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Title: University of Washington Harborview Research and Training Building Environmental Sample Plan for Cs-137 in Soils and Sediments

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University of Washington Harborview Research and Training Building

Environmental Sample Plan for Cs-137 in Soils and Sediments

LA-UR-29102, Rev 4

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Purpose and Scope

On May 2, 2019, a release of Cs-137 from a breached sealed source containing 2,800 curies (Ci) (1E14 Bq) of Cesium-137 (Cs-137) occurred at the University of Washington (UW) Harborview Research and Training Building (HRB). The release occurred during removal of the source from its holder within a portable hot cell in the second floor loading dock area. The loading dock and northeast corner of the building above the ground floor were heavily impacted by the release, while the remaining portions of the building and the exterior of the building were minimally impacted. Recovery from the incident is being conducted in three phases:

- Phase 1: Release of minimally impacted areas of the building,
- Phase 2: Removal of the source and portable hot cell from the loading dock, and
- Phase 3: Remediation of the building for unrestricted release.

Cs-137 in the Environment

Nuclear weapons testing was conducted up until the early 1960's. Cs-137 is one of the radionuclides produced from nuclear weapons testing. This testing injected substantial amounts of radionuclides into the atmosphere where it eventually settled down onto the earth surfaces as fallout. Cs-137 in fallout was produced in enough quantity and has a sufficiently long half-life, that it can be commonly detected in soils. Beck and Bennett (2002) show that Seattle may have received relatively large amounts of the fallout due to the high precipitation rate, since rain efficiently "washes out" the atmospheric dust. The amount of this fallout, decay corrected to today, could be as much as 5.4E4 pCi m^{-2} (2000 Bq $m^{-2)}$. However, Cs-137 fallout in urban environments will wash away relatively quickly during rainfall due to the vast amount of hard surfaces (asphalt, concrete, etc.). Any Cs-137 from fallout remaining in an urban area would most likely be found in the surrounding soils. Beck and Bennett (2002) and the National Council on Radiation Protection and Measurements (NCRP) Report 154 suggests calculations of current global fallout levels in Seattle in undisturbed soil areas would range up to approximately 3 pCi g^{-1} (0.1 Bq g^{-1}). However, there would be large variations based on a variety of transport factors related to the urban environment surrounding the area.

Figure 1 is an aerial view of the University of Washington Medical Center and shows an assortment of buildings, roads, and a few places with vegetation. Cs-137 released during the May 2, 2019 event, like fallout radionuclides, could remain in downwind vegetation and soil. This document provides information for the design and implementation of a technically defensible sampling plan to determine to what extent, if any, residual contamination is present in the soils surrounding the HRB.

Figure 1: Aerial view of the University of Washington Medical Complex

Objective of the Environmental Sampling Plan

The objective of this sampling plan is to confirm, within the stated statistical confidence limits, that the mean level of potential radioactive residual contamination in the soils surrounding the HRB is documented, in appropriate units, and is below the 25 mrem yr^{-1} (0.25 mSv yr^{-1}) dose limit for public residential exposure (NUREG-1757, WAC-246-246-020). The Soil Screening Level (SSLs), as derived in LANL (2019) for a residential scenario, is 34 pCi g^{-1} (1.3 Bq g^{-1}). The University of Washington has requested that the sampling demonstrate a dose less than 15 mrem yr^{-1} (0.15 mSv yr^{-1}).

The sample area was determined based on several factors.

- The downwind direction as was determined in the days immediately following the incident. Determining downwind direction in urban areas presents a challenge due to the “swirling” effects created by buildings. The grid survey of the area encompasses areas in all directions from the source, but is biased in the “downwind” direction.
- Evaluation of the NNSA Consequence Management Home Team Ground-Based Environmental Radiation Survey conducted on 5/21/19 , and RAP Region 8 Surface Contamination surveys and Low Volume Air sampling (Appendix A) data found no surface contamination levels greater than NUREG 1757, Table B.1 Acceptable Screening Levels for Unrestricted Release, of 28,000 dpm/100cm^2 total Cs-137

MARSSIM

The *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM) provides detailed guidance on how to demonstrate that a site is in compliance with a radiation dose- or risk-based regulation. MARSSIM focuses on the demonstration of compliance during the final status survey following scoping, characterization and any necessary remedial actions.

The design of the site characterization survey is conducted by several processes which include, but are not limited to, the Historical Site Assessment (HSA) and the Data Quality Objective (DQO) (EPA 2000). The HSA is an investigation to collect existing information describing the site's history. Following the HSA, the DQO process is conducted to develop performance and acceptance criteria (or data quality objectives) that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions.

Characterization surveys for surface and subsurface soils and media involve employing techniques to determine the lateral and vertical extent and radionuclide concentrations in the soil. These techniques, may be performed using (1) soil sampling and laboratory analyses, (2) direct surface radioactivity measurements on hard surfaces or (3) *in situ* gamma spectrometry analyses, depending on the detection capabilities of each methodology for the expected contaminants and concentrations. Note that *in situ* gamma spectrometry analyses or any direct surface measurement cannot easily be used to determine vertical distributions of radionuclides. Sample collection followed by laboratory analysis introduces several additional sources of uncertainty that need to be considered during a survey design. In many cases, a combination of direct measurements and samples is required to meet the objectives of the survey.

