) and Below Detection Limit (BDL) Observations

Statistical Approaches for Data Sets with Nondetect Observations

Nondetect (ND) or below detection limit (BDL) observations are inevitable in environmental data sets. Statisticians (e.g., Helsel, 2005, Singh, Maichle, and Lee, 2006) have developed defensible statistical methods to handle data sets consisting of ND observations with single and multiple detection limits. Singh, Maichle, and Lee (EPA, 2006) studied the performances of the various upper confidence limit computation methods (e.g., Cohen, KM, bootstrap) including the simple substitution methods (such as the DL/2 and DL methods, regression on order statistics – ROS methods) for data sets with ND observations. They concluded that the upper limits obtained using the substitution methods (proxy methods), including the replacement of nondetects by respective DL/2 do not perform well even when the percentage of nondetect observations is low, such as 5%-10%. Therefore, for all statistical analyses, use of substitution methods such as the DL/2 and DL methods will be avoided. Specifically, the use of substitution methods will be avoided to perform GOF test, to perform two sample comparisons, to compute summary statistics and various other limits (e.g., UTL, UPL) used to estimate the background threshold values. For more accurate and defensible results and conclusions, statistically rigorous methods such as the Kaplan-Meier method and bootstrap methods (now available in ProUCL 4.00.04 and Scout 2008) will be used to compute UPLs and UTLs to estimate BTVs.

Also as mentioned in main body of the report, appropriate hypotheses testing approaches such as Gehan test, WRS test, and Quantile test that also handle ND observations (ProUCL.4.00.04) will be used on RBRA and DTL data sets consisting of NDs. It needs to be emphasized that the use of appropriate statistical methods is very important to derive correct and defensible conclusions. For an example, a simple WRS test used on data sets with NDs may lead to incorrect conclusions. For data sets with NDs, it is preferable to use appropriate corrected WRS test (single detection limit) and/or Gehan test (multiple detection limits). For details of these methods with examples, refer to ProUCL 4.00.04 Technical Guide (EPA, 2009).

Appropriate statistical methods (instead of simple Wilcoxon Rank Sum Test) should be used to compare surface soil and subsurface soil concentrations for data sets with nondetects. Several statistical tests (e.g., WRS test, Gehan Test, Quantile Test, Boxplots) are included in ProUCL 4.0 to compare concentrations of two populations (e.g., surface versus subsurface) based upon data sets with and without nondetect observations.

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Attachment D

Avoid the use of Log-transformation and Lognormal Distribution

Avoid the use of Transformations

The process of using statistical methods in the transformed space (e.g., log-transformed space) and then back-transforming the results in the original scale is not a straight forward process. Moreover, back-transformed statistics and estimates (e.g., from log-scale to original scale) often suffer from an unknown amount of transformation bias. The back-transformation formulae vary from transformation to transformation (log, square root, or some other Box-Cox type transformations). Therefore, in case the distributional assumptions (e.g., normality, gamma model) are not satisfied by the data set in the original scale, it is preferable to use nonparametric statistical methods such as the Mann-Whitney or Kruskal Wallis test to compare two or more populations. The nonparametric tests should be supplemented with graphical displays and various other percentiles (e.g., 25%, 50%, 75%, 90%, etc.) useful to compare data sets from two or more populations.

Avoid the use of Log-transformation and Lognormal Distribution

It should be noted that the use of lognormal distribution often tends to hide contamination by accommodating outliers. Moreover, since all decisions need be made based upon values of contaminant of potential concern (COPC) in the original scale, therefore all statistics computed using log-transformation need to be back-transformed in the original scale. Back-transformed statistics suffer from transformation bias. It is also well known that the use of lognormal distribution often yields unrealistic and unstable values of upper limits such as 95% UCL, 95% UPL, and UTLs (e.g., Singh, Singh, and Engelhardt, 1997). Therefore, in order to derive correct and defensible conclusions, the use of lognormal distribution will be avoided; and all statistical tests including outlier tests, two sample t-test and WRS test will be performed in the original raw scale. Specifically, all parametric (in case of normally distributed data sets) and nonparametric tests will be performed on original untransformed data sets.

