Environmental Sciences Section

# Hanford Environmental Radiation Oversight Program 2011 Data Summary Report

April 2013

Washington State Department of Health

Division of Environmental Health

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## Acknowledgements

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# Acronyms

| | |
|---|---|
| ALARA | As Low As Reasonably Achievable |
| DOE | Department of Energy (United States) |
| DOH | Department of Health (Washington State) |
| EML | Environmental Measurement Laboratory |
| EPA | Environmental Protection Agency |
| ERDF | Environmental Restoration Disposal Facility |
| LIGO | Laser Interferometer Gravitational-wave Observatory |
| LLD | Lower Limit of Detection |
| MAPEP | Mixed Analyte Proficiency Evaluation Program |
| MDA | Minimum Detectable Activity |
| MSA | Mission Support Alliance |
| NCRP | National Council on Radiation Protection and Measurements |
| PFP | Plutonium Finishing Plant |
| PHL | Public Health Laboratories |
| PNNL | Pacific Northwest National Laboratory |
| QATF | Quality Assurance Task Force of the Pacific Northwest |
| SI | International Scientific Units |
| TEDF | Treated Effluent Disposal Facility |
| TLD | Thermoluminescent Dosimeters |
| TPA | Tri-Party Agreement |
| WAC | Washington Administrative Code |

## Summary

The Washington State Department of Health (DOH) has operated an environmental radiation monitoring program since 1961. The early program looked primarily at fallout from atmospheric testing of nuclear weapons and off-site environmental impacts related to Hanford operations. Currently, DOH conducts radiological surveillance in many geographical areas of the state, and routinely splits (co-samples) environmental samples with state-licensed and federal environmental monitoring programs.

Since 1985, the Washington State Department of Health's Hanford Environmental Radiation Oversight Program has participated with the U.S. Department of Energy (DOE) in the collection of environmental samples on or near the Hanford Site. The purpose of the program is to independently verify the quality of DOE environmental monitoring programs at the Hanford Site, to assess the potential for public health impacts, and to address public concerns related to environmental radiation at Hanford.

DOH collects environmental samples that are either split or collocated with DOE contractors, and the results are compared to verify the quality of the DOE monitoring programs at Hanford. Samples of air, groundwater, surface water, riverbank seep water, drinking water, sediment, food and farm products, fish and wildlife, and vegetation are typically collected. In addition, ambient external radiation levels are measured using radiation dosimeters.

In this report, DOH uses the categories of good, fair, and poor to qualitatively describe the agreement between DOH and DOE radioactivity concentrations in environmental media. The DOH and DOE contractor data are not expected to be in exact agreement because of the random nature of radioactive decay, the fact that samples collected from the field are not identical, and that the analytical methods are not identical. In situations where there are gross discrepancies in results or where there is a continued (systematic) disagreement, DOH is proactive in resolving these issues.

The analytical results and the comparisons and evaluation of the data are found in Sections 3 and 4. Many environmental samples analyzed by DOH have radioactivity concentrations either below detection limits or consistent with background. Some samples have concentrations elevated above background; however, in most cases the concentrations are consistent with historical trends. Generally, there is good agreement between analytical results from samples split between DOH and DOE contractors.

The 2011 Hanford Environmental Radiation Oversight Program met the program objectives and made the following conclusions.

- The DOH independently evaluated and verified the U.S. Department of Energy monitoring programs by conducting split and collocated sampling, and comparing and analyzing the split/collocated data. When appropriate, differences in results were investigated. The good agreement between the limited split data gives confidence that the remainder of the DOE environmental data are valid.

- The DOH environmental monitoring data continues to find that Hanford operations have resulted in radionuclides entering the environment and that DOH data indicate that the public exposure to radioactivity from Hanford is far below regulatory limits.

- The DOH takes very seriously any concerns that the public has over radiation issues at Hanford and readily addresses issues that members of the public raise to the DOH. The DOH is a participant in the Hanford Advisory Board where the public can raise issues or express concerns. DOH follows up on the items expressed in this forum.

# 1. Introduction

Chapter 70.98 of the Revised Code of Washington designates the Washington State Department of Health (DOH) as the state agency with the responsibility to protect human health and the environment from the effects of ionizing radiation. To meet this legislative mandate, DOH conducts radiological monitoring throughout the state, placing emphasis on major nuclear facilities with known or potential radiological impacts associated with the facility operations, decommissioning, or cleanup. This report summarizes environmental radiation sampling results from the Department of Health's Hanford Environmental Radiation Oversight Program.

From 1943 until the mid-1980s, the primary mission of the U.S. Department of Energy's (DOE) Hanford Site was the production of plutonium for nuclear weapons. Operations resulted in releases of radioactivity to the environment. Today, weapons production operations have ceased, and the current mission of the Site includes cleanup of radioactive waste originating from the plutonium production era. DOE has extensive monitoring programs to characterize and track this contamination as it moves through the environment. The primary purpose of the DOH Hanford Environmental Radiation Oversight Program is to provide oversight of the DOE monitoring programs.

The primary objectives of the oversight program are:

- To independently verify the quality of the U.S. Department of Energy monitoring programs at the Hanford Site by conducting split, collocated, and independent sampling at locations having the potential to release radionuclides to the environment or locations which may be impacted by such releases.

- To independently assess impacts to the public, using the DOH oversight data, to compare radionuclide concentrations in samples potentially impacted by Hanford with concentrations in background samples. With the primary role of oversight, the DOH monitoring program is not intended to completely characterize environmental radiation from the Hanford Site, nor is it intended to find and report the highest environmental contaminant concentrations.

- To address public concerns related to environmental radiation at Hanford.

This report presents the annual results of environmental radiation measurements made by the Washington State Department of Health's Hanford Environmental Radiation Oversight Program.

Section 2 describes the Hanford Environmental Radiation Oversight Program, including a discussion of laboratory qualifications and how to interpret the results presented in this report. Environmental results are presented in Section 3. Tutorial information on radiation is found in Appendix A. The laboratory lower limits of detection are listed in Appendix B. Appendix C lists a glossary of radiation terms. Appendix D lists the full element names of the radionuclides discussed in this report; i.e., H-3 is Hydrogen-3.

**2.      The Hanford Environmental Radiation Oversight Program Description**

The objectives of the Oversight Program (see Section 1, Introduction) are met through collection and analysis of environmental samples and interpretation of results. Samples are either split or collocated with DOE contractors.

Split samples are prepared by dividing a sample into two parts. Collocated samples are those samples that are collected adjacent to the DOE contractor sample. In each case, the DOH sample is sent to the Washington State Public Health Laboratory (PHL) in Shoreline, Washington for radiochemical analysis. Results of the DOH analyses are compared to the DOE contractor results to assess the quality of the federal monitoring program at the Hanford Site. In addition, the results are compared to historical data to identify trends, and are used to identify impacts to public health and the environment.

**2.1      Laboratory Qualifications**

Analytical techniques are based on laboratory standard operating procedures (Appendix B). The PHL serves as a regional reference laboratory and, as such, operates under a rigorous quality assurance program. This program contains quality control elements, which help ensure the laboratory's high analytical proficiency and accuracy. Laboratory quality control includes analysis of samples distributed by the federal government's quality assurance programs; split samples distributed on a smaller scale between cooperating federal, state, and private laboratories; and internal procedures related to the counting facilities and analytical techniques. Collectively, the PHL's quality assurance program encompasses:

  Personnel requirements and qualifications
  Quality control
  Sample handling and custody requirements
  Analytical methods
  Equipment calibration and maintenance
  Data reporting
  Records management and archiving
  Corrective action

The PHL participates in three intercomparison programs: DOE's Environmental Measurement Laboratory (EML) intercomparison, the Mixed Analyte Proficiency Evaluation Program (MAPEP), and the Quality Assurance Task Force of the Pacific Northwest (QATF) intercomparison. These programs provide an independent check of laboratory proficiency for analyzing environmental samples. Additionally, the laboratory proficiency is checked through the analysis of standard reference samples. Reference material is generally any environmental media containing known quantities of radioactive material in a solution or homogenous matrix.