Surface scans for gamma activity should be conducted in areas likely to contain residual activity. Beta scans may be appropriate if the contamination is near the surface and represents the prominent radiation emitted from the contamination (see Appendix A).

Exposure rate measurements at 1 meter above the sampling location may also be appropriate. Each surface and subsurface soil sampling and measurement location should be carefully recorded (see Appendix A).

Data Quality Objectives for Environmental Sampling Plan

A MARSSIM survey approach will be used to perform the characterization surveys of soils and sediments for residual radioactive contamination. Per MARSSIM Section 2.4, there are six principal steps in the MARSSIM Radiation Survey and Site Investigation Process (EPA 2000):

- Site Identification
- Historical Site Assessment (HSA)
- Scoping Survey
- Characterization Survey
- Remedial Action Support Survey
- Final Status Survey

The first two principal steps (i.e., site identification and HSA) have already been completed and the results are detailed in this document. The purpose of this plan is to satisfy bullets three and four (scoping and characterization surveys) to assess for radiological impact, and, if impacted, to characterize the potential contamination. While this plan is for providing scoping data, the rigor of the sampling is designed to meet the quality objectives of a characterization and/or final status survey, if remediation is not required.

The MARSSIM HSA information for the area is that operational, surveillance, and maintenance activities, prior to the breach of the Cs-137 source, suggests that this area did not contain source Cs-137. The MARSSIM surveys will be used to assess for the possibility of residual contamination. The survey results will be evaluated for radioactive contamination against anticipated background levels due to prior nuclear testing.

Per MARSSIM Chapter 2, Section 2.4.4,

> "If an area could be classified as Class 1 or Class 2 for the final status survey, based on the HSA and scoping survey results, a characterization survey is warranted. This type of survey is a detailed radiological environmental characterization of the area (EPA 2000). "

Based on the HSA, Class 1 final status survey units are unlikely, but there is a possibility of contamination in isolated areas. While the less rigorous elements of a scoping survey may be sufficient in the decision unit in this plan, a characterization survey structure was used.

The primary objectives of a characterization survey are to (EPA 2000):

- Determine the nature and extent of the contamination.
- Collect data to support evaluation of remedial alternatives and technologies.
- Evaluate whether the survey plan can be optimized for use in the final status survey.
- Provide input to the final status survey design.

Furthermore, per MARSSIM Chapter 2, Section 2.4.4,

> "The characterization survey is the most comprehensive of all the survey types and generates the most data. This includes preparing a reference grid, systematic as well as judgment measurements, and surveys of different media (*e.g.*, surface soils, interior and exterior surfaces of buildings). The decision as to which media will be surveyed is a site-specific decision addressed throughout the Radiation Survey and Site Investigation Process (EPA 2000)."

Once the scoping survey has been completed per this plan, the data will be analyzed using the MARSSIM statistical methods. The MARSSIM statistical method results will be used to plan for the remedial action support surveys and/or final status survey, as appropriate.

Measurement Quality Objectives (MQOs)

Measurement Quality Objectives (MQOs) are a statement of a performance objective or requirement of a particular survey method performance characteristic (MARLAP 2004). The following are the characterization survey method performance characteristics.

1. Minimum Detectable Concentration (MDC) should be below 0.5 $pCig^{-1}$ (0.02 Bq g^{-1}).

2. Minimum Detectable Activity (MDA) should be below the surface contamination levels in NUREG 1757, Table B.1 Acceptable Screening Levels for Unrestricted Release, of 28,000 $dpm/100cm^2$ total Cs-137.

3. The degree of measurement uncertainty (combined precision and bias) should be reported and the degree should allow for the needed level of detection and for making statistical decisions with acceptable confidence.

4. The range of the instrument and measurement technique should be appropriate for the concentrations expected.

5. The instrument and measurement technique should be specific for the radionuclide (Cs-137) being measured. Specificity is the ability of the measurement method to measure Cs-137 in the presence of interferences.

6. For field instruments, the instrument should be rugged enough to consistently provide reliable measurements.

General Sampling Instructions

Soil sampling at the 0- to 2-inch depth is most appropriate for these soils using a scoop method. The following are general steps that could be used to obtain the soil samples.

1. Locate the sampling areas.

2. Collect debris such as pine needles or other surface organic debris.

3. Collect soil or sediment from the 0- to 2-inch depth with a plastic scoop or stainless steel scoop. (WDOH protocol is 12"x12"x1" collection area, and should be considered when developing sampling procedures.)

4. Place samples into the appropriate sampling containers.

5. Place the matching sample identification chain-of-custody label on sampling containers and record the sampling date and time.

6. Complete the chain-of-custody form with the appropriate sampling information such as recording the type of sample (i.e., individual), tools used (i.e., scoop, ring, auger), depth, and the sample location, date, time, and sampler's name.