Not to Use t-test on Log-transformed Data

Some EPA guidance documents (e.g., EPA 1989, EPA 1992, EPA QA/ G-9, 2006) suggest the use of a two sample Student's t-test on log-transformed data to compare the "means" of two skewed populations. Actually, it is observed that a lognormal model is often used as a default model (e.g., EPA RAGS document (1992)) for skewed data distribution even when the data set may not pass a lognormal goodness-of-fit test. The EPA QA/G-9 (2000) document, Section 4.6 (page 4-41) states that: "By transforming the data, assumptions that are not satisfied in the original data can be satisfied by the transformed data. For instance, a right skewed distribution can be transformed to be approximately Gaussian (normal) by using a logarithmic/square-root transformation. Then the normal-theory procedures can be applied to

the transformed data. If data are lognormally distributed, then apply parametric procedures to logarithms of the data."

However, no mention of back-transformation has been stated associated with this statement. Also, no statement or guidance has been provided about how to interpret and use those test statistics obtained based upon transformed data sets. This has resulted in frequent improper use of log-transformation in many environmental applications. Specifically, the test statistics computed based upon log-transformed data are used to derive conclusions in the original scale! It should be noted that the equality of means in the transformed space does not ensure the equality of means in the original space. This is further illustrated by a simulated example discussed in the following.

When applicable (both data sets are normally distributed), parametric two sample Student's t-test will be performed on original untransformed data set. Since, the remediation and cleanup decisions have to be made using statistics and results computed in the original scale, therefore, it is recommended to perform statistical tests in the original scale. No attempt will be made to transform data using a log-transformation (or some other transformation), and perform a t-test on log-transformed data, as the equality of means in the log-scale does not imply the equality of means of two populations (e.g., Chatsworth and Santa Susana formations) in the original scale.

Improper Use of Student's t-test to Compare Means of Two Populations Using Log-transformation

Hypotheses testing for population means based upon a t-test using the raw data and log-transformed data are not equivalent procedures. Conclusions derived based upon Student's t-statistic obtained using log-transformed data can lead to incorrect conclusion regarding the equality of the means of the two populations under study (e.g., here the RBRA and DTL). Consider two data sets that follow lognormal distributions. Note that if the mean and standard deviation (SD) of log-transformed population are μ and s^2 , then the mean of the lognormal distribution is given by $\exp(\mu + s^2/2)$. The detailed discussion about these issues can be found in Singh, Singh, and Engelhardt (1997). The mean of the lognormal population (raw) depends both upon the mean and SD of the log-transformed data - a fact often forgotten by a typical user. It should also be pointed out that comparing the medians of two populations is not equivalent to comparing the means of two populations unless the populations are normally or approximately normally (symmetrically) distributed.

For positively skewed data sets, the mean is much greater than the median. For highly skewed data sets, the actual difference between the median and mean can be enormously high. For example, the median of a lognormal population, LN(5, 4²) is only 148.4 where as the mean is 442413.39. Obviously, for such highly skewed data sets, the cleanup decisions made based upon sample median (=148.4) can incorrectly lead to the decision that the site represented by a LN(5, 4²) population is clean, and site concentrations are similar to those of the background population, LN(5, 1²) with median 148.4, and mean = 244.69. Note that the medians of the

lognormal populations LN (5, 1²) (= background), LN (5, 2²), LN (5, 3²) and LN (5, 4²) are all the same, but their means are significantly different. Specifically, the medians of LN (5, 1²) and LN (5, 4²) are the same (=148.4), but the means are very different. The population represented by LN (5, 4²) is highly contaminated and is far different from the cleaner background population represented by LN (5, 1²) with mean =244.69. Obviously, the equality of two medians does not imply the equality of two means.

To illustrate this issue in mathematical terminology, let a_1 and a_2 be the true means of the two lognormal distributions with the corresponding means and standard deviations of the log-transformed populations as (μ_1, s_1) , and (μ_2, s_2) . The means, a_1 and a_2 , of the two lognormal populations (in original scale) are given by $\exp(\mu_1 + s_1^2/2)$ and $\exp(\mu_2 + s_2^2/2)$, respectively. Also note that the corresponding medians of the original lognormal populations are $\exp(\mu_1)$ and $\exp(\mu_2)$. Thus testing for the equality of μ_1 and μ_2 (means of log-transformed data) does not necessarily imply the equality of the means, a_1 and a_2 , in the original scale. If the objective is to compare the medians (and not the means) of two populations, then one may use t-test on log-transformed data. However, as discussed above, the equality of medians is not sufficient and adequate enough to demonstrate that the site concentrations are similar to those of the background (e.g., are not impacted by the site activities). Under this scenario, many site observations can be highly contaminated, but the equality of medians can lead to the incorrect conclusion that the site and background concentrations are comparable.