## 2.2      Interpretation of Results

Environmental radiation data are reported as the number of radiation decays per unit time period per unit quantity of sample material. Most results are reported in units of picocuries. A picocurie equals 2.22 decays per minute. Airborne radioactivity is expressed as picocuries per cubic meter ($pCi/m^3$); radioactivity in liquids such as water and milk is expressed as picocuries per liter (pCi/L); and radioactivity in solid material such as soil, vegetation, and food is expressed as picocuries per gram (pCi/g). Ambient gamma radiation is expressed as radiation exposure, measured in milliroentgens per day (mR/day). Radiation exposure is discussed in Appendix A, and the units used to quantify radioactivity and exposure are defined in Appendix C.

### 2.2.1      Uncertainty in Radioactivity Measurements

All radioactivity measurements (i.e., counting the number of decays per unit time) have an associated uncertainty, which originates from random and systematic effects. Counting uncertainty is the dominant source of laboratory random measurement uncertainty. It is an estimate of the possible range of radioactivity results due to the fact that radioactive decay is a random process. If a sample was measured many times, each result would vary randomly around the mean of all measurements. Systematic uncertainty comes from the measurement process itself and is observed as a bias, or tendency, for the results to be higher or lower than the true value.

The uncertainties reported in this report are primarily counting uncertainties, although for gamma emitting radionuclides, the systematic uncertainty associated with calibrating the detector is included. A limited effort is made to estimate other sources of uncertainty, however, the laboratory does not attempt to completely identify and quantify all sources of uncertainty.

The uncertainties are reported as a 2-sigma (two standard deviation) confidence interval. A 2-sigma uncertainty means there is 95% confidence that the true concentration in the sample lies somewhere between the measured concentration minus the uncertainty, and the measured concentration plus the uncertainty.

### 2.2.2      Detection Limits

The laboratory is capable of measuring very small amounts of radioactivity in environmental samples, but there is a limit below which a sample's radiation cannot be distinguished from background radiation. This limit is called the lower limit of detection and depends on several factors, including the sample size, analytical method, counting time, and background radiation. Appendix B lists the typical lower limits of detection that are achievable by the PHL.

### 2.2.3  Background and Negative Results

The environmental results are reported as net sample activity, which is defined as gross sample activity minus background activity. Gross sample activity and background activity are measured separately. Gross sample activity results from the sum of radioactivity in the environmental sample and the background radiation originating from sources outside of the sample. Background activity is measured by counting the radioactivity in a blank sample.

A negative net sample activity is occasionally reported for environmental samples. When the amount of radioactivity in the sample is very small, the random nature of radioactive decay may result in a gross sample activity that is less than the background activity. In this case, the net result will be negative. In most cases, negative results have an associated uncertainty range that includes zero activity. A negative result indicates that radioactivity in the sample was not detected at concentrations above the detection limit.

The net sample activity represents the best estimate of the true value of the sample activity. Therefore, to prevent biased reporting, DOH reports the net sample activity even when the result is negative (as opposed to reporting a value of "zero" or "not detected"). The negative results are included in statistical analyses of data to look for systematic bias in laboratory procedures and to provide a more accurate measure of analytical detection limits.

### 2.2.4     Techniques for Comparison of DOH and DOE Contractor Data

Since the primary purpose of the DOH Hanford Environmental Radiation Oversight Program is to verify the quality of DOE environmental monitoring programs, DOH either splits samples or collects collocated samples with DOE contractors. The DOH and DOE samples are independently analyzed and the results compared. At the very least, qualitative data comparisons are made (see Section 2.2.4.1). When sufficient data are available, the analysis is supplemented by a quantitative linear regression analysis (see Section 2.2.4.2).

Currently, the oversight program uses a qualitative approach as the primary method to compare DOH and DOE contractor data. Several arguments support this approach.

1) A goal of the oversight program is to validate as many different types of environmental samples and test for as many different radioactive contaminants as possible. Since the total number of samples is fixed by the budget, this goal often limits the number of samples for any given type. There are often too few samples or too few detectable results of a given sample type for a rigorous quantitative evaluation.
2) Samples are often collocated, not split, and the radioactivity results are not expected to be identical because they represent distinctly different samples.
3) For split samples, the non-homogeneous nature of environmental samples may result in the two splits containing different amounts of radioactivity, and the results are not expected to be identical.

4) The evaluation of uncertainty in the DOH and DOE contractor data is limited, whereas a rigorous quantitative approach requires a more complete characterization of uncertainty.

### 2.2.4.1    Qualitative Comparisons

All of the collocated or split data are sorted by sample type and radionuclide. Then, for each sample type and radionuclide, all of the DOH and DOE contractor data for each sample location are plotted on a graph and visually inspected to qualitatively assess the agreement of the data. In addition, graphs of historical data are inspected to ascertain temporal trends.

The qualitative agreement is categorized as either *good*, *fair*, or *poor*. Good agreement indicates that the uncertainty range (see Section 2.2.1) of the split or collocated concentrations overlaps for a majority of the samples. Fair agreement indicates that the split or collocated concentrations are similar, but the uncertainty range does not overlap for a significant number of samples. This is often indicative of a systematic bias in a laboratory procedure, and often shows up as the contractor and DOH results differing by a consistent percentage. Poor agreement indicates that the uncertainty range of the split or collocated concentrations does not overlap for a majority of the samples, and there is no apparent systematic bias.

The results of regression analysis and visual inspection of scatter plots (discussed in Section 2.2.4.2 below) are assessed and incorporated into the qualitative assessment when appropriate.

The results of the assessment are discussed in the text of the report. Figures of the graphical representation of the data are included in the report to better explain the more complicated comparison data.

### 2.2.4.2      Regression Analysis and Scatter Plots

In addition to qualitative assessment, linear regression analysis is used to compare DOH and DOE data when appropriate. In this report, regression analysis is carried out when:
(a) there are a sufficient amount of data to analyze; (b) the data are consistently greater than the detection limit; and (c) the data are sufficiently correlated.

Assuming there is a sufficient amount of data above the detection limit for a meaningful regression analysis, each of the split or collocated DOH and DOE results for a given sample type and radionuclide are formed into an (x, y) pair. The x-value represents the DOH result and the y-value represents the DOE result for a particular sample. The paired data for all samples of a given sample type and radionuclide are plotted on a two-dimensional scatter plot. The correlation coefficient R is then calculated for the set of (x, y) pairs. R can vary from -1 to +1. A value near ±1 implies a strong correlation, while a value near 0 implies a weak or non-correlation.

If the two data sets are sufficiently correlated (in this report, the criterion is R > 0.75), the best-fit straight line that describes the relationship between the two monitoring programs is determined. The parameters that describe the straight line are the slope and y-intercept. The functional form of the straight line is $y = ax + b$, where a is the slope and b is the y-intercept.

If the results between the DOH and DOE monitoring programs were in perfect agreement, the slope of the best-fit line would be 1, and the y-intercept would be 0. A zero value for the y-intercept means that if DOH measures zero activity, then DOE also measures zero for the same sample. A non-zero y-intercept indicates an overall offset between DOH and DOE results. The slope is simply the ratio of the DOH and DOE results.

If a regression analysis is carried out, a scatter plot (x, y paired data) of the DOH and DOE split or collocated sample data may be presented in this report. Along with the data, these plots also show the straight line representing the ideal case where the data sets are in perfect agreement and the best-fit straight line. The slope and y-intercept of the best-fit straight line are shown in the plot legend.

If the two data sets are not sufficiently correlated (R < 0.75), it is not meaningful to find a best-fit straight line describing the relationship between the two data sets. In this case, the comparison is limited in this report to a qualitative assessment.