7. Dispose of the plastic scoop or wash the sampling equipment with water and dry with paper towels or similar product; perform this step after every sampling location.

8. Package the samples for shipping and send to the appropriate analytical laboratory.

In-Situ sampling should consist of a 60-second scalar direct survey or equivalent spectroscopy on hard surfaces (concrete, asphalt). In conjunction with the direct survey, a 100 cm^2 smear survey of the location should be performed.

1. Locate the sampling areas; brush away debris such as pine needles and surface organic debris. Removal of debris prevents instrument damage (e.g., punctured mylar) and provides better geometry for greater instrument efficiency.

2. Perform direct survey, then perform smear survey.

3. Place smear into the appropriate sampling container.

4. Place the matching sample identification chain-of-custody label on sampling containers and record the sampling date and time.

5. Complete the chain-of-custody form with the appropriate sampling information such as recording the type of sample (i.e., smear), and the sample location, date, time, and sampler's name.

6. Package the sample for shipping and send to the appropriate analytical laboratory.

Visual Sample Plan

Visual Sample Plan (VSP) is a software tool that supports the development of a defensible sampling plan based on statistical sampling theory and the statistical analysis of sample results to support confident decision making (Matzke et al. 2014). Developed with support from DOE, EPA, DoD, the Department of Homeland Security (DHS), the Centers for Disease Control (CDC), and the United Kingdom, VSP has more than 5000 users. VSP couples site, building, and sample location visualization capabilities with optimal sampling design and statistical analysis strategies. VSP is currently focused on design and analysis for the following applications.

- Environmental characterization and remediation
- Environmental monitoring and stewardship
- Response and recovery of chemical/biological/radiation terrorist event
- Footprint reduction and remediation of Unexploded Ordnance (UXO) sites
- Sampling of soils, buildings, groundwater, sediment, surface water, subsurface layers

Summarized below are the details of the technical basis for sampling design, *Systematic sampling locations for comparing a median with a fixed threshold (nonparametric – MARSSIM)*, generated from Visual Sample Plan (VSP). Its purpose is to support confident decision making concerning final status of the area surrounding HRB.

Summary

Herein, summarizes the sampling design that was used, the associated statistical assumptions, as well as the general guidelines for conducting post-sampling data analysis. Sampling plan components include how many sampling locations to choose and where within the sampling area to collect those samples. The type of media to sample (i.e., soil, groundwater, etc.) and how to analyze the samples (in-situ, fixed laboratory, etc.) are addressed in other sections of the sampling plan.

Table 1 lists the sampling design objectives and results. Sample locations are marked by red stars within the sample area highlighted as a blue rectangle, all sample locations are ground level. Sample locations are approximate and the nearest soil/sediment should be sampled.

Based upon the review and initial assessment of previously obtained in-situ data (NNSA Consequence Management Home Team 5/21/19, and RAP Region 8), targeted in-situ sampling locations are marked, in Figure 4, by red stars within the sample area highlighted as a blue rectangle. In-Situ samples should be taken on hard surfaces (concrete sidewalks, asphalt). Judgmental sample locations are marked, in Figure 3, by red stars within the sample area highlighted as a blue rectangle.

Table 1. Environmental sampling design objectives and results

Primary Objective of Design	Compare a site mean or median to a fixed threshold
Type of Sampling Design	Nonparametric
Sample Placement (Location) in the Field	Systematic with a random start location
Working (Null) Hypothesis	The median (mean) value at the site exceeds the threshold
Formula for calculating number of sampling locations	Sign Test - MARSSIM version
Calculated number of samples	9
Number of samples adjusted for EMC	9
Number of samples with MARSSIM Overage	11
Number of samples on map [a]	11
Number of selected sample areas [b]	1
Grid pattern	Triangular

[a] This number may differ from the calculated number because of 1) grid edge effects, 2) adding judgment samples, or 3) selecting or unselecting sample areas.

[b] The number of selected sample areas is the number of colored areas on the map of the site. These sample areas contain the locations where samples are collected.

Figure 2: Soil/Sediment Sampling Locations (red stars are specific sampling locations within the blue rectangle sample area)

