

Data Quality Objectives Summary Report: Evaluation of Natural Beryllium and Its Ratio to Other Metals in Background Hanford Surface Soils

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management



U.S. DEPARTMENT OF
ENERGY

Richland Operations
Office

P.O. Box 550
Richland, Washington 99352

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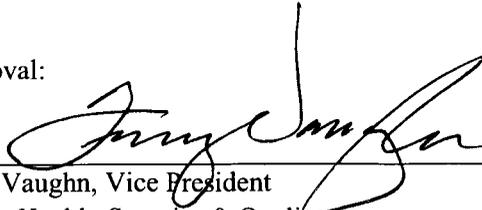
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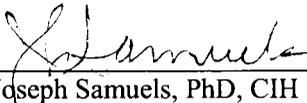


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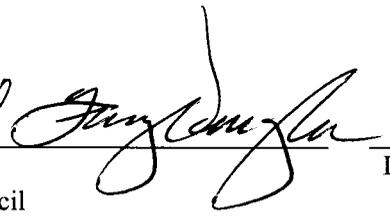
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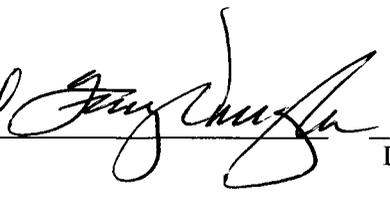
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Contents

1	Introduction	1-1
1.1	Purpose	1-1
1.2	Background	1-1
1.3	Existing References	1-3
1.4	Conceptual Site Model	1-3
1.5	Assumptions	1-5
1.6	Statement of the Problem	1-6
2	Identify the Decision	2-1
3	Identify Inputs to the Decision	3-1
4	Define the Boundaries	4-1
4.1	Target Analytes	4-1
4.2	Sampling Locations	4-1
4.2.1	Candidate Locations	4-1
4.2.2	Screening Criteria	4-2
4.2.3	Final List of Suggested Locations	4-3
5	Develop the Analytic Approach	5-1
6	Specify Limits on Decision Error	6-1
7	Optimize the Design for Obtaining Data	7-1
8	References	8-1

Appendices

A	Conceptual Model for Naturally Occuring Beryllium in Hanford Site Soil Materials	A-i
B	Selected Sampling Locations	B-i

Figures

Figure 4-1.	Candidate Locations before Screening	4-1
Figure 4-2.	Candidate Locations after Screening	4-2
Figure 4-3.	Selected Locations	4-3
Figure 4-4.	Location Overlay	4-3

Tables

Table 1-1.	Data Quality Objective Team Members	1-2
Table 1-2.	Summary of Principal References	1-3
Table 2-1.	Summary of Data Quality Objective Information	2-1
Table 3-1.	Target Analytes and Analytical Methods	3-2

Terms

A-Be	anthropogenic beryllium
AA	alternative action
CHPRC	CH2M HILL Plateau Remediation Company
CSM	conceptual site model
DOE	U.S. Department of Energy
DQO	data quality objective
DS	decision statement
HAMTC	Hanford Atomic Metal Trades Council
HRNM	Hanford Reach National Monument
HSS	DOE Office of Health, Safety, and Security
IBOT	Independent Beryllium Oversight Team
LMIT	Lockheed Martin Information Technology
MSA	Mission Support Alliance
N-Be	natural beryllium
PNNL	Pacific Northwest National Laboratory
PSE	prediction standard error
PSQ	principal study question
SESP	Surface Environmental Surveillance Project
WCH	Washington Closure Hanford
WRPS	Washington River Protection Solutions
WSCF	Waste Sampling and Characterization Facility

1 Introduction

1.1 Purpose

The purpose of this data quality objective (DQO) summary report is to develop a defensible approach for comparing natural beryllium (N-Be) to other metals in windblown soils. This comparison should facilitate identification of a per weight ratio or set of ratios by which N-Be concentrations can then be predicted in trackable and windblown soils found in Hanford Site buildings, thereby distinguishing N-Be from anthropogenic beryllium (A-Be) in these materials.

1.2 Background

As Hanford Site cleanup continues, a variety of dust generating activities will increase. These activities will increase the potential of worker exposure to A-Be. Beryllium is a naturally occurring element in the mineralogy of the Columbia Basin, and deposition of windblown material is common in many Hanford Site facilities. The presence of naturally occurring beryllium becomes an issue in characterizing facilities as either beryllium contaminated or beryllium cleared. The current consensus in the professional and medical community is that natural (mineral) forms of beryllium present little or no hazard, while the anthropogenic (process) form presents the greatest risk to the worker. Therefore, it is important to develop a method of distinguishing A-Be from the N-Be forms.

The current facility characterization and assessment processes involve collection of bulk material from those surfaces with a heavy dust loading for comparison to background beryllium soil levels. The basis for the background soil beryllium level was developed from DOE/RL-92-24, *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes*, and is consistent with the levels reported by the U.S. Geological Survey and the State of Washington. As part of the U.S. Department of Energy (DOE) Office of Health, Safety, and Security (HSS) oversight inspection of March 2010 (HSS, 2010, *Independent Oversight Inspection of the Hanford Site Chronic Beryllium Disease Prevention Program*), issues were raised as to the applicability of current Hanford Site beryllium soil background levels used for building characterization. Other approaches used in the DOE complex rely heavily on the analysis of wipe samples obtained from surfaces within facilities. Current discussions involve using a combination of wipe and bulk samples for these processes.

To accomplish the task of adequately characterizing facilities, the DOE Richland Operations Office has requested that the site contractors consider the metal ratio in the determination of naturally occurring background beryllium levels used as part of the facility characterization process. CH2M HILL Plateau Remediation Company has taken the lead in addressing this concern raised by the HSS inspection and initiated this DQO process to ensure that appropriate data are collected to support the establishment of background beryllium soil levels for the site's facility characterization process for beryllium (see Table 1-1 for a list of DQO team members). The DQO process was implemented in accordance with EPA QA/G-4, *Guidance for the Data Quality Objectives Process*. The DQO process is iterative, and changes in this document may be made during implementation when data are obtained indicating that changes in the requirements are needed. As data required by this document are obtained, requirements may be added or deleted, as necessary.

Table 1-1. Data Quality Objective Team Members

Name	Organization	Role and Responsibility
David F. Farler	CHPRC	DQO Lead
Russ Brown	CHPRC	DQO Facilitator
Tami Keas	CHPRC	DQO Scribe
Mario Moreno, CIH	DOE	DOE Representative
Silvette Boyajian	DOE/IBOT	Lead Independent Beryllium Oversight Team
John Herber	DOE/IBOT	Independent Beryllium Oversight Team
Mary Sams	MSA	Beryllium Awareness Group Representative
Thomas Morris	WRPS	Beryllium Awareness Group Representative
Larry Sherman	WCH	HAMTC Representative
Victor Sims	MSA	HAMTC Representative
Charles Davis	Envirostat	Statistician
Tim Legore	LMIT	Statistician/Historical Sampling
Jim Hoover	CHPRC	Geologist
Jonathan Kon	WSCF	Laboratory Representative
Tonya Bean	CHPRC	Contractor Representative
Karl Agee	WCH	Contractor Representative
Rob Garrett	WCH	Contractor Representative
Joseph Samuels	MSA	Contractor Representative
Colby Smith	WRPS	Contractor Representative

CHPRC = CH2M HILL Plateau Remediation Company

DOE = U.S. Department of Energy

DQO = data quality objective

HAMTC = Hanford Atomic Metal Trades Council

IBOT = Independent Beryllium Oversight Team

LMIT = Lockheed Martin Information Technology

MSA = Mission Support Alliance

WCH = Washington Closure Hanford

WRPS = Washington River Protection Solutions

WSCF = Waste Sampling and Characterization Facility

1.3 Existing References

Table 1-2 lists references that are relevant to the development of this DQO. The reference and a brief summary of the pertinent information obtained from each reference are provided.

Table 1-2. Summary of Principal References

References	Summary
DOE/RL-92-24, <i>Hanford Site Background: Part 1, Soil Background for Non-Radioactive Analytes</i>	This 1992 study provides information on the selection of 14 sampling sites in the context of establishing Hanford Site soil background levels and developing a conceptual model. It provides general and site-specific geologic characteristics and addresses specific sampling objectives.
PNNL-18577, <i>A Review of Metal Concentrations Measured in Surface Soil Samples Collected on and Around the Hanford Site</i>	This 2009 PNNL study discusses the results of metals analysis performed on surficial soil samples taken in 2008 from 41 locations on and around the Hanford Site, as well as the results for samples collected at 117 locations in the HRNM in 2004 and 2005. It concludes that background metal concentrations in these surficial soils were within an expected range of concentrations consistent with previous samples collected around the Hanford Site.
HSS, 2010, <i>Independent Oversight Inspection of the Hanford Site Chronic Beryllium Disease Prevention Program</i>	This audit report documents the findings of a 2010 inspection by the HSS in response to concerns about the adequacy of implementation of the Hanford Site chronic beryllium disease prevention program. The focus was on worker protection and medical surveillance, and engaged representatives from several stakeholder groups. However, the most relevant aspects to this document were suggestions to consider a metal ratios approach for determination of background beryllium soil levels in facilities.
Modification of Contract DE-AC06-08RL14788 between DOE and CH2M HILL Plateau Remediation Company dated 9/7/2010	Interim Levels: Sets beryllium concentration-based release criteria at 0.1 µg/100 cm for wipes and 1 ppm for bulk samples while also directing contractors to address corrective actions developed in response to the independent oversight inspection (HSS, 2010). These corrective actions include F-1.5, which directs contractors to consider the potential of metal ratio analysis to distinguish anthropogenic beryllium from background and is the driving force behind the study described by this DQO report.

DQO = data quality objective

HRNM = Hanford Reach National Monument

HSS = DOE Office of Health, Safety, and Security

PNNL = Pacific Northwest National Laboratory

1.4 Conceptual Site Model

Conceptual site models (CSMs) are an integral part of the DQO process established by the U.S. Environmental Protection Agency as a strategic planning approach used to prepare for data collection. The CSM provides a simplifying framework in which information can be organized and used to define the data needed to meet the objectives of the problem. The CSM is based on field, laboratory, literature, and other relevant data, and descriptive site information and is continuously refined as data

become available. A CSM provides the background and technical basis for describing and understanding the origin, nature, and geochemistry of the soils that can be blown and/or tracked into Hanford Site facilities, and how and where beryllium occurs naturally in Hanford Site soils. Details of the CSM are provided in Appendix A.