In order to compare the means in the original scale, one also has to account for the standard deviations, s_1 and s_2 (which are unknown in practice and may have to be estimated using the available data) in the exponents. At best, such a t-test will provide only an approximate test for comparing two population means of approximately symmetric to mildly skewed lognormal populations (when the mean and median of lognormal populations (original scale) tend to be roughly the same). The issue that the use of a t-test on log-transformed data is not appropriate to test the equality of means of two moderately to highly skewed lognormal populations can be very simply illustrated by writing down the hypotheses in both scales: the original scale and the log scale.

Original Scale: The main objective here is to test whether the site mean, a_2 is comparable (or significantly greater than) to the background mean, a_1 , at some level of significance (say $\alpha = 0.05$). Thus the null and the alternative hypotheses to be tested may be $H_0: a_1 = a_2$, vs. $H_1: a_1 \neq a_2$ (or $a_1 > a_2$).

Log Scale: When a t-test is used on log-transformed data, the hypotheses in the log-scale are given by the statements: $H_0: \mu_2 = \mu_1$, vs. $H_1: \mu_2 \neq \mu_1$ (or $\mu_2 > \mu_1$). This is not what we are trying to test, we want to compare a_1 and a_2 , not μ_1 and μ_2 .

As shown above, there can be a huge difference between the values of a_1 and a_2 , and only a minor difference in the values of μ_1 and μ_2 . Thus based upon the data sets, if it is concluded that there is no significant differences between μ_2 and μ_1 does not necessarily imply that there

are no significant differences in a_1 and a_2 . An example illustrating this issue is discussed as follows.

Example: Using the statistical software package, MINITAB, data sets of size 20 each are generated from two lognormally distributed populations (e.g., one background and one from a contaminated site area of concern) with means of the log-transformed data for both populations as $\mu_1 = \mu_2 = 5$ and the standard deviations as $s_1 = 2$ and $s_2 = 4$, respectively with the background population having the $sd = 2$, and the site area having the $sd = 4$. Note that the true mean, a_1 , of the background population is 1096.63, and the true mean, a_2 , of the contaminated site area is 442413.39. The generated data sets do follow lognormal distributions. Note that the mean of log-transformed data being 5 for both populations, therefore, the two populations have the same median = 148.4 but the means are significantly different. The objective is to test whether the means, a_1 and a_2 , of the two populations in the original scale are equal. The two sample, t-test when used on the log-transformed data leads to the conclusion that there is no significant difference in the mean concentrations, μ_1 and μ_2 , of the log-transformed data. This does not imply that the true means, a_1 and a_2 are also equal. The t-test results obtained using MINITAB on these log-transformed data are summarized as follows.

	N	Mean	StDev	SE Mean
P1(Background)	20	5.07	1.85	0.41
P2(Site)	20	5.11	4.20	0.94
95% CI for mu P1 - mu P4: (-2.15, 2.07)				
T-Test mu P1 = mu P2 (vs <): T = -0.04, P = 0.48, DF = 26				

For the log-transformed data, the t-value is = -0.04, which is not significant at any of the commonly used levels (= 0.05, 0.1, 0.2.). This observation leads to the conclusion that there are no significant differences in the means of the two log-transformed populations (which is true). But this does not imply that the means in the original scale are also equal - a common practice used by practitioners in environmental applications. The equality of medians is not good enough to come to the conclusion that the site concentrations are not impacted and comparable to those of the background.

A more serious problem: Using the same two sample t-test on log-transformed data to test the hypothesis $H_0: a_1 \geq a_2$ vs. $H_1: a_1 < a_2$, exact the same t-test statistic (= -0.04) will be obtained leading to the conclusion of not rejecting the null hypothesis and concluding (in log-scale) that the background mean may be greater than the site mean! A naive user may conclude that the background mean in original scale is also greater than the site mean - which, of course, is not true. It is, therefore, strongly recommended not to use the t-test to compare the means of two populations based upon log-transformed data for both forms of hypothesis testing, Background Form 1 and Background Form 2. It is always useful to supplement statistical tests (especially when formulated and used incorrectly) with graphical displays.