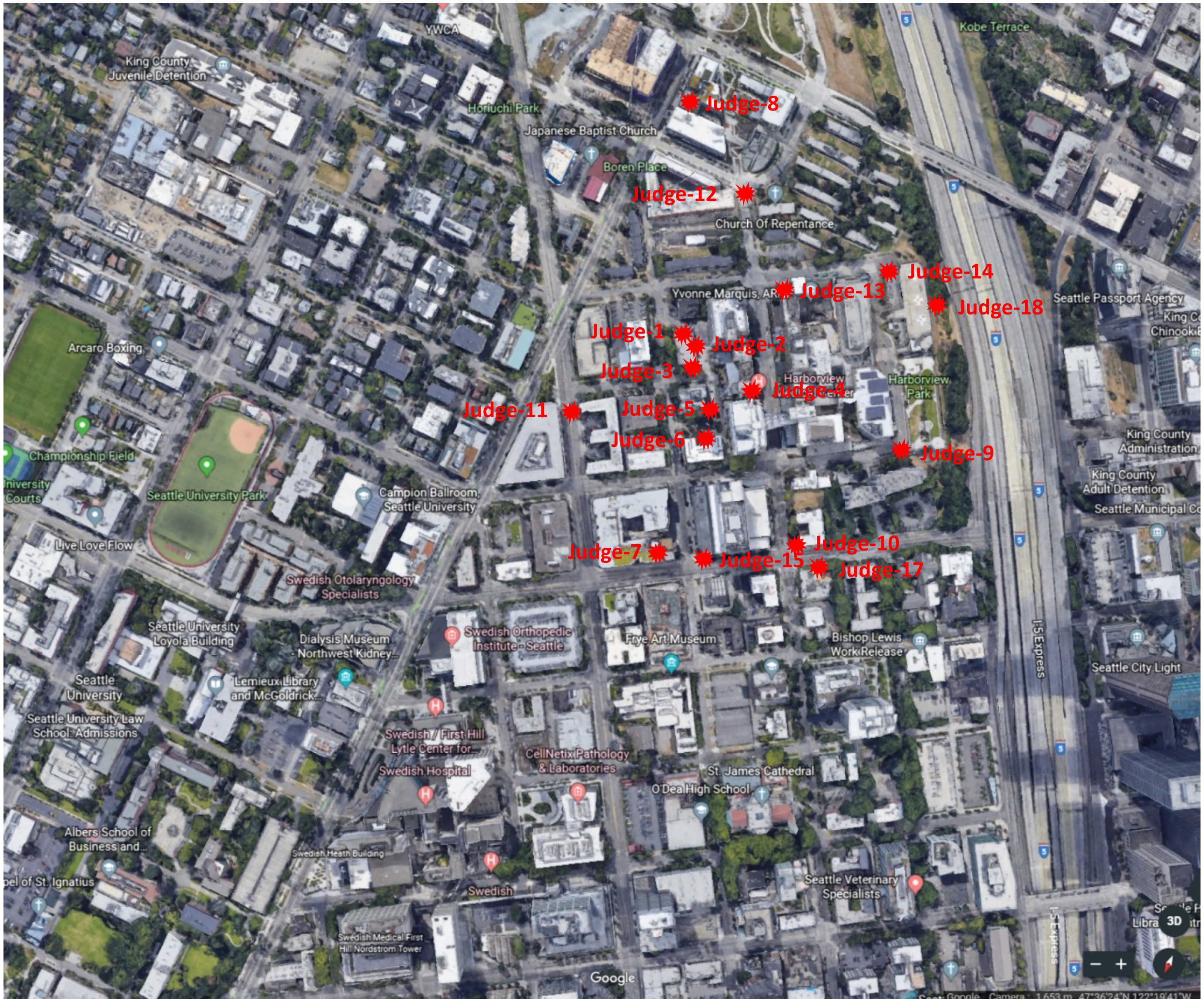

Figure 3: Soil/Sediment Judgmental Sampling Locations (red stars are specific sampling locations within the blue rectangle sample area)