This CSM is based on the physical and chemical composition of dust and other geologic material transported into the Hanford Site facility/operations buildings, that are a subset of the surficial deposits comprising the uppermost parts of the vadose zone, as the material is segregated and fractionated from the topsoils by eolian (i.e., wind related) processes. For simplicity, all surficial soil materials, including topsoils and dust, are collectively referred to here as topsoils. Geochemically, the background compositions of topsoils and dust components (including beryllium contents) are expected to have a range of concentrations for each analyte that reflects the proportions and compositions of the constituent physical components (e.g., feldspar, basalt, and quartz). These ranges are expected to vary linearly with the proportions of each physical component, with the exception of localized outliers attributable to other materials (e.g. volcanic ash, organic material, or exotic "nugget effect" materials). The beryllium levels in background samples collected around the Hanford Site are consistent with these expected variations and range from as low as 0.19 to 2.5 mg/kg in highly alkaline soils. Further detail is provided in Table A-1 (Appendix A).

The physical and chemical compositions of the vadose zone soils, and topsoil materials derived from them, are related because both have the same primary physical components. However, the proportions of physical components in the topsoils can differ from those in vadose zone soils due to the effects of segregation and fractionation of wind related (eolian) processes. The eolian transported materials are fractionated from the parental soils by density and grain size, with smaller and less dense fractions of basalt and quartzo-feldspathic components being the most readily wind transported materials. Therefore, the physical composition of many topsoil and dust materials may be expected to have somewhat greater proportions of the lower density quartzo-feldspathic material and/or lower density basaltic components (e.g., feldspar and glass). The chemical composition of these soils should, therefore, reflect the combined chemical compositions of the physical components. Soil containing relatively larger proportions of feldspars, for example, may be expected to have higher concentrations of aluminum, potassium, sodium, calcium, and trace elements such as barium and lead. The compositions of soils with relatively larger proportions of quartz typically have lower concentrations than most analytes because quartz is nearly devoid of chemicals other than silicon dioxide. The soil background levels of beryllium should also be a reflection of these relationships because naturally occurring beryllium in most Hanford Site soil is expected to be primarily contained in feldspar and glass components. Thus, dust materials may be expected to have compositions that correlate with the proportions of lower density physical components (e.g., feldspar and glass). Other topsoil materials that have more refractory physical composition from the removal of small and low density components can have higher proportions of the denser and larger physical components (e.g., basalt). These soil materials are expected to have chemical compositions more highly correlated with basaltic components (e.g., iron, manganese, chromium, and nickel) and are expected to be less common in dust materials. A small percentage of soils are expected to have compositions that extend or depart from the main population of topsoils due to modified compositions resulting from pedogenic (soil forming) processes, the presence of organic components, and/or the presence of exotic (nugget) components. However, the majority soils, topsoils, and derivative dust materials should contain the same types of physical components (in varying proportions) that are repositories of all the naturally occurring analytes, including beryllium. The following physical components serve as the naturally occurring repositories for the background analytes (further information on each component is provided in Appendix A):

- Primary Components:
 - Basalt (rock material)
 - Quartzo-feldspathic minerals (quartz and feldspar)
 - Volcanic ash (ubiquitous component)
 - Organic material (some soils)
- Secondary Components:
 - Volcanic ash
 - Components from pedogenetic (soil forming) processes
 - Organic components
 - Nugget components
 - Coal fly ash (limited distribution)

According to the simplified mass balance scenarios in Table A-4 (Appendix A), the magnitude and direction of the differences in beryllium concentrations between the soils (overall), topsoils, and derivative dust are consistent with the differences in modal proportions of the basaltic and quartzo-feldspathic components described in the CSM for the processes associated with: (1) the derivation of topsoil from the underlying soils, and (2) the derivation of dust material from the surficial materials. In these scenarios, the beryllium levels in topsoils are about two-thirds of those in the underlying soils, and the beryllium level in the dust material is about one-half of that in the topsoil, due to the dilution effect of mixing with beryllium free organic material. However, total beryllium concentrations can and do vary with differences in the proportions of each physical component, as well as with the beryllium concentrations within each individual physical component. Although these example scenarios are not unique solutions, they indicate that the CSM is consistent with the relative amounts of beryllium in the soils, topsoil, and dust and with the magnitude of total beryllium levels in the soil materials, the types and proportions of physical components observed in the soils, and the ranges of beryllium estimated to occur in these materials. This exhibition of the relationship between physical and chemical components of these soils in the CSM also serves as the basis for expected correlations between the levels of beryllium and other metals, because both are expected to vary with the types and proportions of physical components comprising those soils. Such correlations can provide a basis for the use of metal ratio relationships as a viable tool in distinguishing N-Be from operations-related A-Be.

1.5 Assumptions

The following assumptions were made during this DQO process:

- Top soil is a source of building dust, and analyzing the blowable/trackable fractions of top soil (e.g., particles smaller than 1,000 μm) will produce data that can be used to draw conclusions about building dust.
- Based on existing soil data from previous studies conducted for different purposes, consistent trends in ratios between beryllium and other metals exist that can be identified, evaluated, and used to predict levels of natural beryllium in Hanford Site facility dust (bulk) samples.
- The pool of sampling locations previously used in background studies is representative of natural soil metal ratios and appropriate potential sites for sampling in accordance with this effort.

- These background ratios of beryllium to other metals in top soil are similar enough to allow facility specific determinations using data derived from a site-wide study. Facility-specific background evaluations will not be necessary.

1.6 Statement of the Problem

There is a need at the Hanford Site to distinguish N-Be from A-Be, as it relates to facility or work area characterization. An approach used successfully at the Nevada Test Site that involves comparing the ratio(s) of N-Be to other soil metals looks promising for possible adaptation and refinement to more geochemically complex soil mixtures, such as those found at the Hanford Site, and should be evaluated.

2 Identify the Decision

In the DQO process, principal study questions (PSQs) need to be answered. In this study, there is only one PSQ; Table 2-1 presents the PSQ and the alternative actions (AAs) that will be taken, along with a description and severity rating of the consequences of implementing the wrong AA. A decision statement follows.

Table 2-1. Summary of Data Quality Objective Information

AA Number	Description of AA	Description of Consequences for Implementing the Wrong AA	Severity of Consequences (Low/Moderate/Severe)
PSQ 1 —Do background surface soils have compositional characteristics that allow them to be distinguished from materials containing anthropogenic beryllium?			
1-1	Determine that materials containing anthropogenic beryllium can be distinguished from those not containing anthropogenic beryllium.	Health risk to workers managing materials containing anthropogenic beryllium as if they contain only natural beryllium, or unnecessary cost of cleaning up facilities containing only natural beryllium as if they contained anthropogenic.	Moderate to severe
1-2	Determine that no reliable method exists for distinguishing anthropogenic beryllium from natural, background sources.	Unnecessary cost of cleaning up all facilities containing beryllium above some concentration (to be determined), including those that contain only natural beryllium; health risk to workers in the event that the decision concentration is determined inappropriately.	Low to severe
DS 1 —Determine that a metals ratio approach can reliably distinguish anthropogenic beryllium from the natural beryllium in background soils and use this data to evaluate facility cleanup options OR determine that the metals ratio cannot reliably distinguish anthropogenic beryllium from natural beryllium in Hanford surface soils and pursue other options for minimizing cleanup costs while protecting workers.			
AA = alternative action DS = decision statement PSQ = principle study question			

3 Identify Inputs to the Decision

Data describing the range of concentrations of beryllium and its relationship with the concentrations of other potential indicator metals in background surface soils at the Hanford Site must be generated. The data must be representative for the locations and metals described in Chapter 4 and will be evaluated on more than one occasion to allow for fine tuning of the analytical procedure (including preparation, target analytes, and specific analytical methods), the CSM, and the predictive methods that result from a statistical study of the ratios of natural beryllium to other metals. Data will likely be useful in an initial statistical analysis without regard to detection limits; however, exceptionally high or low recovery percents or failure of laboratory internal quality assurance/quality control processes may exclude some data from the analysis. These exceptions will be considered and agreed upon by the project manager and relevant project staff (e.g., assigned statistician, laboratory contact, and geochemist).

The data generated in the course of this project will be reported as uncensored, and concentration values below typical reporting levels are anticipated. As the project progresses, the preparatory method, dilutions, target analyte list, and expected reporting limits will be developed and further refined to a process that can be implemented in a production mode, as all subsequent metals ratio analysis applications will be contingent upon an identical process being followed.

Table 3-1. Target Analytes and Analytical Methods

Target Analyte	Chemical Abstracts Service Number	Target Analyte	Chemical Abstracts Service Number
Aluminum	7429-90-5	Nickel	7440-02-0
Antimony	7440-36-0	Niobium	7440-03-1
Arsenic	7440-38-2	Phosphorus	7723-14-0
Barium	7440-39-3	Potassium	7440-09-7
Beryllium	7440-41-7	Rubidium	7440-17-7
Boron	7440-42-8	Selenium	7782-49-2
Calcium	7789-78-8	Silicon	7440-21-3
Cadmium	7440-43-9	Silver	7440-22-4
Cerium	7440-45-1	Sodium	7440-23-5
Cesium	7440-46-2	Strontium	7440-24-6
Chromium	7440-47-3	Titanium	7440-32-6
Cobalt	7440-48-4	Thallium	7440-28-0
Copper	7440-50-8	Thorium	7440-29-1
Iron	7439-89-6	Tin	7440-31-5
Lanthanum	7439-91-0	Tungsten	7440-33-7
Lead	7439-92-1	Uranium	7440-61-1
Lithium	7439-93-2	Vanadium	7440-62-2
Magnesium	7439-95-4	Yttrium	7440-65-5
Manganese	7439-96-5	Zinc	7440-66-6
Molybdenum	7439-98-7	Zirconium	7440-67-7

4 Define the Boundaries

The boundaries of this study comprise two lists: the population of potential target analytes and the geographic sampling locations.