## 2.2.5 Comparison of Current DOH Results to Historical Results

The range of DOH concentrations for the current year is compared to the range of historical concentrations for the same analyte and sample type. If current year data are similar to historical results, then there are no anomalous data. If current year data differ from historical results, then there are anomalous data, and these data are discussed in the text.

## 2.2.6 Gamma Analysis

For many samples, concentrations of the gamma emitting radionuclides Co-60 and Cs-137 are reported, regardless of whether the concentrations are above or below a detection limit. Occasionally, Cs-134 is also reported. These specific radionuclides are often reported because of their significant presence in historical Hanford waste streams.

Gamma spectroscopy is the method used to determine concentrations of Co-60 and Cs-137, and this method also has the capability to measure concentrations of any other gamma emitting radionuclides. DOH will report concentrations of all radionuclides found above detection limits in the gamma spectroscopy analysis. The absence of a reported concentration for a gamma emitting radionuclide indicates that it was not detected.

Other possible gamma emitting radionuclides at Hanford include, but are not limited to, Eu-152, Eu-154, Eu-155, Ru-106, and Sb-125.

## 3.    Environmental Monitoring Results

This section presents the DOH and DOE contractor results for the Hanford Environmental Radiation Oversight Program. The types of samples collected are intended to encompass all of the potential public exposure pathways. These samples include air (Section 3.1); groundwater, riverbank seep water, surface water, drinking water, and discharge water (Section 3.2); dosimeters measuring external gamma radiation (Section 3.3); soil and sediment (Section3.4); food and farm products (Section 3.5); fish and wildlife (Section 3.6); and vegetation (Section 3.7). Each of these sample types is discussed in the sub-sections below. Note that the figures for each sub-section are located at the end of the sub-section.

**3.1      Ambient Air Monitoring**

Major Findings:

- The DOH and DOE contractor biweekly air concentrations are in fair agreement for gross alpha and gross beta. The concentrations are similar and follow the same trends over time, but there is a small systematic discrepancy between the data sets.
- The DOH and DOE contractor monthly composite tritium (H-3) results are in poor agreement. The discrepancy is not understood at this time and is under investigation.
- The DOH and DOE contractor quarterly composite results are in good agreement for gamma emitting radionuclides and in fair agreement for isotopes of uranium. In all cases, the concentrations are very small.
- The DOH and DOE contractor semiannual composite results are in good agreement for all gamma emitting radionuclides except for Cs-137 where the agreement is fair.
- Most DOH concentrations are consistent with historical results. However, elevated radionuclide concentrations in air have been detected for several years near Hanford's 100K Area, likely due to nearby storage of radioactive material and consequences of cleanup activities. The concentrations in 2011 are back to normal.

**3.1.1      Purpose and General Discussion**

Atmospheric releases of radioactive material from the Hanford Site are a potential source of human exposure. DOE contractors monitor radioactivity in air to determine if the Hanford Site is contributing to airborne contamination. DOH collects air samples that are collocated with samples collected by DOE contractors.

Sources of Hanford-specific airborne emissions include resuspension of contaminated soil (caused by wind or cleanup activities, for example) and escape of radioactive particulates and gasses from facilities and operations. Sources of natural airborne radioactivity include natural radon gas and its decay products; resuspension of soil containing natural radionuclides such as U-234, U-238, and K-40; and radioactive atoms such as Be-7 and H-3 (tritium) that are generated in the atmosphere by interactions with cosmic radiation. Other sources of man-made airborne radioactivity include resuspension of fallout from historical atmospheric testing of nuclear weapons, including Cs-137 and Pu-239/240.

**3.1.2      Sample Types and Monitoring Locations**

Ambient air monitoring locations fall into two categories: (1) Near Facilities and Operations; and (2) Site-Wide and Offsite. For the Near Facilities program, most air samplers are located within 500 meters, and in the prevailing downwind direction from sites having the potential for environmental releases. For the Site-Wide and Offsite program, samplers are located throughout the Hanford Site, along the Hanford perimeter, in nearby communities, and in

distant communities. Mission Support Alliance (MSA) is the DOE contractor for this program.

DOH collected air samples collocated with the Near Facilities and Operations program at five locations, four of which are near facilities that have the potential to emit radionuclides to the air. These locations include a tank farm in the 200 Area (C Farm), the Environmental Restoration Disposal Facility (ERDF-SE), the 100K East Area fuel storage basins (100K East Basin), and the Plutonium Finishing Plant in the 200 Area (PFP). The fifth collocated site, which is not near any facility, is at the Wye Barricade.

DOH collected air samples collocated with the Site-Wide and Offsite program at six locations. These locations include the 300 Area Water Intake, Wye Barricade, Prosser Barricade, and Yakima Barricade, which are located throughout the Hanford Site; Station 8, which is located along the Hanford perimeter; and Battelle Complex, which is located in the nearby community of Richland. Note that the Yakima Barricade is in the prevailing upwind direction of potential sources of airborne radioactivity.

DOH also collects biweekly air samples at the LIGO facility. This sampling location is not collocated with DOE.

The DOH collocated air sampling sites are shown in Figure 3.1.1.

### 3.1.3      Monitoring Procedures

Airborne particles are sampled by continuously drawing air through a filter. The filters are collected at each sample location every other week (biweekly), are stored for three days, and then analyzed for gross beta and gross alpha activity. The storage period allows naturally occurring short-lived radionuclides to decay that would otherwise obscure detection of radionuclides potentially present from Hanford Site emissions. Note that DOH did not carry out a gross alpha analysis for all collocated samples.

The amount of radioactive material collected on a filter in a two-week time period is typically too small to accurately detect concentrations of individual radionuclides. In order to increase the sensitivity and accuracy, so that individual radionuclide concentrations can be determined, the biweekly filter samples for a three or six-month period are dissolved and combined into quarterly or semiannual composite samples. The quarterly composite samples (Site-Wide and Offsite program) are analyzed for gamma emitting radionuclides and isotopes of uranium. The semiannual composite samples (Near Facilities and Operations program) are analyzed for gamma emitting radionuclides and isotopes of uranium and plutonium. Note that analysis for all radionuclides is not carried out at every sample location.

It is a challenge to compare the DOH and DOE quarterly and semiannual air sample results. 1) In most cases, both DOH and the DOE contractor report concentrations below laboratory detection limits. In this situation, a comparison only determines if both parties agree that the concentrations are too small to detect. 2) In some cases, concentrations are reported as "detected"; however, the concentrations are usually very small and similar in value to the

detection limit. In this situation, the comparison attempts to determine if one or both parties detects the contaminant. However, since the DOH and DOE contractor detection limits may differ, and since the concentrations are very near to the detection limit, it is often difficult to definitively make this determination. 3) Finally, in rare cases, concentrations are clearly "detected" above the detection limit. In this situation, the number of detected results is typically too small for a meaningful quantitative comparison by a statistical analysis.

The oversight of composite air samples typically confirms that concentrations are either not detectable or are very small. The low detection limits ensure that measurements are made at levels that can verify protection of public health and the environment.

The Site-Wide and Offsite program also collects atmospheric water vapor for tritium (H-3) analysis by continuously drawing air through samplers containing adsorbent silica gel. Collocated samples are collected from only two locations for this analysis, the 300 Water Intake and Battelle Complex. The collected water is distilled from the silica gel and analyzed for its tritium content. The DOE contractor collects and exchanges their samplers every four weeks, while DOH collects and exchanges their collocated samplers every month. This leads to a situation where the collocated results do not represent the exact same collection time period. DOH is working with DOE contractors to synchronize the collection schedules starting with the 2012 sampling campaign.