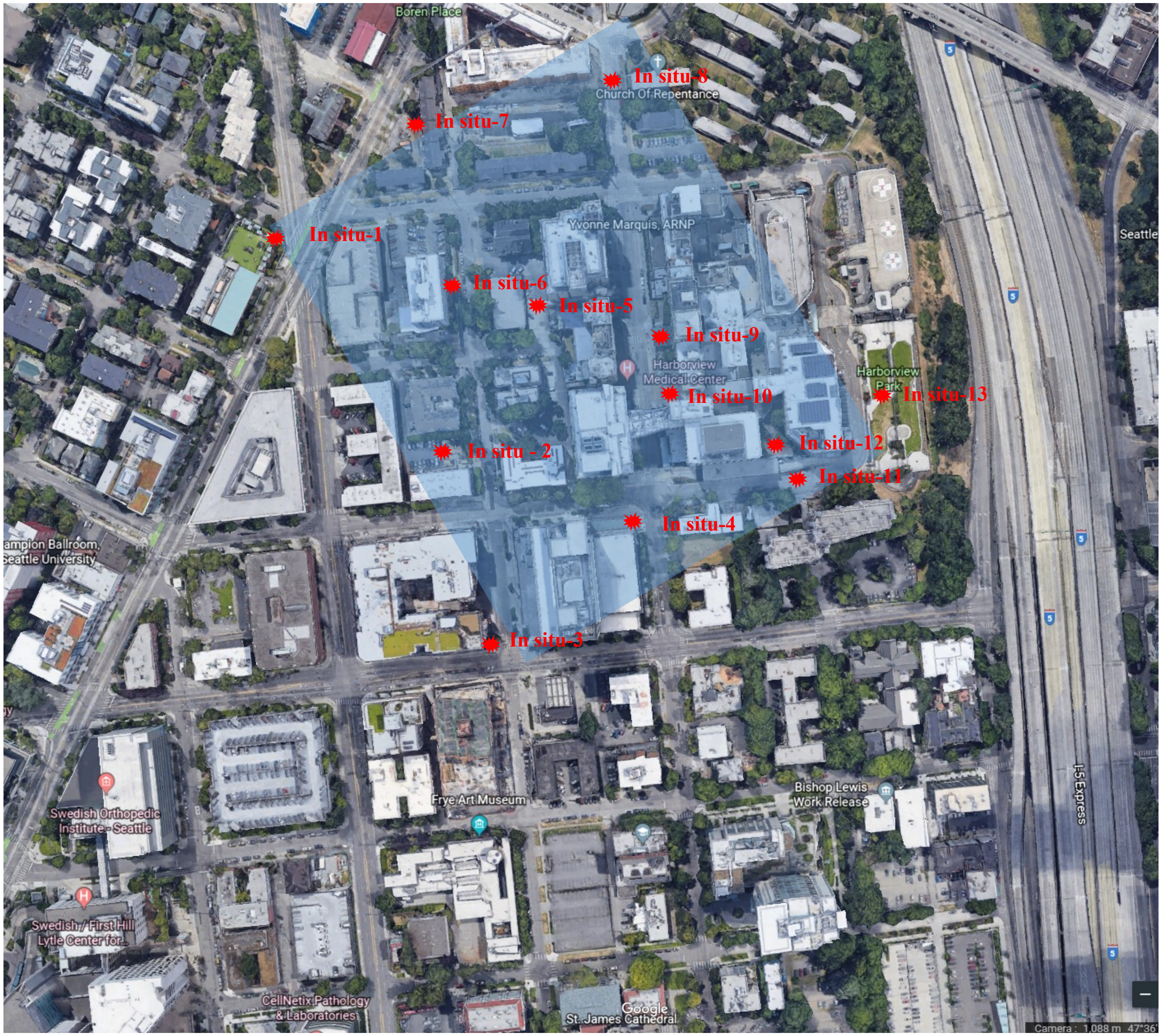

Figure 4: In-Situ Sampling Locations (red stars are specific sampling locations within the blue rectangle sample area)

Table 2. Sampling Coordinates

Location	Coordinates
Soil/Sediment Samples - Figures 2 & 3	
VSP - 1	47° 36′ 15″ N, 122° 19′ 15″ W
VSP - 2	47° 36′ 18″ N, 122° 19′ 19″ W
VSP - 3	47° 36′ 21″ N, 122° 19′ 25″ W
VSP - 4	47° 36′ 17″ N, 122° 19′ 27″ W
VSP - 5	47° 36′ 16″ N, 122° 19′ 22″ W
VSP - 6	47° 36′ 14″ N, 122° 19′ 19″ W
VSP - 7	47° 36′ 12″ N, 122° 19′ 17″ W
VSP - 8	47° 36′ 10″ N, 122° 19′ 21″ W
VSP - 9	47° 36′ 14″ N, 122° 19′ 24″ W
VSP - 10	47° 36′ 15″ N, 122° 19′ 29″ W
VSP - 11	47° 36′ 14″ N, 122° 19′ 31″ W
Judgmental - 1	47° 36′ 14″ N, 122° 19′ 20″ W
Judgmental - 2	47° 36′ 15″ N, 122° 19′ 20″ W
Judgmental - 3	47° 36′ 15″ N, 122° 19′ 21″ W
Judgmental - 4	47° 36′ 15″ N, 122° 19′ 24″ W
Judgmental - 5	47° 36′ 16″ N, 122° 19′ 23″ W
Judgmental - 6	47° 36′ 33″ N, 122° 19′ 22″ W
Judgmental – 7 (Rooftop garden)	47° 36′ 21″ N, 122° 19′ 23″ W
Judgmental – 8 (Rooftop garden)	47° 36′ 07″ N, 122° 19′ 15″ W
Judgmental – 9 (storm drain)	47° 36′ 15″ N, 122° 19′ 31″ W
Judgmental – 10 (storm drain)	47° 36′ 19″ N, 122° 19′ 29″ W
Judgmental – 11(storm drain)	47° 36′ 18″ N, 122° 19′ 17″ W
Judgmental – 12 (storm drain)	47° 36′ 10″ N, 122° 19′ 20″ W
Judgmental – 13	47° 36′ 12″ N, 122° 19′ 23″ W
Judgmental – 14	47° 36′ 10″ N, 122° 19′ 27″ W
Judgmental – 15	47° 36′ 21″ N, 122° 19′ 25″ W
Judgmental – 16 (Yesler Community Gardens)	47° 35′ 59″ N, 122° 19′ 15″ W *(not shown on map)
Judgmental – 17	47° 36′ 20″ N, 122° 19′ 30″ W
Judgmental – 18	47° 36′ 11″ N, 122° 19′ 31″ W
Direct Readings (sidewalks, asphalt, etc) – Figure 4	
In situ - 1	47° 36′ 16″ N, 122° 19′ 13″ W
In situ - 2	47° 36′ 18″ N, 122° 19′ 20″ W
In situ - 3	47° 36′ 21″ N, 122° 19′ 24″ W
In situ - 4	47° 36′ 18″ N, 122° 19′ 27″ W
In situ - 5	47° 36′ 15″ N, 122° 19′ 21″ W
In situ - 6	47° 36′ 15″ N, 122° 19′ 19″ W
In situ - 7	47° 36′ 12″ N, 122° 19′ 16″ W
In situ - 8	47° 36′ 10″ N, 122° 19′ 20″ W
In situ - 9	47° 36′ 13″ N, 122° 19′ 23″ W
In situ - 10	47° 36′ 15″ N, 122° 19′ 25″ W
In situ - 11	47° 36′ 16″ N, 122° 19′ 28″ W
In situ - 12	47° 36′ 16″ N, 122° 19′ 30″ W
In situ - 13	47° 36′ 13″ N, 122° 19′ 31″ W