4.1 Target Analytes

The initial list of target analytes defined by DQO team members is provided in Table 3-1 and was based on the following criteria:

- Methods will include inductively coupled plasma mass spectroscopy and inductively coupled plasma atomic emission spectroscopy to give the broadest range of candidates that may demonstrate a predictable concentration-based relationship with N-Be.
- Specific analytes were excluded due to known or predicted interference (e.g., those used in internal standards).

4.2 Sampling Locations

DQO team members evaluated the numbers of locations that would be desirable, in order to provide acceptable precision and repeatability in the sample results, using a Pacific Northwest National Laboratory (PNNL) study (PNNL-18577, *A Review of Metal Concentrations Measured in Surface Soil Samples Collected on and Around the Hanford Site*). Two rather different approaches were followed; both resulted in recommendations that a minimum of approximately 60 locations vetted for previous studies should be sampled, assuming that the variability in the target population resembles that of the PNNL study (PNNL-18577).

4.2.1 Candidate Locations

The PNNL study of surface soil chemistry used 117 archived samples from the 2004 to 2005 studies conducted on the Arid Lands Ecology Reserve, McGee Ranch, and North Slope portions of what was to become the Hanford Reach National Monument (HRNM), augmented by 41 new samples obtained from locations included in the ongoing Surface Environmental Surveillance Project (SESP). Nine of the SESP samples were obtained from locations distant from the Hanford Site, such as Benton City and Walla Walla, and are not considered viable candidates for this study.

Subsequently, Hanford personnel suggested adding some locations that had been sampled in other past studies to the candidate list: 15 site-wide background and 8 ecological locations discussed in the Hanford Site background study (DOE/RL-92-24).

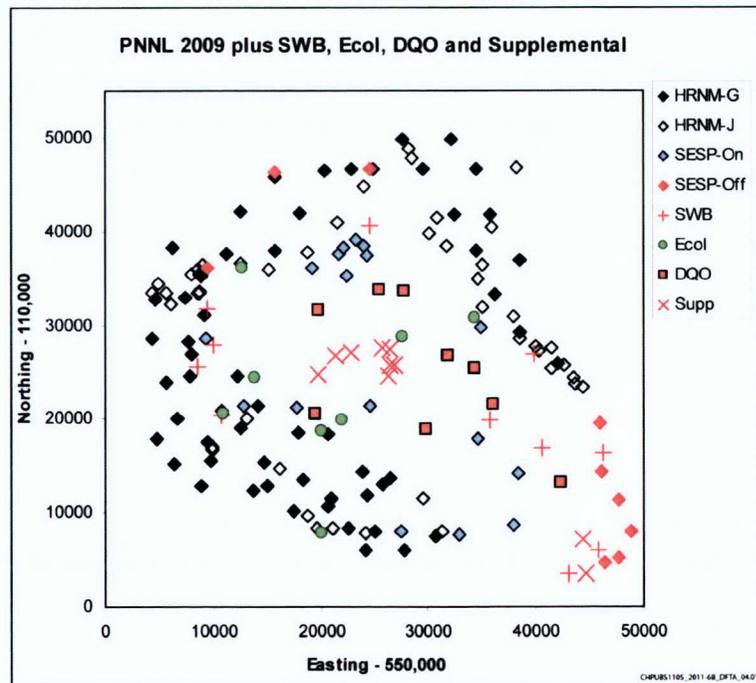


Figure 4-1. Candidate Locations before Screening

In addition, a small number of supplemental locations in possibly contaminated 200 Area regions of the Central Plateau and the 300 Area would be sampled for comparison, not to be included in the background data to be used for facility evaluations.

Location coordinates were obtained for all of these locations. The coordinates last to be obtained were for the majority of the SESP locations and were eventually read (approximately) from maps included in the 2004 Hanford Site Environmental Report.

When an initial selection of 60 locations was presented to the DQO team, a relative lack of onsite locations was noted. The team identified seven areas on the Hanford Site, that were thought to be adequately far from potential sources of past or current contamination, which should also be included in the background data. Hanford personnel provided nine additional candidate locations in those areas (Figure 4-1).

4.2.2 Screening Criteria

Locations were screened using various criteria. In particular, a large number of judgment locations had been included in the 2004 to 2005 HRNM studies. The goal of those studies was to confirm that radiological contamination was absent from those areas before release for public use. Some of those judgment locations included lysimeter fields in which radionuclide tracer tests of groundwater flow had been conducted, a railroad classification yard in which some leakage from rail cars may have taken place, and numerous locations on Savage Island, which had a reputation for having high uranium. These locations were removed from consideration as background locations for the current study.

Other reasons for not selecting particular locations included coarse materials and past agricultural uses. The latter is relevant because soils that are routinely irrigated are not so prone to be blown about and might have had metals introduced by fertilization, particularly at Savage Island. Locations close to facility operations were also deselected.

Following application of the screening criteria, the candidate locations that remained are shown in Figure 4-2. In total, 126 candidate background locations and 10 potential supplemental locations are listed.

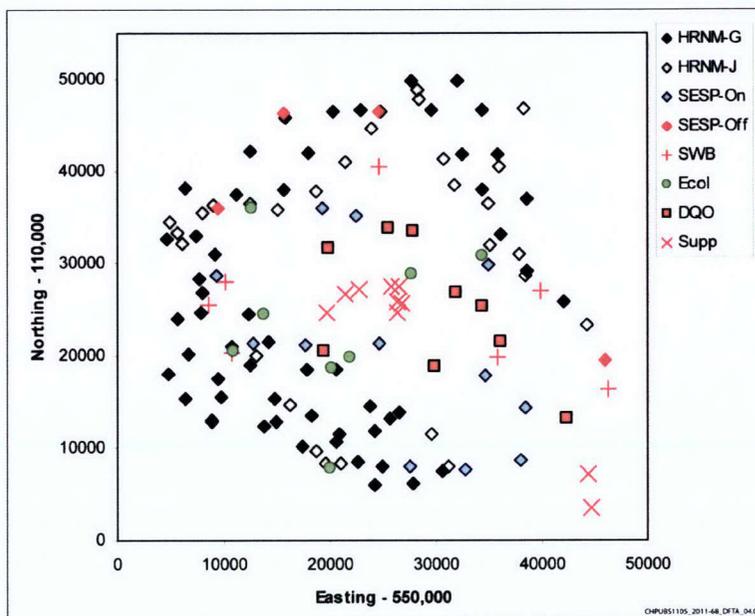


Figure 4-2. Candidate Locations after Screening

4.2.3 Final List of Suggested Locations

In order to narrow the set of candidate background locations down to a final list of locations, a grid was overlaid on the diagram. The grid spacing is 3,500 m (11,483 ft), which was selected to provide approximately 60 grid cells that included locations sampled during previous studies coordinates that were available when the first cut at location selection was prepared. The grid's starting location was selected randomly. Inside the Hanford Site, the locations proposed most recently were generally accepted.

Within the HRNM, one location was generally selected within each grid cell where any locations were present. Some of the more recently suggested locations were also located in the HRNM. Precedence was given to the recently suggested locations and then to the random grid locations from the HRNM study. Where there was more than one candidate in a cell, consideration was given to spreading the locations.

When the remaining SESP and DQO location coordinates were added and the same algorithm was applied, 72 background locations resulted, including the 60 previously agreed upon by the DQO team. Those selected are circled in red on Figure 4-3. The plot also includes five supplemental locations: three in the 200 Areas and two in the 300 Area.

The selected locations are overlaid on a site diagram in Figure 4-4, and a table of the selected locations is provided in Appendix B (Table B-1). Some of the coordinates were read from maps in published reports and are approximate. Coordinates from HRNM locations are as sampled rather than as planned.