### 3.1.4 Comparison of DOH and DOE Contractor Data

Table 3.1.1 summarizes the comparison of DOH and DOE contractor data. Section 2.2 discusses the methods for comparing split or collocated data. Each table lists the analytes, the collection period, and the number of collocated samples. The tables also list the quality of agreement for the collocated samples (see Section 2.2.4.1) and the range of concentrations measured by DOH. Finally, the "Anomalous Data ?" column denotes whether any of the DOH concentrations for the current year are anomalous compared to historical results (see Section 2.2.5).

The text following the table discusses cases in which 1) the agreement between DOH and DOE data is not good (i.e. is fair or poor), and 2) some of the DOH data are anomalous compared to historical results. A value for the "DOH Data Range" prefaced by the "less than" symbol (<) indicates that some or all DOH results are less than the listed detection limit.

| Analyte | Collection Period | # Collocated Samples | Agreement | DOH Data Range (pCi/m$^3$) | Anomalous Data ? |
|---|---|---|---|---|---|
| Gross Alpha | biweekly[a] | 104 | **fair** | 0.0004 to 0.006 | no |
| Gross Beta | biweekly[a] | 232 | **fair** | 0.003 to 0.07 | no |
| H-3 | monthly | 23 | **poor** | < 0.6 to 70 | no |
| Co-60 | quarterly | 20 | good | < 0.001 | no |
| Cs-134 | quarterly | 17 | good | < 0.001 | no |
| Cs-137 | quarterly | 20 | good | < 0.001 to 0.0015 | no |
| Eu-152 | quarterly | 15 | good | < 0.001 | no |
| Eu-154 | quarterly | 14 | good | < 0.001 | no |
| Eu-155 | quarterly | 15 | good | < 0.001 | no |
| Ru-106 | quarterly | 16 | good | < 0.01 | no |
| Sb-125 | quarterly | 16 | good | < 0.003 | no |
| U-234 | quarterly | 12 | **fair** | < 0.000005 to 0.0001 | no |
| U-235 | quarterly | 12 | good | < 0.000004 | no |
| U-238 | quarterly | 12 | **fair** | < 0.00003 to 0.0001 | no |
| Am-241 | semiannual[b] | 4 | | | |
| Co-60 | semiannual | 8 | good | < 0.0007 | no |
| Cs-134 | semiannual | 8 | good | < 0.0008 | no |
| Cs-137 | semiannual | 8 | **fair** | < 0.0006 to 0.004 | no |
| Eu-152 | semiannual | 8 | good | < 0.0008 | no |
| Eu-154 | semiannual | 8 | good | < 0.0006 | no |
| Eu-155 | semiannual | 8 | good | < 0.0009 | no |
| Pu-238 | Semiannual[b] | 8 | | | |
| Pu-239/240 | Semiannual[b] | 8 | | | |
| Pu-241 | Semiannual[b] | 2 | | | |
| Ru-106 | semiannual | 8 | good | < 0.007 | no |
| Sb-125 | semiannual | 8 | good | < 0.002 | no |
| Sr-90 | Semiannual[b] | 7 | | | |
| U-234 | Semiannual[b] | 8 | | | |
| U-235 | Semiannual[b] | 8 | | | |
| U-238 | Semiannual[b] | 8 | | | |

(a) Biweekly at most sites, weekly at sites collocated with Columbia Generating Station.
(b) DOH data not available at time of publishing. Results will be discussed in a future report.

Table 3.1.1    Summary of Samples Collocated with MSA

The DOH and DOE contractor gross alpha concentrations are in fair agreement. The collocated concentrations are similar and follow the same temporal trend at each of the monitoring locations, but many of the uncertainty bars do not overlap. The collocated data at the Battelle Complex are shown in Figure 3.1.2. In this example, the concentrations reported by DOE are approximately one-half the value reported by DOH.

The scatter plot for DOH and DOE gross alpha data is shown in Figure 3.1.3. This plot shows the data from all sites that are collocated with the DOE contractor. There is significant scatter about the theoretical line in which the DOH and DOE results are identical, with differences up to a factor of two being common. In addition, there is a systematic bias between the DOH and DOE results. The regression analysis indicates that, on average, DOE reports concentrations approximately 46% lower than those reported by DOH.

The DOH and DOE contractor gross beta concentrations are in fair agreement. The collocated concentrations are similar and follow the same temporal trend at each of the monitoring locations, but many of the uncertainty bars do not overlap. The collocated data at Prosser Barricade are shown in Figure 3.1.4. In this example, the concentrations reported by DOE are approximately twice the value reported by DOH.

The scatter plot for DOH and DOE gross beta data is shown in Figure 3.1.5. This plot shows the data from all sites that are collocated with the DOE contractor. There is significant scatter about the theoretical line in which the DOH and DOE results are identical, with differences up to a factor of two being common. In addition, there is a systematic bias between the DOH and DOE results. The preponderance of data points to the left of the theoretical line indicates that, on average, DOE reports higher concentrations than DOH.

The gross beta concentrations at 100K East Basin were anomalously high in 2009 compared to historical results at this site. Smaller anomalies were seen in 2008 and 2010. However, in 2011, the concentrations are similar to historical data. The last eight years of data are shown in Figure 3.1.10. Radioactive material has been temporarily stored outside of the KE Basin facility since 2005. In addition, remediation has been ongoing in this area. It is possible that the increased air concentrations were a result of these activities.

The DOH and DOE contractor H-3 concentrations are in poor agreement, as can be seen in the graph of data at Battelle Complex shown in Figure 3.1.6 and in the scatter plot of data from all sites in Figure 3.1.7. The discrepancies are not understood at this time, and are under investigation.

The DOH and DOE U-234 and U-238 concentrations in quarterly composite air samples are in fair agreement. The U-238 data are shown in Figure 3.1.8 (the U-234 data are similar). The DOH and DOE concentrations are similar, but in most cases the error bars do not overlap. The concentrations are very small, only slightly above the detection limits.

In addition to the analytes for the collocated quarterly composite sample analysis listed in Table 3.1.1, most of the DOE samples were also analyzed to determine concentrations of Am-241, Pu-238, Pu-239/240, and Sr-90. All results for these additional analyses were below the DOE contractor detection limits. DOH did not report results for these radionuclides in the quarterly composite air samples.

The DOH and DOE Cs-137 concentrations in semiannual composite air samples are in fair agreement, as can be seen in Figure 3.1.9. DOH and DOE report similar concentrations, most either below or only slightly above the detection limits. However, in cases where the isotope is clearly detected, DOH often reports concentrations higher than those from the DOE contractor. This discrepancy has been observed historically for cases where Cs-137 has been detected.

The collocated semiannual composite air samples were also analyzed for Am-241, Pu-238, Pu-239/240, Pu-241, Sr-90, U-234, U-235, and U-238. The DOH results for these analytes are not available at this time, and therefore the analysis of the collocated data will be presented in a future report.

### 3.1.5 Other Discussion

The gross beta results at all sites show a trend of higher concentration during the winter months, typically October through February. These higher gross beta activities are attributed to increased concentrations of radon decay products due to decreased atmospheric mixing during the winter months when there is decreased atmospheric heating. The annual cycle of increased gross beta activity in the winter months can easily be seen in Figure 3.1.11, which shows gross beta activity at Wye Barricade over the last decade from 2001 through 2010.

DOH detected anomalously high concentrations of gross beta and Cs-137 in 2009 and 2010 at 100K East Basin. In addition, external radiation exposure rates, as discussed in Section 3.3, are also elevated at this site. Radioactive material has been temporarily stored outside of the KE Basin facility since 2005, resulting in increased external exposure rates. The storage area was properly posted and access restricted. In addition, cleanup activities may have resulted in temporary increased exposure rates as well as increased atmospheric concentrations.

Concentrations reported for plutonium isotopes are often either below or only slightly above the detection limit. In either case, the question arises as to whether plutonium is actually detected or not. As discussed above, the DOH results for plutonium isotopes in composite air samples are not available at this time, and therefore they will be discussed in next year's report.