References

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Glossary of Terms

Accuracy of an estimate: Degree to which the estimate matches the true parameter such as mean

Below Detection Limit (BDL) or Nondetect (ND) observations: Represent those values present at low concentration/trace levels and cannot be measured below certain detection limits (DLs). For instance, assume that certain instrumentation that can only read measurements within a certain range—data obtained from this instrument may result in a left censored data sets, as measurements below the DLs cannot be measured.

Confidence coefficient/Level: The measure of probability ($1 - \alpha$) associated with a confidence interval (such as upper confidence limit = UCL) that the interval will include the true population parameter (e.g., population mean, μ) of interest (We can be 95% confident that this interval encloses the actual population parameter.)

Data: Information, measurements, analytical results (e.g., radionuclides) obtained from a survey, sampling experiment, investigation. Data (numerical values) are stored in a database, usually in electronic form such as Excel Spreadsheets.

Raw data: Data that has not been subjected to any sort of mathematical manipulation or statistical treatment such as grouping, coding, censoring, or transformation.

Hypothesis: A statistical hypothesis is a statement concerning the value of parameters or form of a probability distribution for a designated population or populations. More generally, a statistical hypothesis is a formal statement about the underlying mechanisms that generated some observed data. For an example, hypothesis can be stated as: Mean of Population 1 = Mean of Population 2.

Hypothesis testing: A term used to refer to testing whether observed data (sampled data, observed measurements) support a statement or hypothesis.

Null hypothesis, H_0 : In general, this term relates to a particular research hypothesis being tested, as distinct from the alternative hypothesis, which is accepted if the research hypothesis is rejected. Contrary to intuition, the null hypothesis is often a research hypothesis that the analyst would prefer to reject in favor of the alternative hypothesis, but this is not always the case. For example, the null hypothesis specifies that there is no difference, no effect or no relationship.

Alternative Hypothesis, H_1 : The hypothesis, which one accepts when the null hypothesis, H_0 (the hypothesis under test) is rejected. It is usually denoted by H_1 .

One-tail (one-sided) test: Also known as a one-sided test, a test of a statistical hypothesis in which the region of rejection consists of either the right hand tail or the left hand tail of the

sampling distribution of the test statistic. Philosophically, a one-sided test represents the analyst's a priori belief that a certain population parameter is either greater or less than a specified value. One tail tests provide more specific information and make it easier to gain statistical significance than two tailed tests.

Two-tailed (two-sided) test: A test of significance in which both directions are, a priori, equally likely.

Type I error, Alpha Level, α of significance: Alpha is the probability assigned by the analyst that reflects the degree of acceptable risk for rejecting the null hypothesis when in fact the null hypothesis is true. In other words, the level of significance, α is the probability of rejecting a null hypothesis, when it is in fact true. It is also known the probability of committing a Type I error. Erroneous rejection of the null hypothesis is known as a Type I error. Alpha, or level of significance, is pre-selected by the analyst to determine the type I error rate. The level of confidence of a particular test is given by $1 - \alpha$.

Type II error, β : If, as the result of a test statistic computed on sample data, a statistical hypothesis is accepted when it is false, i.e. when it should have been rejected, then a type II error has been made. Erroneous acceptance of the null hypothesis is known as a Type II error. Beta is pre-selected by the analyst to determine the type II error rate. The Power of a particular test is given by $1 - \beta$.

p = 0.05: The most common probability used as alpha level in statistical inference testing.

Data Distribution: Probability model (e.g., normal, gamma) assigned (based upon statistical goodness-of-fit tests) to the sampled data set of analytical results.

Gamma distribution: The Gamma distribution includes as special cases the chi-square distribution and the exponential distribution. This distribution is often used to model positively skewed data sets.

Normal /Gaussian distribution: The Gaussian (another name for normal) distribution is characterized by its symmetric shape and has a bell-shaped appearance. The normal distribution is the most commonly used model, and forms the cornerstone of a substantial portion of statistical theory. Gaussian distribution has the two parameters mean, μ and SD, s ; when $\mu = 0$ and $s = 1$, it is said to be in its standard form, and it is referred to as the standard normal distribution.