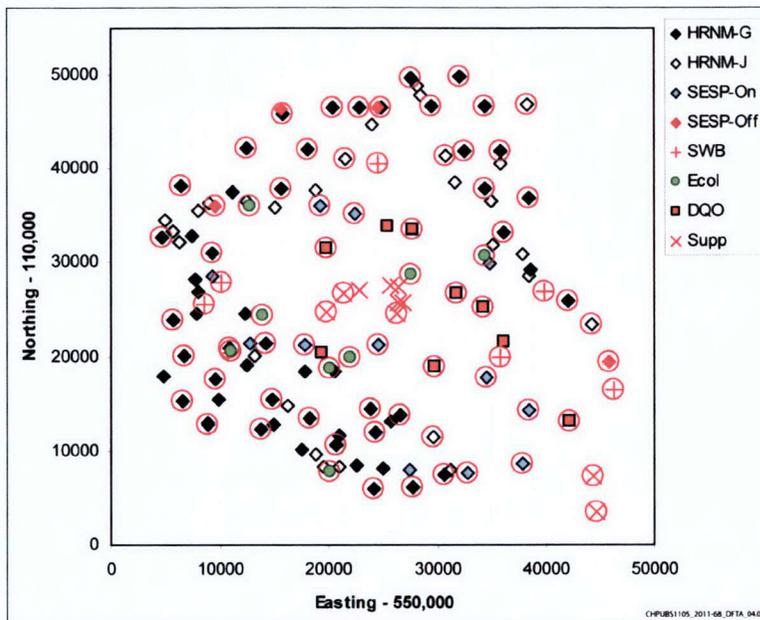


Figure 4-3. Selected Locations

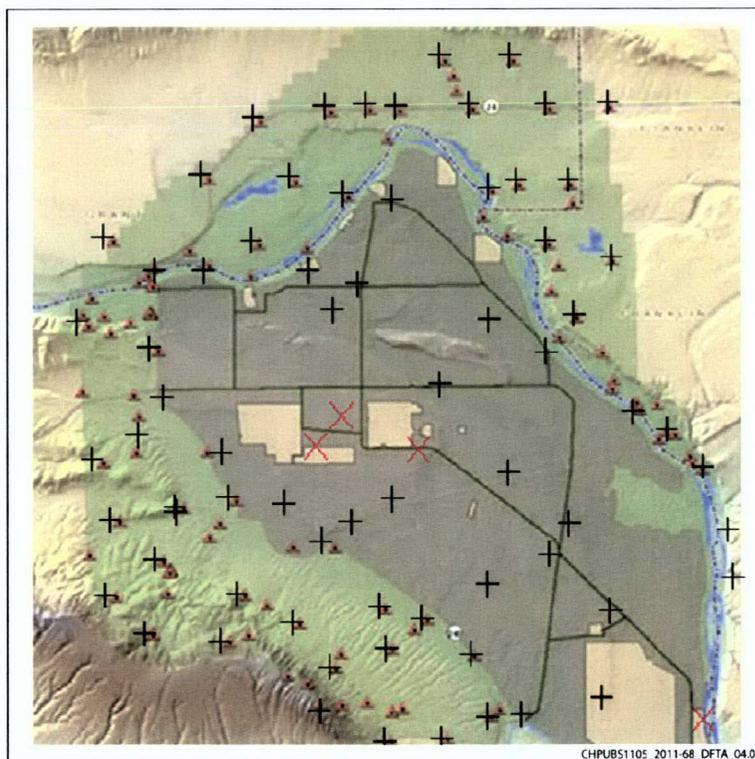


Figure 4-4. Location Overlay

5 Develop the Analytic Approach

Sample data collected during this effort will be used to develop effective and reliable algorithms for predicting N-Be concentrations in future samples to be obtained inside facilities using a metal ratios approach. The effectiveness of a candidate algorithm will be evaluated on the basis of its ability to accurately predict N-Be. Additional considerations will involve whether candidate metals can readily be analyzed by a single method, how many different dilutions would be required of each digested sample, whether the analyses are likely to be reliably reproduced by other laboratories using similar methods, and whether the candidate metals might be or have been introduced into facilities from other than wind blown or tracked soils. With respect to the latter, consideration will be given to the possible use of certain metals in ordinary maintenance and shop operations (such as copper, aluminum, iron, and lithium) as well as metals that might be present as a legacy of nuclear reactions (such as yttrium, uranium, cesium, and zirconium). Statistical methods to be used will include regression/prediction modeling, correlation analysis, various plotting techniques, cluster analysis, outlier analysis, and cross validation.

6 Specify Limits on Decision Error

The probabilities of making decision errors in the actual use of metal ratio methods in facility characterization and assessment will depend on a variety of technical issues related to policy determinations yet to be made and outside the scope of this DQO process. The issue is to determine whether algorithms using metal ratios will provide sufficiently accurate predictions of N-Be in the mineral content of soils that might have blown and/or been tracked into facilities being characterized or assessed.

The usefulness of these metal ratio methods depends on how accurately they allow one to predict the amount of N-Be that should be present in a bulk or wipe sample obtained inside a facility. For this purpose, an appropriate metric is the log-scale prediction standard error (PSE). PSEs as low as 0.10 are ideal, and 0.15 is quite acceptable; these will give prediction accuracy comparable with the accuracy of actual laboratory analyses of beryllium. A PSE of 0.25 is excessively large; if PSE values of 0.20 or better cannot be achieved regardless of the choice of predictor metals, the utility of the metal ratio methods should be reconsidered. Preliminary studies using the data from the PNNL study (PNNL-18577) suggest that a PSE of 0.15 or lower is possible and would allow for using metal ratio methods to provide a substantial improvement in the capability to distinguish A-Be from N-Be over previously suggested methods.

7 Optimize the Design for Obtaining Data

Several steps in the DQO process have resulted in refinements that will optimize the collection and utility of data for its intended purpose. The sample site selection process described in Chapter 4 produced a set of sample locations that are presumed to be representative of background, and select judgment based sample locations for evaluating possible onsite effects on background ratios (e.g., effects from coal fly ash) are also provided. Samples will be screened to a particle size not exceeding 1,000 μm in order to focus on particles that could reasonably be expected to comprise the windblown fraction. Samples will be analyzed both in bulk and on wipes for development of an analytical method that is appropriate for both sample types while also allowing for the effects (if any) of wipe materials in the matrix. Duplicate samples for initial analytical method development will be taken at 10 percent of the sampling locations to provide the laboratory a subset of representative samples with which the preparatory method can be refined and any dilutions, interferences, and expected reporting levels can be identified. Two analytical techniques will be employed, and those analytes that can be quantified by either method will be evaluated by both methods to allow the broadest range of possible “fingerprints” (sets of related metal ratios). The data produced by these methods will be reported “uncensored” to allow a broader analysis of ratios than would be possible with numerous nondetect values. Finally, when the data analysis is complete and an initial predictive model has been developed, the laboratory analyses will be repeated to evaluate the accuracy and precision of the predictions produced, refine the model as needed, and demonstrate repeatability at an acceptable level.

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Appendix A

Conceptual Model for Naturally Occurring Beryllium in Hanford Site Soil Materials

Contents

A1	General Conceptual Model.....	A-1
	A1.1 Vadose Zone Soils.....	A-1
	A1.2 Surficial Deposits and Dusts (Topsoils).....	A-2
A2	Geochemistry Conceptual Model Component.....	A-3
	A2.1 Basalt.....	A-5
	A2.2 Feldspars and Quartz.....	A-5
	A2.2.1 Basaltic Feldspars (Plagioclase).....	A-6
	A2.2.2 Quartzo-Feldspathic Material	A-6
	A2.3 Volcanic Ash	A-6
	A2.4 Components from Pedogenetic Processes	A-6
	A2.5 Organic Material.....	A-7
	A2.6 Nugget Components.....	A-7
	A2.7 Coal (Fly) Ash.....	A-8
	A2.8 Potential Yttrium Contribution from Strontium-90 Decay.....	A-8
A3	Mass Balance Scenarios.....	A-11
A4	References	A-13

Tables

Table A-1.	Summary of Background Beryllium Concentrations in Soil Materials at the Hanford Site.....	A-4
Table A-2.	Sources and Levels of Anthropogenic Sr-89 Sr-90, Y-89 and Y-90 Progeny in Hanford Surface Soils	A-9
Table A-3.	Relative Levels of Natural and Anthropogenic Strontium and Yttrium in Hanford Surface Soil	A-10
Table A-4.	Types and Proportions of Physical Components in Hanford Soils and Topsoils and Associated Beryllium Concentrations.....	A-11
Table A-5.	Example Mass Balance Scenarios for Relating Total Beryllium Levels in Soils, Topsoils, and Dust to the Proportions and Levels of Constituent Components.....	A-13

Terms

CM	conceptual model
DQO	data quality objective
N/A	not applicable
NNSS	Nevada National Security Site

This conceptual model (CM) provides the background and technical basis for describing and understanding the origin, nature, and geochemistry of how and where beryllium occurs naturally in soils on or near the Hanford Site. This information is important in the data quality objective (DQO) process because it provides the basis for understanding and interpreting analytical data on dust to sand-size material in Hanford Site facility/operations buildings for the purpose of distinguishing anthropogenic beryllium associated with chronic beryllium disease from naturally occurring beryllium in surface soil materials.

A1 General Conceptual Model

The CM for the soil materials in the Pasco Basin is based on the Hanford Site soil background CM presented in DOE/RL-92-24, *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes*. This general CM describes what the naturally occurring soils on or near the Hanford Site represent in terms of their origin and geologic setting, spatial extent and variability, and physical composition and the relationship of these factors to the chemical composition of the surface soils.

The primary focus of this CM is on factors that are relevant to the origin of the dust and material transported into Hanford Site facility/operations buildings by windblown processes and/or through tracking in by personnel; these factors are also relevant to understanding the naturally occurring beryllium levels in these materials. The nature and amounts of beryllium in the geologic materials in Hanford Site facility/operations buildings originate from the naturally occurring surface soils in the region, and more specifically from the portion of the soil materials subject to surficial transport processes (e.g., windblown material). The surficial deposits and materials are related to the vadose zone sediments because most of the surficial deposits are derived from the uppermost vadose zone materials as remobilized and fractionated material from the vadose zone sediments. Thus, the CM for the physical and chemical composition of dust and other geologic material transported into the Hanford Site facility/operations buildings is a subset of the surficial deposits that comprise the uppermost fraction of the vadose zone, as the material segregated and fractionated from the topsoils by eolian (i.e., wind related) processes. For simplicity, all surficial soil materials, including topsoils and dust, are collectively referred to here as topsoils.

The naturally occurring chemical composition and beryllium contents in the vadose zone soils, topsoils, and derivative dust materials are, therefore, all related to one another because they all share the same basic physical components (e.g., rock and mineral materials) that collectively comprise their chemical compositions and that are also the primary repositories of beryllium in the soil materials. The following subsections summarize the main CM elements for vadose zone soils, topsoils, and derivative dust materials.

A1.1 Vadose Zone Soils

The vadose zone soils include the geologic materials that extend from the surface to the top of the underlying water table. The majority (about 85 to 100 percent) of the vadose zone in the Pasco Basin consists of Hanford formation sediments derived from Pleistocene Age cataclysmic flood deposits, with the remainder consisting of older Plio-Pleistocene sediments and eolian deposits below the Hanford formation, and minor amounts of surficial deposits that include alluvial and eolian deposits, topsoils, and volcanic ash (DOE/RL-92-24). The relationship between the physical and chemical composition of the Hanford Site soil materials is described and verified in DOE/RL-92-24. This aspect of the CM specifies that the chemical composition of a soil sample is the sum of the mass fractions of the compositions of the constituent materials that comprise the soil, which typically include rock fragments and minerals. As described in DOE/RL-92-24, the Hanford formation soils are composed primarily of basalt fragments and mixtures of feldspar and quartz (quartzo-feldspathic material), with subordinate amounts of other materials (rock fragments and/or minerals) (Table A-3). These materials are the physical components that

comprise the parent material for the surficial deposits and topsoil, which is the source of the derivative materials that occur as dust to sand-size material in the facility/operations buildings. Thus, the physical components are common to all of these materials but in different proportions. The following main assumptions and features are associated with the general CM for nonradiological soil background at the Hanford Site:

- The compositions of the Hanford Site soil background samples (for the vadose zone) comprise a population of concentrations for each analyte.
- The population of soil background concentrations are related by the geologic processes associated with the origin and deposition of the sediments as cataclysmic flood deposits (Hanford formation).
- The physical components of most Hanford Site soil background samples are primarily admixtures of basaltic and quartzo-feldspathic materials in various proportions.
- The range of compositions in the soil background population is most appropriately characterized on the scale of the phenomenon associated with their origin (i.e., cataclysmic flood deposits) and associated deposition processes, which for the Hanford Site, is on the scale of the site, and/or the Pasco Basin.
- Digestate analyte concentrations (environmental analyses) are less than or equal to total (bulk) concentrations and vary inversely with particle (grain) size in the samples for many analytes (i.e., samples with smaller grain size yield larger digestate concentrations due to greater effective surface area available for reaction with acidic solvents). The extent of dissolution of the rock mineral components can also vary with mineral type.