DOH intends to measure to the lowest concentration practical and minimize the error of reporting a non-detectable contaminant concentration when the contaminant is actually present. DOH has traditionally used the measured concentration, uncertainty, and minimum detectable activity (MDA) values to determine if a contaminant is present. The MDA represents the balance point between the probability functions that describe the likelihood of false-detection and false-rejection; it is not the point above which calculated activity can be considered to be positively detected. During the last few years, consensus among the environmental radioactivity measurements community has been building to move away from the use of the MDA to determine whether an analyte has been detected, precisely because of this ambiguity.

One additional statistical term that applies to data interpretation where the results are at or very near the limit of detection, is the critical level. This key concept describes the minimum significant concentration that can be discriminated from the concentration observed for a blank sample, thus allowing a decision to be made that the radionuclide was detected or not. DOH is revising data interpretation procedures to include evaluation of the critical level when samples are at the edge of detection capabilities, such as with plutonium in air composite samples.
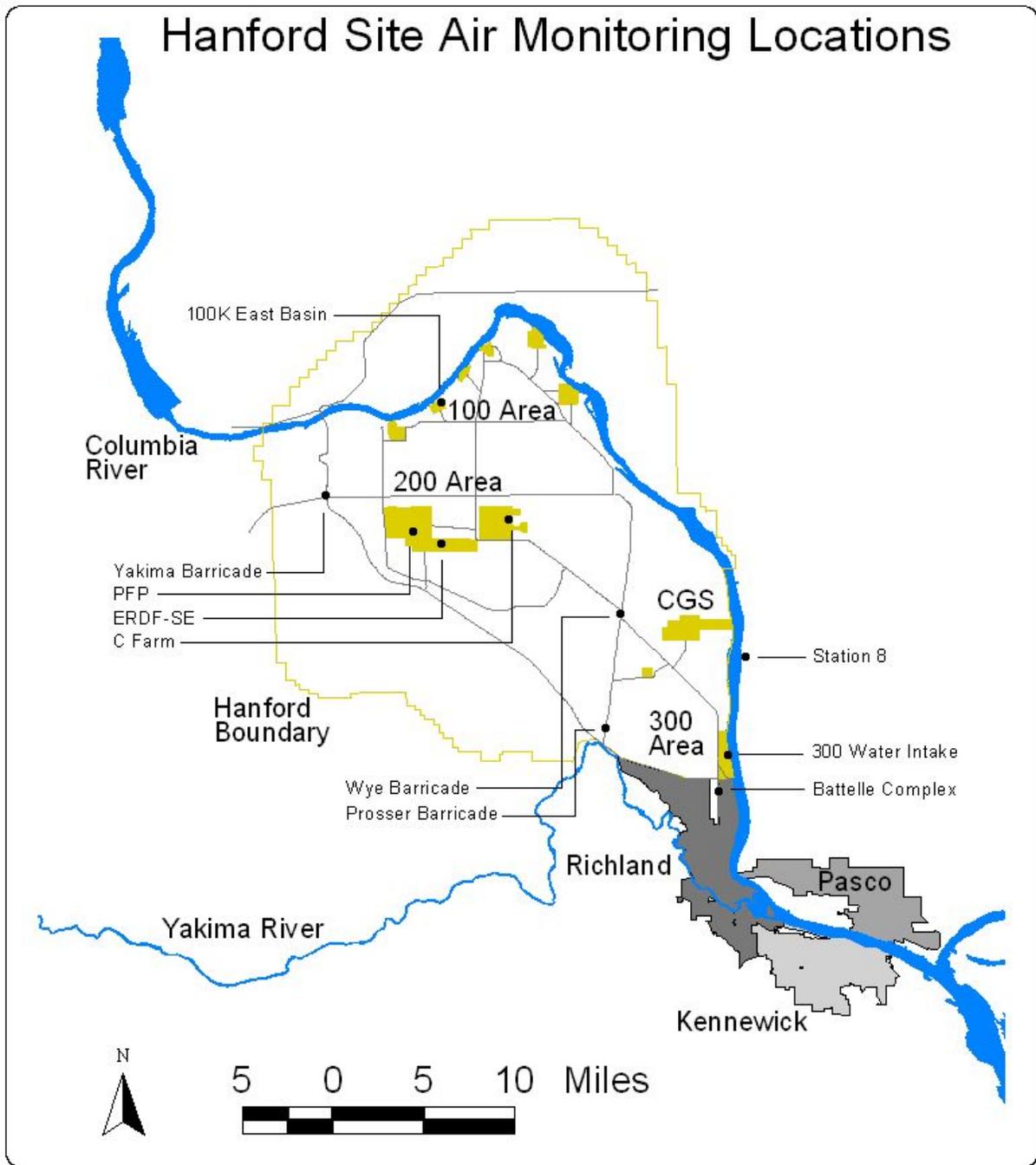
Figure 3.1.1    Hanford Area Air Monitoring Locations
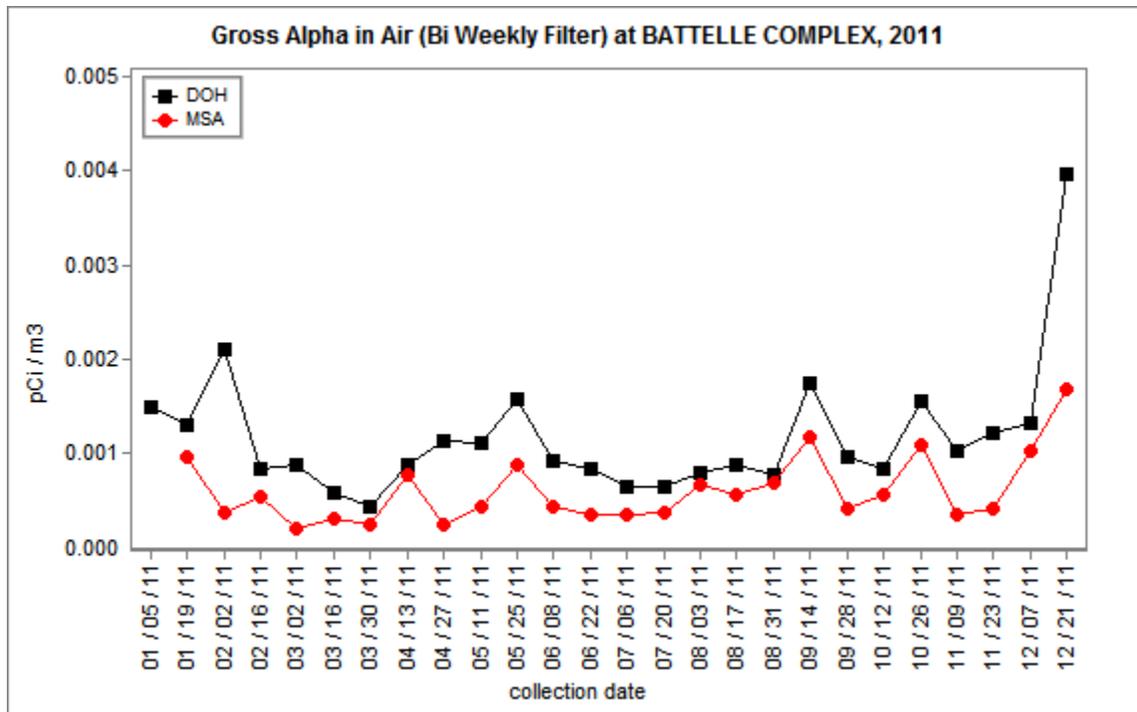
Figure 3.1.2    DOH and MSA Gross Alpha Concentrations in Air at Battelle Complex
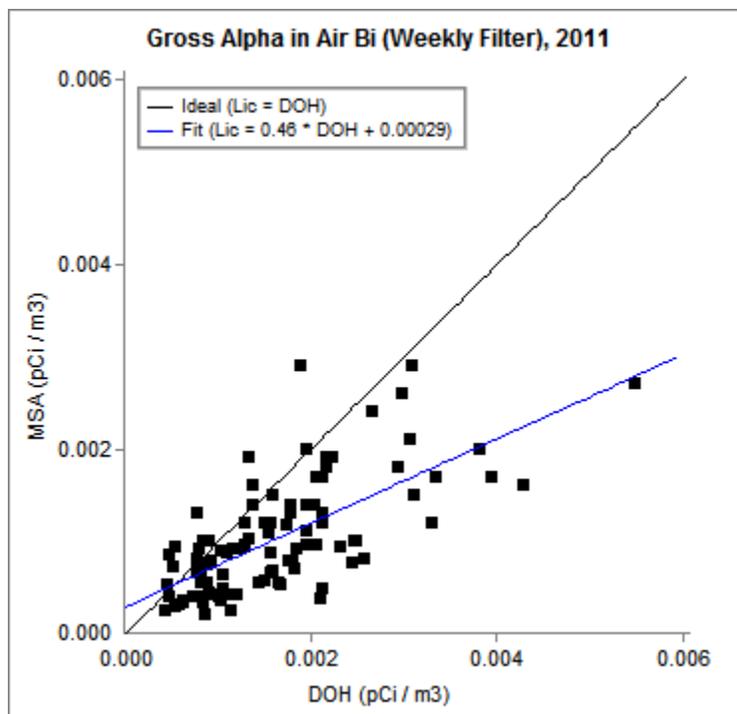