Primary Sampling Objective

The primary purpose of sampling at this site is to compare a site median or mean value with a fixed threshold. The working hypothesis (or 'null' hypothesis) is that the median (mean) value at the site is equal to or exceeds the threshold. The alternative hypothesis is that the median (mean) value is less than the threshold. VSP calculates the number of samples required to reject the null hypothesis in favor of the alternative one, given by the selected sampling approach and the inputs to the associated equation.

Selected Sampling Approach

A non-parametric systematic sampling approach with a random start was used to determine the number of samples and to specify sampling locations. A non-parametric formula was chosen because the conceptual model and historical information (e.g., historical data from this site or a very similar site) indicate that typical parametric assumptions may not be true.

Both parametric and non-parametric equations rely on assumptions about the population. Typically, however, non-parametric equations require fewer assumptions and allow for more uncertainty about the statistical distribution of values at the site. The trade-off is that if the parametric assumptions are valid, the required number of samples is usually less than if a non-parametric equation was used.

VSP offers many options to determine the locations at which measurements are made or samples are collected and subsequently measured. For this design, systematic grid point sampling was chosen. Locating the sample points systematically provides data that are all equidistant apart. This approach does not provide as much information about the spatial structure of the potential contamination as simple random sampling does. Knowledge of the spatial structure is useful for geostatistical analysis. However, it ensures that all portions of the site are equally represented. Statistical analyses of systematically collected data are valid if a random start to the grid is used.

Nuclides

The following table summarizes the contaminants at the site that will be analyzed in the sampling plan, and lists the concentrations that correspond to the 25 mrem/year dose limit, known as the Derived Concentration Guideline Level (DCGL).

Table 3. Nuclide analyzed by the study

Nuclide	**DCGLw** *pCi/g*
Cesium-137	34

Number of Total Samples: Calculation Equation and Inputs

The equation used to calculate the number of samples is based on a Sign test (see PNNL 13450 for discussion). For this site, the null hypothesis is rejected in favor of the alternative one if the median (mean) is sufficiently smaller than the threshold. The number of samples to collect is calculated so that if the inputs to the equation are true, the calculated number of samples will cause the null hypothesis to be rejected.

The formula used to calculate the number of samples is:

$$n = \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{4(SignP - 0.5)^2}$$

Where:

$$SignP = \Phi\left(\frac{\Delta}{S_{total}}\right)$$

$\Phi(z)$	is the cumulative standard normal distribution on $(-\infty,z)$ (see PNNL-13450 for details),
n	is the number of samples,
S_{total}	is the estimated standard deviation of the WDOH samples measured values (0.26 pCi g^{-1}),
Δ	is the width of the gray region (DCGL – Median of WDOH samples = 34 pCi g^{-1} – 0.08 pCi g^{-1} = 33.92 pCi g^{-1}),
α	is the acceptable probability of incorrectly concluding the site median (mean) is less than the threshold,
β	is the acceptable probability of incorrectly concluding the site median (mean) exceeds the threshold,
$Z_{1-\alpha}$	is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\alpha}$ is $1-\alpha$,
$Z_{1-\beta}$	is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\beta}$ is $1-\beta$.

Note: MARSSIM suggests that the number of samples should be increased by at least 20% to account for missing or unusable data and uncertainty in the calculated value of n. VSP allows a user-supplied percent overage as discussed in MARSSIM (EPA 2000).

The inputs and results of the Sign test calculation is summarized in Table 4.

Table 4. Sign test summary

Nuclide	**n**[a]	**n**[b]	**n**[c]	**Parameter**					
				S_{total}	Δ	α	β	$Z_{1-\alpha}$ [d]	$Z_{1-\beta}$ [e]
Cesium-137	9	9	11	0.26	33.92	0.05	0.1	1.64485	1.28155

[a] The number of samples calculated by the formula.
[b] The number of samples increased by elevated measurement comparison (EMC) calculations.
[c] The final number of samples increased by the MARSSIM Overage of 20%.
[d] This value is automatically calculated by VSP based upon the user defined value of α.
[e] This value is automatically calculated by VSP based upon the user defined value of β.