A1.2 Surficial Deposits and Dusts (Topsoils)

The physical and chemical compositions of the parent soil material are related to those of the surficial deposits and soil related materials at the facility/operations buildings in a number of ways (ECF-HANFORD-11-0038, *Soil Background for Interim Use at the Hanford Site*). Based on the relationships between chemical composition and the physical composition in the Hanford Site soil background CM, these relationships are consistent with the following interpretations and also serve as CM components for the topsoils and derivative dust material:

- The surficial deposits (i.e., topsoils) comprise a subpopulation of overall soil background.
- The origin of topsoil in the Pasco Basin tends to be primarily associated with eolian processes involving windblown fractionation of soil/sediment components (i.e., basalt and quartzo-feldspathic material) based on particle size and density.
- Windblown fractions of topsoil materials (e.g., dust) are a subset of the topsoil population.
- The physical and chemical composition and beryllium contents of the topsoils reflect their origins from vadose zone sediments, modified by surficial sorting, fractionation, and alteration processes (e.g., eolian process, pedogenesis, and bioaccumulation).
- Some topsoils may contain alteration products of basaltic and feldspathic components (e.g., clay/smectite from incipient pedogenic processes).
- Some topsoils may also represent and/or contain “nugget” components with soil compositions that appear as naturally occurring outliers.

The aspects of the CM pertaining to the relationship of chemical composition to the types, compositions, and proportions of geologic physical constituents (rock and mineral materials) are described in the following chapter in the context of the geochemical CM component.

A2 Geochemistry Conceptual Model Component

The geochemistry component of the CM is intended to provide information and insight on the characteristics, processes, and factors that affect the chemical compositions of the Hanford Site soils and surficial soil materials and the relationships between them. This CM emphasizes the significance of these factors on the naturally occurring levels of beryllium in these materials, in the context of their relationship to the beryllium levels expected to occur in the dust to sand-size material in Hanford Site facility/operations buildings.

Geochemically, the background composition of topsoils and dust components (including beryllium contents) is expected to have a range of concentrations for each analyte that reflects the proportions and compositions of the constituent physical components (e.g., feldspar, basalt, and quartz). Soil materials that are related because they share the same basic physical components (e.g., rock and mineral grains), which collectively determine the chemical compositions, should have the following chemical characteristics:

1. Chemical compositions (including beryllium contents) reflect and correlate to the proportions and compositions of the constituent (physical) materials.
2. A range (population) of soil compositions is attributable to the variations in the proportions of the largely common physical components.
3. Analyte concentrations of some soils influenced by modification of physical compositions are due to either surficial processes, such as pedogenesis, and/or the inclusion of other components such as volcanic ash, organic material, exotic rock, or mineral materials (nugget effect).

The background concentrations for beryllium in the soils from the Hanford Site, based on environmental analyses, range from 0.46 to 2.1 mg/kg in the vadose zone soils, from 0.2 to 2.1 mg/kg in typical topsoils, up to 2.5 mg/kg in highly alkaline soils, and to values as large as 10 mg/kg for ash (DOE/RL-92-24; PNNL-18577, *A Review of Metal Concentrations Measured in Surface Soil Samples Collected on and Around the Hanford Site*) and are summarized in Table A-1.

Bulk compositional data on the levels of beryllium in 274 surficial soil samples nationwide range from 0.09 to 3.4 mg/kg, with an average of 1.28 mg/kg (USGS, 2005).

The following aspects of the CM address the characteristics and relationships between the vadose zone soils, the topsoils, and derivative wind transported materials, and the associated differences between the beryllium levels in these materials.

The physical and chemical compositions of the vadose zone soils and topsoil materials derived from them are related because both have the same primary physical components. However, the proportions of physical components in the topsoils can differ from those in vadose zone soils due to the effects of segregation and fractionation on wind related (eolian) processes. The eolian transported materials represent materials fractionated from the parental soils by density and grain size because smaller and less dense materials are more readily segregated and transported by wind related processes. The most readily wind transported components of the Hanford Site soil should be the smaller sized fractions of the basalt and quartzo-feldspathic physical components. The physical composition of many topsoil and dust materials may, therefore, be expected to have somewhat greater proportions of the lower density

quartzo-feldspathic material and/or lower density basaltic components (e.g., feldspar and glass). The chemical composition of these soils and those with incipient alteration products (e.g., clay and smectite) should contain relatively larger concentrations of the analytes in those components (e.g., aluminum, potassium, sodium, calcium, and the trace elements such as barium and lead). The bulk composition of soil materials with relatively larger proportions of quartz decreases the total amounts of analytes not present in quartz because quartz is nearly exclusively silicon dioxide. These types of soil characteristics are expected to be more common in dust materials.

Table A-1. Summary of Background Beryllium Concentrations in Soil Materials at the Hanford Site

Soil Material	Range of Beryllium Concentrations (mg/kg)	Reference/Source
Vadose Zone Soils	0.46 to 2.1 (1.07)	DOE/RL-92-24
Typical Topsoils and Surficial Deposits	0.2 to 2.1 (0.99/0.37)*	DOE/RL-92-24; PNNL-18577
Highly Alkaline Soil	Up to 2.5 (2.25)	DOE/RL-92-24
Volcanic Ash	0.62 to 10 (0.68/3.01)**	DOE/RL-92-24
Coal Fly Ash	0.07 to 0.44 (0.25)	DOE/RL-94-16

* Average values in parentheses are from DOE/RL-92-24, *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes*, and PNNL-18577, *A Review of Metal Concentrations Measured in Surface Soil Samples Collected on and Around the Hanford Site*, respectively.

** Average values in parentheses are for data without and with the 10 mg/kg value.

Other topsoil materials, that have more refractory physical composition from the removal of small and low density components, can have higher proportions of the denser and larger physical components (e.g., basalt). These soil materials are expected to have chemical compositions more highly correlated with basaltic components (e.g., iron, manganese, chromium, and nickel). These types of soil characteristics are expected to be less common in dust materials.

A small percentage of soils are expected to have compositions that extend or depart from the main population of topsoils due to modified compositions resulting from pedogenic (soil forming) processes, the presence of organic components, and/or the presence of exotic (nugget) components.

The majority soils, topsoils, and derivative dust materials should, therefore, all contain the same types of physical components that are repositories of all naturally occurring analytes, including beryllium. The following physical components serve as the naturally occurring repositories for the background analytes:

- Primary Components:
 - Basalt (rock material)
 - Quartzo-feldspathic minerals (quartz and feldspar)
 - Volcanic ash (ubiquitous component)
 - Organic material (some soils)

- Secondary Components:
 - Volcanic ash
 - Components from pedogenetic (soil forming) processes
 - Organic components
 - Nugget components
 - Coal fly ash (limited distribution)

The following subsections summarize the CM information pertaining to these compositional repositories.

A2.1 Basalt

Basaltic material is the dominant physical component in most of the soil/sedimentary material in the vadose zone throughout the Pasco Basin that comprises as much as 35 to >70 percent of the soils (by volume). The basaltic clastic materials are the products of erosion of the Columbia River Basalts from Pleistocene Age cataclysmic floods. The cataclysmic floods, responsible for shaping the landscape in eastern Washington into a unique Channeled Scablands landform province, eroded the Columbia River Basalt bedrock up to 4.8 km (3 mi) thick throughout most of eastern Washington and all other geologic materials encountered at extraordinary rates and scales. The floods then redeposited the eroded clastic material as unconsolidated sediments throughout eastern Washington, and extending to the Willamette Valley in central Oregon and into the Pacific Ocean. These sediments are known as the Hanford formation in southeastern Washington, where they are as much as 91.5 m (300 ft) thick.

There are little data on the beryllium concentrations in Columbia River basalts. Environmental analyses of size fractions of crushed Umtanum basalt ranging from 1 mm (0.04 in.) to 0.0156 mm (0 in.) diameter, published in DOE/RL-92-24, provide a conservative¹ estimate of the magnitude of beryllium levels for the basalts. The beryllium concentrations in these samples range from 0.6 to 1.5 mg/kg, and increase systematically with decreasing grain size (DOE/RL-92-24). This is consistent with average levels of beryllium of 1 to 3 mg/kg in coarse-grained compositional equivalents reported by Evensen and London (2002).

The basalt is composed of large crystals (phenocrysts) of feldspar (plagioclase, An₆₀₋₇₀) and iron-magnesium silicates (pyroxene and olivine) in a groundmass of basaltic minerals² and glass quenched from the rapidly cooled magma after eruption. Based on experimentally determined beryllium distribution coefficients of 1.0 to 2.0 between plagioclase and magma, and the beryllium concentrations in feldspars comparable to the phenocrysts in the basalt, the groundmass plus glass material should contain about 0.25 to 2 mg/kg of beryllium.

A2.2 Feldspars and Quartz

It is indicated from geochemical analyses of feldspars and geochemical partitioning relationships that feldspars typically have trace amounts of beryllium that can range from 0 to >20 ppm, depending on the feldspar type and major element composition (i.e., calcic to sodic plagioclase; sodic to potassic alkali feldspars) (Evensen and London, 2002).

¹ The concentrations are considered to be conservative because the "environmental" analyses of incomplete digestates, by SW-846, *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods, Third Edition; Final Update IV-B*, methods are less than those in bulk (e.g., complete digestion) compositions.

² Basaltic minerals typically include plagioclase, pyroxenes, iron-titanium oxides, apatite, and +/- subordinate amounts of sulfide minerals (Hoover and Murphy, 1989).

A2.2.1 Basaltic Feldspars (Plagioclase)

The beryllium concentrations in feldspars with compositions comparable to the phenocrysts in the basalt (e.g., An₆₀₋₇₀) have been found to range from 0.5 to 4 mg/kg (Parsons et al., 2009). The more sodic groundmass feldspars in the basalt typically have somewhat lower beryllium concentrations.