Figure 3.1.3      DOH and MSA Scatter Plot for Gross Alpha Concentrations in Air
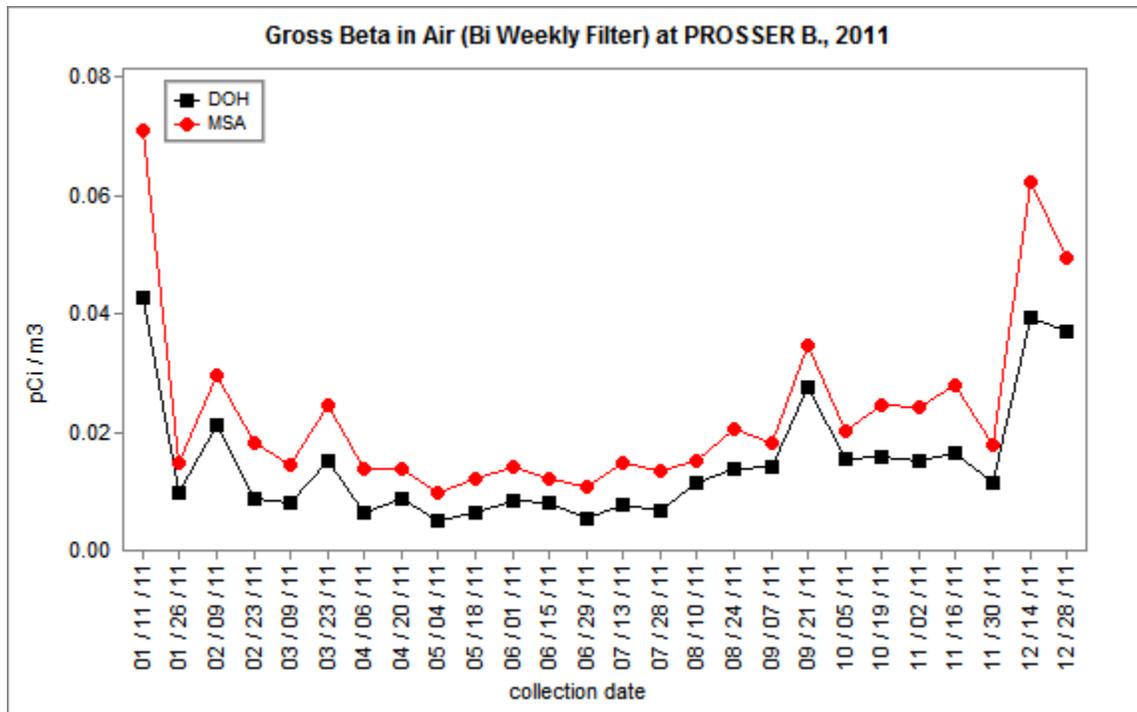
Figure 3.1.4    DOH and MSA Gross Beta Concentrations in Air at Prosser Barricade
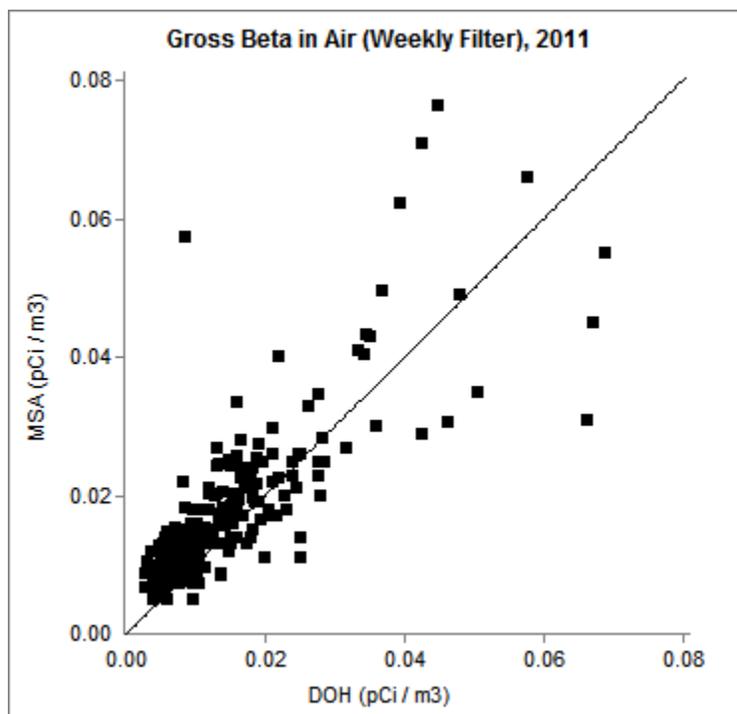