Performance

Figure 5 is a performance goal diagram, described in EPA's QA/G-4 guidance (EPA, 2000). It shows the probability of concluding the sample area is dirty on the vertical axis versus a range of possible true median (mean) values for the site on the horizontal axis. This graph contains all of the inputs to the number of samples equation and pictorially represents the calculation.

The red vertical line is shown at the threshold (action limit) on the horizontal axis. The width of the gray shaded area is equal to Δ; the upper horizontal dashed blue line is positioned at 1-α on the vertical axis; the lower horizontal dashed blue line is positioned at β on the vertical axis. The vertical green line is positioned at one standard deviation below the threshold. The shape of the red curve corresponds to the estimates of variability. The calculated number of samples results in the curve that passes through the lower bound of Δ at β and the upper bound of Δ at 1-α. If any of the inputs change, the number of samples that result in the correct curve changes.

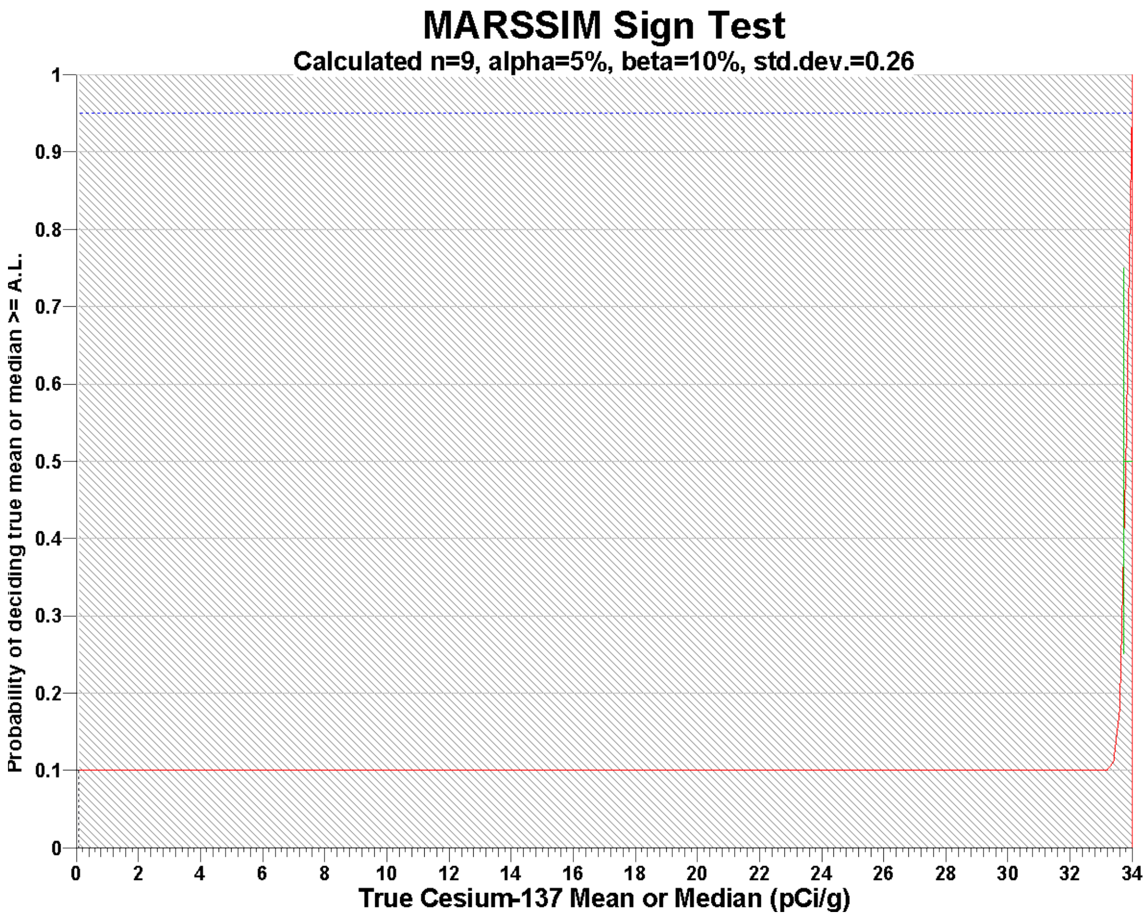

Figure 5. Performance goal diagram

Statistical Assumptions

The assumptions associated with the formulas for computing the number of samples are:

1. the computed sign test statistic is normally distributed,
2. the variance estimate, S^2, is reasonable and representative of the population being sampled,
3. the population values are not spatially or temporally correlated, and
4. the sampling locations will be selected randomly.

The first three assumptions will be assessed in a post data collection analysis. The last assumption is valid because the sample locations were selected using a random process.