A2.2.2 Quartzo-Feldspathic Material

Much of the feldspar and quartz in the quartzo-feldspathic fractions of the soil materials were derived from the disaggregation of coarser-grained phaneritic rocks (e.g., granites) near the headwaters of the cataclysmic floods in Idaho and Montana, and/or from tributary sources in the Cascade Mountains. These feldspars appear to have a larger compositional range of alkali feldspar and plagioclase. The alkali feldspars can have beryllium concentrations >20 mg/kg, but more typically average <10 mg/kg beryllium (Evensen and London, 2002). Quartz can also contain 1 to 2 mg/kg beryllium, ostensibly from inclusions and/or impurities (Evensen and London, 2002).

A2.3 Volcanic Ash

Volcanoes have been erupting in the Cascade Range for over 500,000 years. During the past 4,000 years, the Columbia Basin region has been impacted by 13 volcanoes in Washington, Oregon, and northern California. Ash from the eruption of Mount Mazama (Crater Lake), for example, blew around the Columbia Basin for 3,000 years (Volcanic Tephra Studies website, 2011). However, Mount St. Helens has erupted more frequently than any other volcano in the Cascade Range; consequently, it has had the greatest impact on the soils of the Columbia Basin. One of the most recent large eruptions that occurred in 1980 deposited 1.27 to 5.1 cm (0.5 to >2 in.) of ash throughout the Columbia Basin and was a major component of dust for months to years afterward. Varying proportions of this ash have also since become components of the topsoils and surficial deposits. However, the physical and chemical composition of the topsoil material continues to be dominated by accumulated volcanic ash in some locations.

Although there have been numerous studies on the composition of the 1980 Mount St. Helens ash (e.g., Taylor and Lichte, 1980; Fruchter et al., 1980; Hooper et al., 1980), beryllium data were generally not included in the analyses. Although beryllium levels of 1.2 to 1.6 mg/kg were in the ash from the smaller 2004 to 2005 steam eruptions of Mount St. Helens (Rowe et al., 2008), the origin of these ashes differs from those of the 1980 eruption because the ash compositions were from pre-existing rock, whereas much of the 1980 ash material was from a magmatic source. Thus, there continues to be a general absence of data on the beryllium levels in ash from the 1980 major eruptive phase of Mount St. Helens.

The environmental analyses of soil background in the Pasco Basin (DOE/RL-92-24) include beryllium data on four volcanic ash units (Volcanic Tephra Studies website, 2011). Three of the incomplete digestate concentrations for these ashes ranged from 0.62 to 0.72 mg/kg beryllium, and one contained 10 mg/kg beryllium.

A2.4 Components from Pedogenetic Processes

The effects of surficial pedogenetic (soil forming) processes on most topsoil compositions are generally not significant in the relatively arid climate in this region because there is little pedogenetic chemical alteration apart from the precipitation of secondary minerals (e.g., calcium carbonate and salts). The formation of incipient alteration products (e.g., clay and/or smectite rinds on some minerals) also does not tend to modify bulk compositions. However, a small percentage of soils is more frequently exposed to surface water, and/or repeated wetting and drying, and is subject to more extensive modifications of chemical compositions. Topsoils affected by the Columbia River, in the vicinity of springs and in

ephemeral drainages (e.g., playas), are expected to have compositions that may be more extensively altered by the accumulation or leaching of analytes associated with these surficial alteration processes.

Some of the naturally occurring alkaline soils in the Pasco Basin, for example, have elevated concentrations of many analytes, including beryllium. The alkaline soils contain salts and precipitates leached from soils subject to more frequent wetting conditions and subsequent drying in alkali flats and/or ephemeral lake beds (playas). Naturally occurring beryllium contents in these rarer soil types range to levels of up to 2.5 mg/kg.

A2.5 Organic Material

The presence of organic components as physical components in the soil materials can also affect the chemical composition of soils. Examples include soils in the leaf litter canopy of shrubs, soils containing roots, and soils/dust containing these and/or other floral or faunal organic materials (e.g., woody materials, material from animals or insects). Apart from the effects of bioaccumulation of selected analytes in floral or faunal organic components, the addition of organic components generally tends to decrease analyte concentrations by effectively diluting the analyte levels in the inorganic geologic materials. Dust materials, such as those accumulated in buildings, may contain significant proportions of such organic material; however, the ratios of natural beryllium to other metals is expected to remain constant, thus predictions should remain valid unless/until the concentration of organic material dilutes the reference metals below detection limits.

A2.6 Nugget Components

The soil background CM for the Hanford Site (DOE/RL-92-24) included a provision for unusually large concentrations of some analytes that can occur naturally in some samples due to the presence of small amounts of more exotic components. This provision involves the consideration of samples containing a small amount of a mineral or component containing a large amount of one or more analyte. The existence of a “nugget” of gold or ore mineral with high concentrations of one or more elements, for example, may occur naturally in only a very small percentage of material or samples, but when it does occur, elevated concentrations are observed. In the mining industry, this phenomenon is referred to the “nugget” effect (Knudson and Kim, 1978). Such apparent anomalies may be perceived as contamination or as outliers not belonging to the same population as the majority of samples. However, a small percentage of such “anomalies” are to be expected in natural background populations due to the “nugget” effect.

Examples of the nugget effect in the Hanford background data set are the seemingly anomalously high concentrations of many analytes, including beryllium, observed in the data for the alkaline soil samples, and the beryllium level of 10 mg/kg in one of the samples of volcanic ash, which were both previously described. Although the analyte concentrations appear anomalous compared to the population of most other samples, these samples are examples of naturally occurring “nuggets” in the data set.

Another example on the scale of individual grains within a soil sample is a soil sample that contains a small number of grains (e.g., one or more) of a relatively rare mineral that does not typically occur in most other samples. A classic example is a placer deposit where gold and or “heavy” minerals have been concentrated with naturally high levels of zirconium, thorium, uranium, or rare earth elements. Such placer deposits have been known to occur in the horn of the Hanford Reach since the 1800s. Comparable examples for the existence of naturally occurring beryllium anomalies in some samples are due to the existence of rock fragments and/or mineral grains from granitic source materials (i.e., mica, cordierite, or beryl with very large beryllium concentrations up to >100 ppm, >10,000 ppm, and >50,000 ppm, respectively) (Evensen and London, 2002).

A2.7 Coal (Fly) Ash

Coal ash from coal-fired power plants at various locations around the Hanford Site is included here as a potential component in some soils at the Hanford Site. While there are no current sources of coal ash production at the Hanford Site, there are significant deposits of coal ash at various locations from previous coal-fired power plants. The coal ash is not a naturally occurring component of the soils, but apart from its role as a byproduct of power plant operations, it is unrelated to the contamination generally associated with Hanford nuclear reservation operations.

Additionally, the beryllium found in coal ash is predominantly bound up in a silicate form similar to that present in naturally occurring beryllium. Studies have indicated that the silicate forms of beryllium pose little risk as related to chronic beryllium disease or sensitization. The presents of coal fly ash in a soil sample would be indicated by higher than normal metal concentration in the sample, thus making the sample unusable for our study.

Prior to the stabilization of the coal by crusting agents and disposal at designated disposal sites from 1994 to 1995, many of the ash pits, washdown pits, and disposal piles were sources of plumes of fine windblown dust and potential additional components of affected downwind topsoils. In one report, it was determined that fly ash was prevalent in much of the soils throughout the 100 Area waste sites in the vicinity of the open coal ash sites (DOE/RL-94-16). Large quantities of ash observed on the surface with varied distribution were reported in parts of the 100 Areas; the ash was thinly distributed in some areas and as thick as 7.6 cm (3 in.) in others (DOE/RL-94-16).

The coal fly ash is known to contain levels of many metals that are relatively high compared to the soils, but less than regulatory limits (DOE/RL-2010-119, *Sampling and Analysis Plan for Supplemental Characterization of the 200-CW-1, 200-CW-3, and 200-OA-1 Operable Units*). The beryllium concentrations in "Clean Spoil Pile Sampling and Suspect Contaminated Soil Sampling" based on contract laboratory procedure methods, range from only 0.07 to 0.44 mg/kg beryllium, with most values about 0.2 mg/kg beryllium. Because there are no data available on the fly ash itself, efforts are underway to sample and analyze buried samples of the coal ash (DOE/RL-2010-119).

A2.8 Potential Yttrium Contribution from Strontium-90 Decay

One concern raised during the DQO process was the potential contribution of yttrium (Y) from the decay of strontium (Sr)-90 to Y-90; this is an important issue to address in the DQO because Y-beryllium is a candidate metal ratio for distinguishing natural from anthropogenic beryllium. This issue primarily concerns the potential contributions of anthropogenic Sr and the Y progeny to natural background levels. The main sources of anthropogenic Y in soil as Y-90 progeny are derived from the following:

- Sr-90 and Y-90 progeny as anthropogenic radionuclide soil background (global fallout) (DOE/RL-96-12)
- Sr-90 and Y-90 components in soil from Hanford contaminants associated with the biological uptake of radiological contaminants in vegetation from Hanford waste sites
- Sr-89 and Y-89 components in soil from Hanford contaminants associated with the biological uptake of radiological contaminants in vegetation from Hanford waste sites

Tumbleweeds (Russian thistle) are one of the most important biologic vectors capable of spreading contamination that can potentially contribute to the metal concentrations in soil because they have a deep taproot that can sequester contamination from below the soil surface into the plant body on the surface and have the potential to transfer contamination the farthest distance from their original locations

(PNNL-19455). However, it is indicated from the data and information summarized in Tables A-2 and A-3 that the potential contributions of anthropogenic Sr and/or Y from these sources to surface soils overall are negligible compared to the naturally occurring levels of Sr and Y.