Goodness- of- Fit (GOF): Goodness- of- fit describes a class of statistics (e.g., Shapiro-Wilk statistics, Kolmogorov-Smirnov test) used to assess the fit of a model to observed/sampled data.

Interval Estimate: The estimation of a population parameter by specifying a range of values bounded by an upper and a lower limit, within which the true value is asserted to lie.

Parameter: This word occurs in its customary mathematical meaning of an unknown quantity that varies over a certain set of inputs. In statistical modeling, it most usually occurs in expressions defining frequency or probability distributions in terms of their relevant parameters (such as mean and variance of normal distribution). Of utmost importance is the notion that statistical parameters are merely estimates, computed from the sample data, which are meant to provide insight as to what the true population parameter value is, although the true population parameter always remains unknown to the analyst.

Population (or Universe): In statistical terminology, the word population is applied to any finite or infinite collection of individuals. It is important to distinguish between the populations for which statistical parameters are fixed and unknown at any given instant in time, and the sample of the population, from which estimates of the population parameters are computed. Population parameters are generally unknown because the analyst can rarely afford to measure all members of a population, and so a random sample is drawn.

Prediction interval: A prediction interval is a calculated range of values known to contain some future observation over the average of repeated trials with specific certainty (confidence coefficient, probability).

Precision: The precision or efficiency of an estimator is its tendency to have its values cluster closely around the mean of its sampling distribution. Precise estimators are preferred to less precise estimators.

Probability density functions (probability distributions): knowing the probability that a random variable takes on certain values, judgments can be made as to how likely or unlikely were the observed values.

Robustness: A method of statistical inference is said to be robust if it remains relatively unaffected when all of its underlying assumptions are not met.

Sample: A part or subset of a population, which is obtained through a recruitment or selection process, usually with the objective of understanding better the parent population. Statistics are computed on sample data to make formal statements about the population of interest. If the sample is not representative of the population, then statements made based on sample statistics will be incorrect to some degree.

Significant/Statistically significant: An effect is significant if the value of the statistic used to test it lies outside acceptable limits i.e. if the hypothesis that the effect is not present is rejected.

Skewness: Skewness is the lack of symmetry in a probability distribution. In a skewed distribution the mean and median are not coincident.

Standard normal variable: a normal distributed variable with mean 0 and standard deviation 1.

Statistic: A summary value calculated from a sample of observations; a number calculated from a sample of observed data to make an inference about the population to which the sample belongs

Statistics: The branch of mathematics that deals with all aspects of the science of decision-making and analysis of data in the face of uncertainty.

Statistical inference: statistical inference is a form of reasoning from sample data to population parameters; that is, any generalization, prediction, estimate, or decision based on a sample and made about the population. There are two schools of thought in statistical inference, classical or frequentist statistics for which R. A. Fisher is considered to be the founding father, and Bayesian inference, discovered by a man bearing the same name.

Statistical methods: Statistical methods are similar to a glass lens through which statisticians and other practitioners inspect and evaluate the phenomenon of interest such as a parameter (mean, median) or a statement about those parameters (hypotheses). The underlying mechanisms present in the population represents reality, the sample represents a snapshot of the population, and statistical methods represent a means of quantifying various aspects of the sample.

Transformation: A transformation is the change in the scale of a variable. Transformations are performed to simplify calculations, to meet specific statistical modeling assumptions, to linearize an otherwise non-linear relation with another variable, to impose practical limitations on a variable, and to change the characteristic shape of a probability distribution of the variable in its original scale.

Unbiased Estimator: An estimator whose expected value (namely the mean of the sampling distribution) equals the parameter it is supposed to estimate. In general unbiased estimators are preferred to biased estimators of population parameters. There are rare cases, however, when biased estimators are preferred because they are much more efficient than alternative estimators.

Outlier: A single or several values which lay far outside of the center of distribution. Outliers generally drastically effect (distort) all nonresistant statistics (e.g., mean, UCLs, UPLs) and parametric analyses and hence, should be investigated as to their cause. Outliers are identified as such because they "appear" to be outlying with respect to the main body of the data (dominant population). In many cases outliers can be traced to errors in data collecting, recording, or calculation, and can be corrected or appropriately discarded.