Sensitivity Analysis

The calculation of number of samples is most affected by the relative shift. The relative shift is a unitless number related to the chance that individual measurements will exceed the $DCGL_w$. The smaller the relative shift, the greater the likelihood some measurements exceed the $DCGL_w$ and the greater the number of measurements that should be made. σ is the expected variability of the measurement, it, like the LBGB, is based on earlier characterizations.

$$relative\ shift = \frac{DCGL_W - LBGR}{\sigma}$$

The sensitivity of the calculation of number of samples was explored by varying the standard deviation, lower bound of gray region (% of action level), beta (%), probability of mistakenly concluding that $\mu >$ action level and alpha (%), probability of mistakenly concluding that $\mu <$ action level. This sample plan assumes a LBGR of 0.08 pCi g^{-1} (0.003 Bq g^{-1}), median of WDOH soil samples. The sensitivity analysis shows that the 42 (soil/sediment plus In-situ) samples on the maps would statistically support the more restrictive inputs; LBGR of 30.6 pCi g^{-1}, and beta error of 0.05.

Table 5. Sensitivity analysis summary

Number of Samples							
AL=34		**α=5**		**α=10**		**α=15**	
		s=0.52	**s=0.26**	**s=0.52**	**s=0.26**	**s=0.52**	**s=0.26**
LBGR=90	**β=5**	14	14	11	11	10	10
	β =10	11	11	9	9	8	8
	β =15	10	10	8	8	6	6
LBGR=80	**β =5**	14	14	11	11	10	10
	β =10	11	11	9	9	8	8
	β =15	10	10	8	8	6	6
LBGR=70	**β =5**	14	14	11	11	10	10
	β =10	11	11	9	9	8	8
	β =15	10	10	8	8	6	6

s = Standard Deviation
LBGR = Lower Bound of Gray Region (% of Action Level)
β = Beta (%), Probability of mistakenly concluding that μ > action level
α = Alpha (%), Probability of mistakenly concluding that μ < action level
AL = Action Level (Threshold)

Note: Values in table are not adjusted for EMC.

Acronyms

ALARA	As Low As Reasonably Achievable
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
Cs-137	Cesium-137
DCGL	Derived Concentration Guideline Level
DOE	Department of Energy
DQO	Data Quality Objective
HRB	Harborview Research and Training Building
LBGR	Lower Bound Gray Region
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDC	Minimum Detectable Concentration
MQO	Measurement Quality Objective
NRC	U.S. Nuclear Regulatory Commission
pCi	picoCurie
RAP	Radiological Assistance Program
UW	University of Washington
WAC	Washington Administrative Code
WDOH	Washington State Department of Health

Glossary

Class 1 areas	Areas that have, or had prior to remediation, a potential for radioactive contamination (based on site operating history) or known contamination (based on previous radiological surveys). Examples of Class 1 areas include: 1) site areas previously subjected to remedial actions, 2) locations where leaks or spills are known to have occurred, 3) former burial or disposal sites, 4) waste storage sites, and 5) areas with contaminants in discrete solid pieces of material high specific activity. Note that areas containing contamination in excess of the $DCGL_W$ prior to remediation should be classified as Class 1 areas.
Class 2 areas	These areas have, or had prior to remediation, a potential for radioactive contamination or known contamination, but are not expected to exceed the $DCGL_W$. To justify changing an area's classification from Class 1 to Class 2, the existing data (from the HSA, scoping surveys, or characterization surveys) should provide a high degree of confidence that no individual measurement would exceed the $DCGL_W$. Other justifications for this change in an area's classification may be appropriate based on the outcome of the DQO process. Examples of areas that might be classified as Class 2 for the final status survey include: 1) locations where radioactive materials were present in an unsealed form (e.g., process facilities), 2) potentially contaminated transport routes, 3) areas downwind from stack release points, 4) upper walls and ceilings of some buildings or rooms subjected to airborne radioactivity, 5) areas where low concentrations of radioactive materials were handled, and 6) areas on the perimeter of former contamination control areas.

Class 3 areas	Any impacted areas that are not expected to contain any residual radioactivity, or are expected to contain levels of residual radioactivity at a small fraction of the $DCGL_W$, based on site operating history and previous radiological surveys. Examples of areas that might be classified as Class 3 include buffer zones around Class 1 or Class 2 areas, and areas with very low potential for residual contamination but insufficient information to justify a non-impacted classification.
Derived Concentration Guideline Level (DCGL)	A derived, radionuclide-specific activity concentration within a survey unit corresponding to the release criterion. The DCGL is based on the spatial distribution of the contaminant and hence is derived differently for the nonparametric statistical test ($DCGL_W$) and the Elevated Measurement Comparison ($DCGL_{EMC}$). DCGLs are derived from activity/dose relationships through various exposure pathway scenarios.
Gray Region	A range of values of the parameter of interest for a survey unit where the consequences of making a decision error are relatively minor. The upper bound of the gray region in MARSSIM is set equal to the $DCGL_W$, and the lower bound of the gray region (LBGR) is a site-specific variable.
Lower bound Gray Region (LBGR)	The minimum value of the gray region. The width of the *gray region* (*DCGL-LBGR*) is also referred to as the shift, Δ.
Non parametric test	A non-parametric test (sometimes called a distribution free test) does not assume anything about the underlying distribution (for example that the data comes from a normal distribution).
Parametric test	Parametric tests assume a normal distribution of values, or a “bell-shaped curve.”

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