Figure 3.1.5    DOH and MSA Scatter Plot for Gross Beta Concentrations in Air

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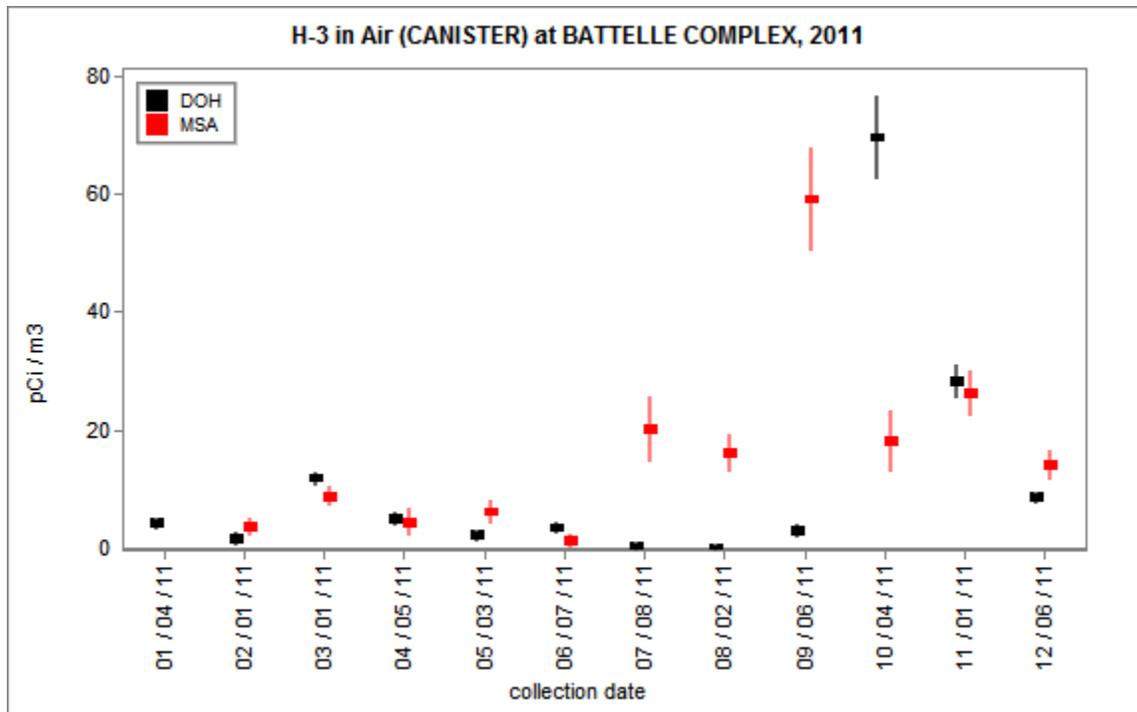
Figure 3.1.6    DOH and MSA H-3 Concentrations in Air at Battelle Complex
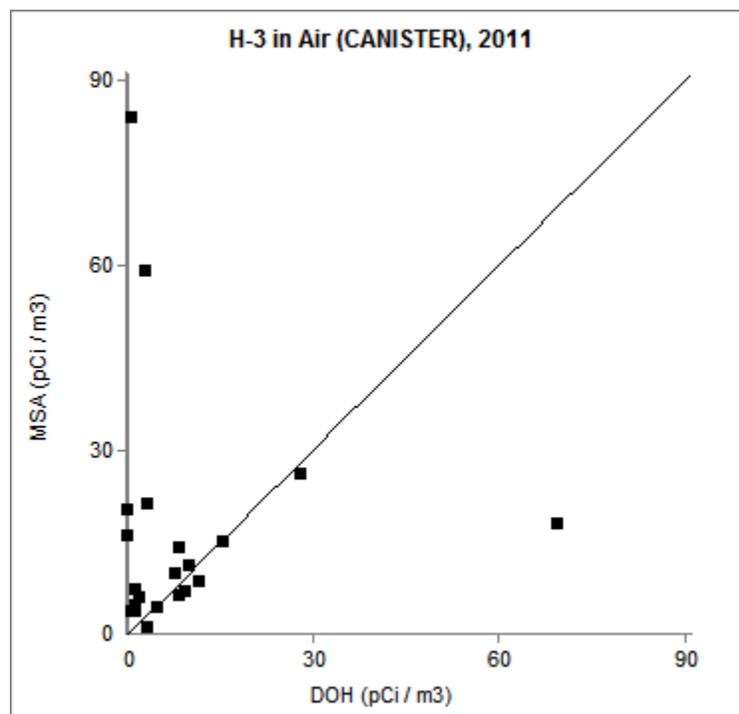


Figure 3.1.7    DOH and MSA Scatter Plot for H-3 Concentrations in Air

20
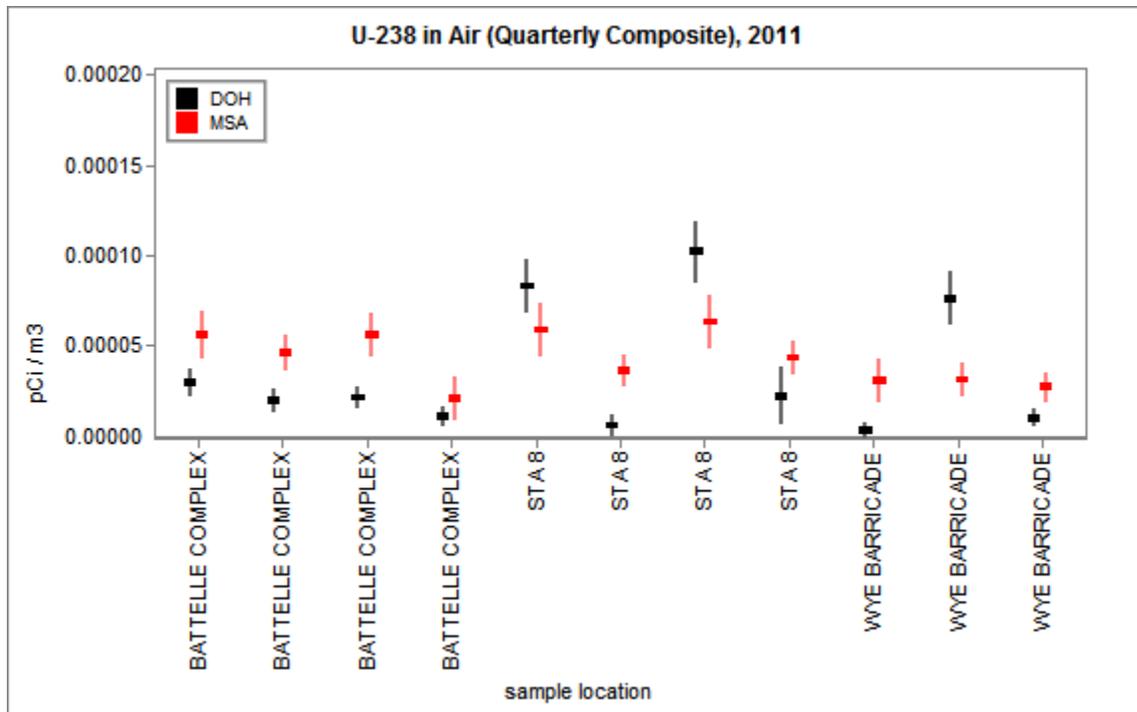
Figure 3.1.8        DOH and MSA Quarterly U-238 Concentrations in Air
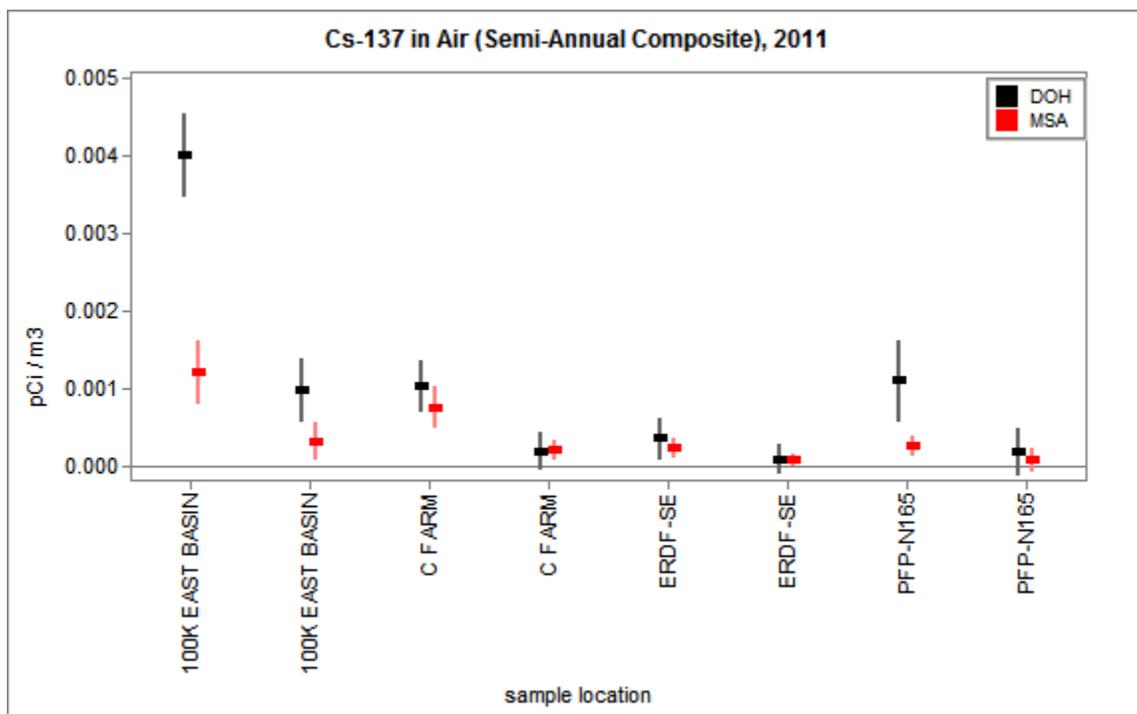