Table A-2. Sources and Levels of Anthropogenic Sr-89 Sr-90, Y-89 and Y-90 Progeny in Hanford Surface Soils

	Sr-90 and Y-90 ^a Activities	Strontium from Sr-90 ^b	Yttrium from Sr-90 ^c	Range of Initial Strontium Levels from Sr-89 ^d	Range of Yttrium Levels from Y-89 ^e
	(pCi/g)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
Anthropogenic Background (Fallout) ^f	0.21	1.50E-09	3.80E-13	--	--
All Vegetation (Maxima) ^g					
2001 to 2006 ^h	68	4.90E-07	1.20E-10	4.9E-07 to 1.6E-09	4.9E-07 to 1.6E-09
2009 ⁱ	1.1	7.90E-09	2.00E-12	7.9E-09 to 2.6E-11	7.9E-09 to 2.6E-11
Tumbleweed Maxima (1981) ^j	3.20E+06	0.023	5.80E-06	0.023 to 7.7E-05	0.023 to 7.7E-05

a. Secular equilibrium (Y-90 = Sr-90 activity) is assumed.

b. Values are based on conversions using specific activity value of 1.4E+02 Ci/g.

c. Values are based on conversions using specific activity value of 5.5E+05 Ci/g.

d. Range is based on lowest NNS Sr-90/89 mass ratio (~ 1:1) from DOE/NV/25946-1189, *Determination of Natural Beryllium in Soil and Swipe Samples Utilizing Yttrium/Beryllium Ratios*, and Hanford reactor fuel Sr-90/89 activity ratio of 1:1.36 (DOE/RL-94-98); mass ratio of 300:1; Sr-89 specific activity of 2.9E+04 used for mass conversions.

e. Values are from ~100% decay of Sr-89 to Y-89 after 1.4 years (10 half-lives).

f. 95th percentile (nonparametric) value is from DOE/RL-95-55, *Hanford Site Background: Evaluation of Existing Soil Radionuclide Data*, Table 3-7.

g. Maximum values are typically from vegetation at or near Hanford Site waste sites.

h. Data are from PNNL-16623, *Hanford Site Environmental Report for Calendar Year 2006*, and PNNL-16623, Appendix 2.

i. Data are from PNNL-19455, *Hanford Site Environmental Report for Calendar Year 2009*, Appendix 2 (undecayed).

j. Data are from WCH-EP-0145-4, *Westinghouse Hanford Company Environmental Surveillance Annual Report—200/600 Areas: Calendar Year 1990*.

Contributions of Y-90 (e.g., from tumbleweeds) are from anthropogenic Sr-90 ($t_{1/2} = 29.1$ years), which decays to Y-90 (64 hours), which in turn decays to Sr-90 (stable). However, Y-90 activities are in secular equilibrium with Sr-90 after about 19 days and thereafter exist at approximately the same activity levels as Sr-90, as long as Sr-90 is present.

The potential contribution of anthropogenic Y-89 to Y-background (natural Y-89) is from the decay of Sr-89 (50.5 days) to Y-89 (stable). The range of levels for parental Sr-89 and Y-89 progeny were estimated from the activity and/or mass ratios Sr-90/Sr-89 from the Nevada National Security Site (NNS) (DOE/NV/25946-1189, *Determination of Natural Beryllium in Soil and Swipe Samples Utilizing Yttrium/Beryllium Ratios*), and from fission product levels in Hanford Site reactor fuel (DOE/RL-94-98, *Hanford Site Radiological Background: Data Quality Objective Issues and Recommendations*). However, anthropogenic Y-89 is not expected to occur in vegetation vectors because Sr-89 decays to stable Y-89

after about 1.4 years (10 half-lives), and would thereafter behave chemically as Y rather than Sr. Even if Y-89 was to occur in biologic vectors, its concentration relative to natural background levels is also negligible, and below the detection levels of typical elemental Y analytical methods.

Table A-3. Relative Levels of Natural and Anthropogenic Strontium and Yttrium in Hanford Surface Soil

		Strontium (Sr)		
			(mg/kg)	(mg/kg)
Natural Soil Background		Sr (metal) ^a	35	35
Anthropogenic			Maxima	Anthropogenic
	Fallout	From Sr-90	1.5E-09 ^b	1.5E-09
	Vegetation Vectors	From Sr-90	0.023 ^b	1.0E-07 ^c
		From Sr-89	0.023 ^d	7.7E-05 ^e
Total Anthropogenic Sr		0.046	0.046	
Anthropogenic Fraction of Natural Background			0.00131	2.19E-06
		Yttrium (Y)		
			(mg/kg)	(mg/kg)
Natural Soil Background		Y (metal) ^f	3	3
Anthropogenic			Maxima	Typical
	Fallout	From Y-90	3.8E-13	3.8E-13
	Vegetation Vectors	From Y-90	5.80E-06	1.00E-12 ^c
		From Y-89 ^g	0.023	7.7E-05
Total Anthropogenic Y		0.023	7.67E-05	
Anthropogenic Fraction of Natural Background			0.0077	2.6E-05

a. Preliminary data are from soil analyses of Hanford Site soil background samples.

b. Values are from Table A-2.

c. Maximum values excluding overall tumbleweed maxima (WHC-MR-0418, *Historical Records of Radioactive Contamination in Biota at the 200 Areas of the Hanford Site*).

d. Based on lowest NNSS Sr-90/89 mass ratio (~1:1) from DOE/NV/25946-1189, *Determination of Natural Beryllium in Soil and Swipe Samples Utilizing Yttrium/Beryllium Ratios*.

e. Sr-89 level is based on Hanford reactor fuel Sr-90/89 activity ratio of 1:1.36 (DOE/RL-94-98, *Hanford Site Radiological Background: Data Quality Objective Issues and Recommendations*); mass ratio of 300:1.

f. Low-end of Y range is estimated from Sr/Y ratios in Columbia River Basalt Group basalts (Hooper, 2006, *Continental Flood Basalts [CFB's]*).

g. Values are from ~100% decay of Sr-89 after 1.4 years (10 half-lives).

Thus, it is indicated that the potential contributions of Sr-90 and the Y-90 progeny,³ and Sr-89 and Y-89 progeny⁴ to background levels of Sr and Y, are negligible based on the relative concentrations in these anthropogenic components compared to the naturally occurring levels in the soils summarized in Table A-2.

Even the largest values of anthropogenic Y (e.g., measured in Russian thistle [$3.2E+06$ pCi/g Sr-90]) correspond to estimated total contributions of only 0.023 mg/kg Sr and Y to the background levels, and more typical levels are estimated to be smaller by orders of magnitude (Table A-2). It has also been estimated that <1% of the tumbleweeds evaluated in conjunction with the Hanford Site vegetation control activities contain radiological contaminants from Hanford Site operations and/or facilities. It is further indicated from the Hanford environmental surveillance studies that the highest levels of Sr-90 in vegetation are at or near waste sites, the overall levels of anthropogenic Sr (measured as Sr-90) in vegetation across the site are significantly lower, and the levels in vegetation have systematically decreased over time to levels near those of vegetation at distal communities and anthropogenic background (global fallout) levels (PNNL-15222, *Hanford Site Environmental Report for Calendar Year 2004*). It is also noted that current laboratory analytical methods for (metallic) Y typically measure only Y-89 with the inductively coupled plasma-mass spectrometry instrumentation, so that Y-90 contributions would not generally be included in the analysis. However, the potential contributions of both Y-90 and Y-89 are included in Tables A-2 and A-3 for completeness. Thus, the weight of evidence indicates that the potential contribution of Y to soil from Y-90 progeny derived from all sources of anthropogenic Sr-90 appears to be negligible.

A3 Mass Balance Scenarios

Examples of the manner in which naturally occurring beryllium concentrations in the Hanford Site soils are related to the compositions and proportions of primary physical components, and how they are also related to one another, are illustrated by the simplified scenarios shown in Table A-5 based on the information in Table A-4. Three example scenarios are shown in Table A-5 for the types, proportions, and beryllium levels of primary component materials: (1) background soils overall, (2) surficial deposits (i.e., topsoils), and (3) derivative dust and windblown material based on the basic Conceptual Site Model information described here. The values used in the three scenarios in Table A-5 are intended to be the representative and/or conservatively high values selected from those in Tables A-2 and A-3, and for the types, proportions, and beryllium concentrations. The main differences between the scenarios are in the proportions of basaltic and quartzo-feldspathic materials. Beryllium free organic material is also included in scenario III as a significant component of the dust material.

Table A-4. Types and Proportions of Physical Components in Hanford Soils and Topsoils and Associated Beryllium Concentrations

Soil Components (Rocks and Minerals)	Modal Proportions (Approximate Percent)	Beryllium Concentration Range (mg/kg)	Source/Reference	Beryllium Levels Used in Mass Balance Calculations
Basalt (Rock Material)	35 to >70	0.5 to >1.5	Hoover and Murphy, 1989; DOE/RL-92-24	1.2

³ Although Y-90 decays to Sr-90 (stable), Y-90 activity levels are in secular equilibrium with Sr-90 so that after about 19 days, Y-90 activity levels remain constant (\approx Sr-90 activity) as long as Sr-90 is present.

⁴ Most Sr-89 decays to Y-89 (stable) after about 10 half-lives (\sim 1.4 years).

Table A-4. Types and Proportions of Physical Components in Hanford Soils and Topsoils and Associated Beryllium Concentrations

Soil Components (Rocks and Minerals)		Modal Proportions (Approximate Percent)	Beryllium Concentration Range (mg/kg)	Source/Reference	Beryllium Levels Used in Mass Balance Calculations
Quartzo-Feldspathic Minerals		30 to 65	0.2 to >2.0	DOE/RL-92-24; Evensen and London, 2002	0.5
	Quartz	15 to 33	0 to 7	DOE/RL-92-24; Evensen and London, 2002	0
	Feldspar	15 to 33	0.5 to 20	DOE/RL-94-16; Evensen and London, 2002; Parsons et al., 2009	1
Volcanic Ash		<5	0 to >30	DOE/RL-92-24	N/A
Coal Fly Ash		0 to <10	0.07 to 0.44	DOE/RL-94-16	N/A
Alkaline Soil		N/A	2.5	DOE/RL-92-24	N/A
Organic Material		0 to >50	0 to ?	Estimated	0

As indicated from the simplified mass balance scenarios in Table A-5, the magnitude and direction of the differences in beryllium concentrations between the soils (overall), topsoils, and derivative dust are consistent with the differences in modal proportions of the basaltic and quartzo-feldspathic components described in the CM for the processes associated with: (1) the derivation of topsoil from the underlying soils, and (2) the derivation of dust material from the surficial materials. In these scenarios, the beryllium levels in topsoils are about two-thirds of those in the underlying soils, and the beryllium level in the dust material is about one-half of that in the topsoil, due to the dilution effect of mixing with beryllium free organic material.

These examples are not unique solutions because total beryllium concentrations can vary with difference in the proportions or beryllium concentrations in the constituent physical components used in the scenarios. However, these scenarios are consistent with the CM in terms of the relative amounts of beryllium in the soils, topsoil, and dust in these scenarios, are also consistent with the magnitude of total beryllium levels in the soil materials, the types and proportions of physical components observed in the soils, and the ranges of beryllium estimated to occur in these materials. Variations in the beryllium concentrations could also result from the consideration of one or more of the aforementioned components. These scenarios are not intended to suggest that the physical compositions of the soils must also be determined in the analysis of soil compositions, but rather as examples of the relationships between physical and chemical composition in the CM. Perhaps the most important implication of this aspect of the CM is to illustrate the correlation between beryllium contents in soil and the types and proportions of

physical components in the soil, which is the basis for the use of metal ratio relationships as a viable tool in distinguishing natural beryllium from anthropogenic beryllium.

Table A-5. Example Mass Balance Scenarios for Relating Total Beryllium Levels in Soils, Topsoils, and Dust to the Proportions and Levels of Constituent Components

Scenario	Component	Basalt	Quartzo-Feldspathic Material	Organic Material
I. Soils (Overall)	Beryllium Concentration (ppm)	1.5	0.5	--
	Proportion (fraction)	70%	30%	--
	Beryllium Contribution (ppm)	$1.5 \times 0.7 = 1.05$	$0.5 \times 0.3 = 0.15$	--
	Total Beryllium (ppm)	$1.05 + 0.15 = 1.2$		
II. Topsoils	Beryllium Concentration (ppm)	1.5	0.5	--
	Proportion (fraction)	30%	70%	--
	Beryllium Contribution (ppm)	$1.5 \times 0.3 = 0.45$	$0.5 \times 0.7 = 0.35$	--
	Total Beryllium (ppm)	$0.45 + 0.35 = 0.80$		
III. Dust (with Organic Material)	Beryllium Concentration (ppm)	1.5	0.5	0
	Proportion (fraction)	15%	35%	50%
	Beryllium Contribution (ppm)	$1.5 \times 0.15 = 0.225$	$0.5 \times 0.35 = 0.175$	$0 \times 0.5 = 0$
	Total Beryllium (ppm)	$0.225 + 0.175 + 0 = 0.40$		

A4 References

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Appendix B
Selected Sampling Locations

Table B-1. Selected Sampling Locations

Original Sample Identification	Original Site Name/Description	Source	Easting	Northing	Longitude	Latitude
Background Locations						
B193K9	ALE W2	HRNM	555,611	133,936	119.77499	46.53604
B193L3	ALE W5	HRNM	556,696	130,107	119.76132	46.50150
B193L5	ALE W6	HRNM	560,776	130,938	119.70805	46.50862
B193L9	ALE W9	HRNM	559,486	127,550	119.72530	46.47826
B193M1	ALE W11	HRNM	556,445	125,264	119.76517	46.45795
B193M5	ALE W14	HRNM	558,851	122,808	119.73416	46.43565
B193M9	ALE E3	HRNM	568,245	123,523	119.61182	46.44120
B193N1	ALE E4	HRNM	573,776	124,453	119.53970	46.44898
B193N3	ALE E5	HRNM	576,522	123,781	119.50407	46.44263
B193N7	ALE E8	HRNM	574,266	121,884	119.53373	46.42582
B193N9	ALE E10	HRNM	570,603	120,666	119.58157	46.41525
B193P1	ALE E14	HRNM	574,134	115,952	119.53640	46.37247
B193P3	ALE E15	HRNM	577,777	116,087	119.48903	46.37327
B193R3	ALE W7	HRNM	564,170	131,463	119.66376	46.51303
B193R7	ALE W13	HRNM	564,734	125,391	119.65726	46.45835
B193R9	ALE W15	HRNM	563,711	122,330	119.67099	46.43091
B193W1	ALE 9	HRNM	579,559	121,482	119.46494	46.42160
B193X1	ALE E13	HRNM	580,636	117,553	119.45161	46.38612
B1D2Y0	HRNM NS-1	HRNM	591,980	135,884	119.30052	46.54957
B1D2Y2	HRNM NS-4	HRNM	556,313	148,206	119.76411	46.66436
B1D2Y4	HRNM NS-13	HRNM	565,764	155,855	119.63952	46.73231
B1D2Y5	HRNM NS-14	HRNM	570,325	156,495	119.57975	46.73760
B1D2Y6	HRNM NS-15	HRNM	574,800	156,573	119.52118	46.73782
B1D2Y7	HRNM NS-16	HRNM	579,501	156,649	119.45966	46.73796
B1D2Y8	HRNM NS-17	HRNM	584,419	156,646	119.39532	46.73733
B1D300	HRNM NS-27	HRNM	588,280	156,795	119.34477	46.73817
B1D305	HRNM NS-3	HRNM	586,130	143,210	119.37543	46.61625
B1D306	HRNM NS-7	HRNM	584,380	147,962	119.39741	46.65922

Table B-1. Selected Sampling Locations

Original Sample Identification	Original Site Name/Description	Source	Easting	Northing	Longitude	Latitude
B1D307	HRNM NS-8	HRNM	588,482	146,921	119.34402	46.64933
B1D308	HRNM NS-11	HRNM	582,459	151,847	119.42182	46.69441
B1D309	HRNM NS-12	HRNM	585,785	151,803	119.37835	46.69359
B1D315	HRNM NS-6	HRNM	565,676	147,962	119.64180	46.66131
B1D317	HRNM NS-9	HRNM	562,473	152,143	119.68308	46.69923
B1D318	HRNM NS-10	HRNM	568,014	152,012	119.61065	46.69751
B1D319	HRNM NS-18	HRNM	572,843	156,600	119.54679	46.73828
B1D320	HRNM NS-19	HRNM	577,658	159,760	119.48325	46.76616
B1D321	HRNM NS-20	HRNM	582,095	159,770	119.42517	46.76572
B1D327	HRNM NS-35	HRNM	571,460	150,982	119.56575	46.68789
B1D329	HRNM NS-37	HRNM	580,766	151,401	119.44403	46.69060
B1D334	HRNM NS-42	HRNM	594,260	133,403	119.27130	46.52694
B1D341	HRNM MCG-4	HRNM	559,179	141,075	119.72757	46.59996
B1D342	HRNM MCG-5	HRNM	554,678	142,717	119.78612	46.61511
B1X3D3	100-K Area	SESP-On	569,224	146,076	119.59711	46.64381
B1X3D9	100 Area fire station	SESP-On	572,395	145,209	119.55563	46.63603
B1X3F4	Southwest of B/C Crib	SESP-On	574,633	131,349	119.52635	46.51155
B1X3F6	South of 200 West	SESP-On	567,736	131,188	119.61657	46.51011
B1X3F9	400 E	SESP-On	588,421	124,283	119.34598	46.44809
B1X3H0	Southeast side of FFTF	SESP-On	587,923	118,658	119.35250	46.39759
B1X3H4	Wye Barricade	SESP-On	584,606	127,841	119.39589	46.48005
B1X3H5	Prosser Barricade	SESP-On	582,787	117,645	119.41969	46.38848
B1X3H7	North end Vernita Bridge	SESP-Off	559,492	146,069	119.72443	46.64375
B1X3J0	Ringold area	SESP-Off	595,872	129,476	119.24852	46.49473
SWB3	Hanford Site Gravel Pit #9	SWB	585,821	129,866	119.38000	46.49824

Table B-1. Selected Sampling Locations

Original Sample Identification	Original Site Name/Description	Source	Easting	Northing	Longitude	Latitude
SWB4	River Bank South of Old Hanford Town Site—Alluvial Deposits	SWB	589,892	136,951	119.32674	46.56186
SWB5	Hanford Site Gravel Pit #21 (100 Area—River Corridor)	SWB	574,625	150,583	119.52646	46.68429
SWB11	Cold Creek Slack Water Facies—ALE	SWB	558,513	135,554	119.73723	46.54932
SWB14	Mouth of Ringold Coulee (Across River from Energy Northwest Plant)	SWB	596,217	126,410	119.24400	46.46720
SWB15	Yakima Barricade Borehole	SWB	560,085	137,948	119.71666	46.57082
E1	Rattlesnake Mountain Soil	Ecol	570,029	117,835	119.58658	46.39019
E2	Rattlesnake Springs (Alkaline Soil)	Ecol	560,911	130,574	119.70586	46.50459
E3	Riparian (Juniper Soil)	Ecol	562,652	146,078	119.68308	46.64383
E4	Topsoil (DC Well Site)	Ecol	577,655	138,787	119.48681	46.57835
E5	Old Field Topsoil	Ecol	584,370	140,798	119.39898	46.59641
E6	Columbia River Plain (Sage Brush)	Ecol	571,936	129,903	119.56164	46.49857
E7	Playa (Spiny Hopsage)	Ecol	570,112	128,730	119.58549	46.48803
E8	Columbia River Plain	Ecol	563,812	134,429	119.66790	46.53921
D2	Onsite, added by DQO team	DQO	577,809	143,569	119.4848	46.6213
D3	Onsite, added by DQO team	DQO	581,821	136,821	119.4323	46.5607
D4	Onsite, added by DQO team	DQO	584,289	135,329	119.4000	46.5473
D5	Onsite, added by DQO team	DQO	569,837	141,642	119.5891	46.6040
D6	Onsite, added by DQO team	DQO	579,826	128,894	119.4584	46.4895

Table B-1. Selected Sampling Locations

Original Sample Identification	Original Site Name/Description	Source	Easting	Northing	Longitude	Latitude
D9	Onsite, added by DQO team	DQO	592,268	123,148	119.2956	46.4379
Supplemental Locations						
B1X3F2	200 East-Southeast	SESP-On	576,340	134,592	119.50403	46.54068
B1X3F5	East of 200 West gate	SESP-On	569,755	134,722	119.59016	46.54185
B1X3H1	North 300 Area	SESP-On	594,316	117,245	119.26887	46.38489
B1X3H2	South 300 Area	SESP-On	594,682	113,510	119.26408	46.35135
SWB9	Old Concrete Batch Plant (between 200 East and West)	SWB	571,415	136,705	119.56845	46.55965

Note: A few coal fly ash and/or Mount St. Helens ash locations may be added.

ALE = Arid Lands Ecology

DQO = data quality objective

Ecol = ecological

FFTF = Fast Flux Test Facility

HRNM = Hanford Reach National Monument

SESP = Surface Environmental Surveillance Project

SWB = site-wide background