Figure 3.1.9        DOH and MSA Semiannual Cs-137 Concentrations in Air

21
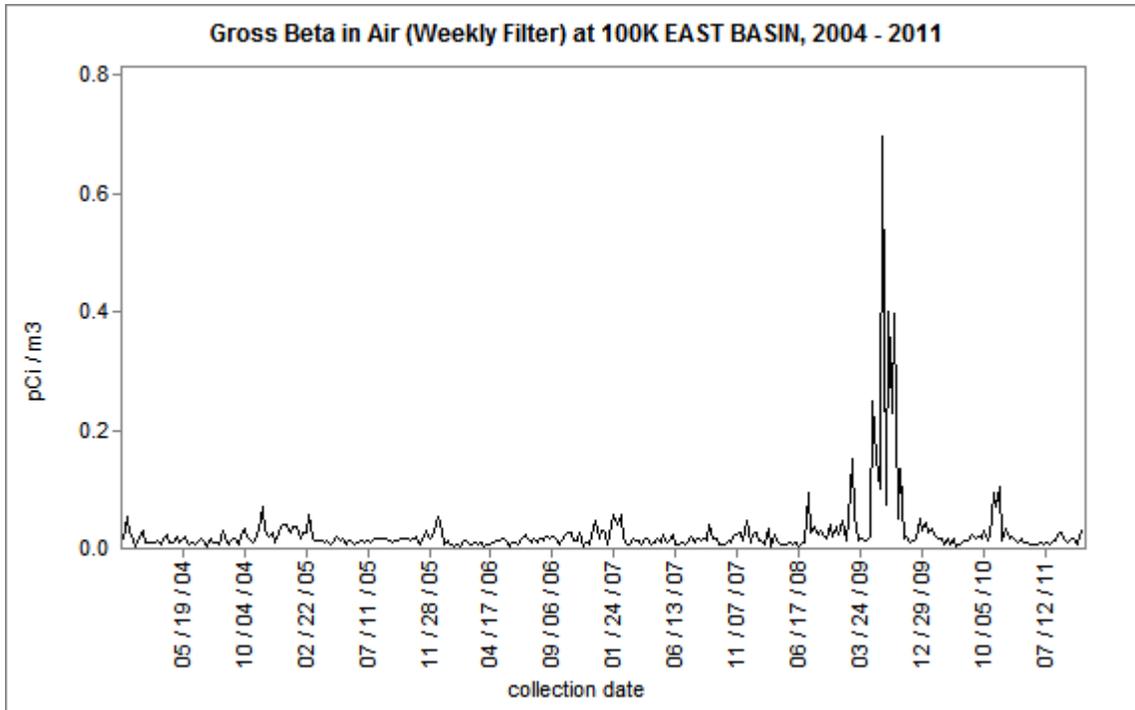
Figure 3.1.10     DOH Gross Beta Concentrations in Air at 100K East Basin
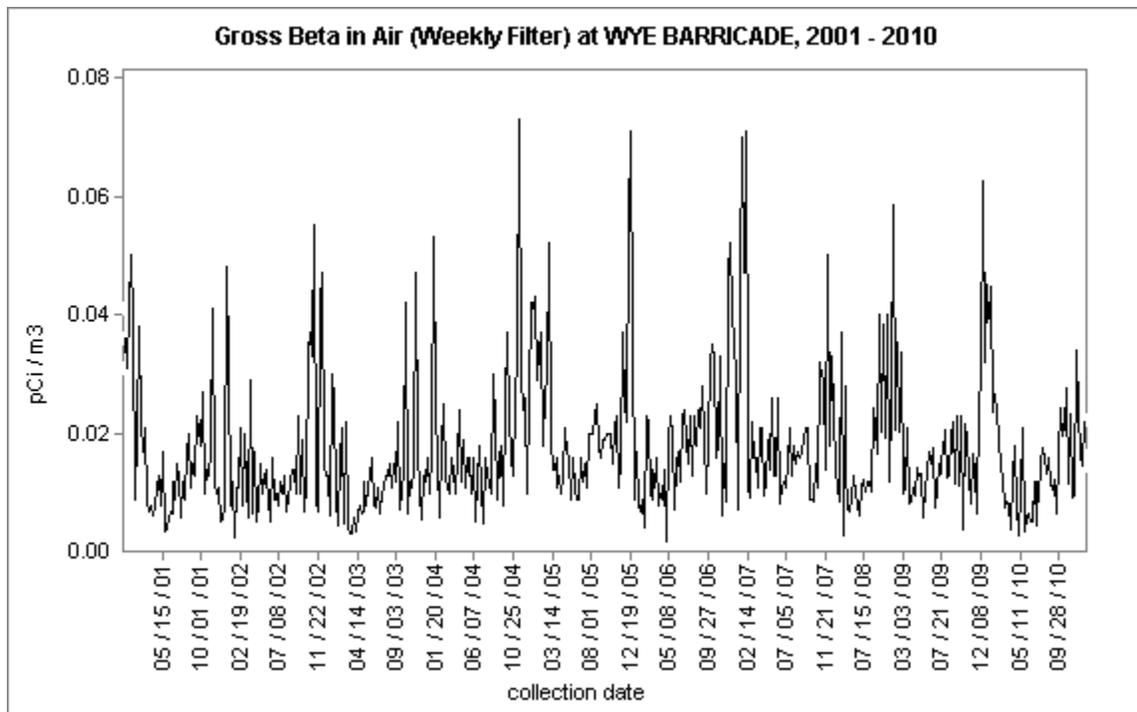


Figure 3.1.11     DOH Historical Gross Beta Concentrations in Air at Wye Barricade

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**3.2     Groundwater, Riverbank Seep, and Surface Water Monitoring**

Major Findings:

- The DOH and DOE contractor split water concentrations are in poor agreement for C-14 and isotopes of uranium; fair agreement for H-3, and I-129; and good agreement for all other radionuclides.
- Radionuclides were detected in groundwater in the vicinity of known groundwater plumes, and in riverbank seep water and Columbia River surface water in the vicinity of plumes known to be entering the Columbia River.
- DOH detected C-14, H-3, I-129, Pu-238, Pu-239/240, Sr-90, Tc-99, and isotopes of uranium in some Hanford groundwater, seep water, and surface water samples. Most concentrations are consistent with historical trends.
- DOH detected anomalously elevated isotopic uranium concentrations in a 300 Area groundwater well.
- Radionuclide concentrations in drinking water samples analyzed by DOH are all below federal standards.

**3.2.1     Purpose and General Discussion**

Operations at the Hanford Site have resulted in contaminated groundwater and surface water. Radioactive contaminants have leached from waste sites in the soil to groundwater beneath the Site, and then have migrated with groundwater towards the Columbia River. Groundwater may also enter the Columbia River through riverbank seeps.

Human exposure to contaminants can occur directly through ingestion of, or swimming in, contaminated water, or indirectly through ingestion of plants, animals, or fish that have been exposed to contaminated water. Radioactive contaminants are monitored by collecting samples from inland groundwater wells, riverbank seeps, and Columbia River water.

DOH splits groundwater, surface water, riverbank seep water, and drinking water samples with various DOE contractors. Monitoring is carried out to track contaminant plumes and to evaluate impacts to the public and environment. While the DOH program does not sample enough groundwater wells to track groundwater plumes, the riverbank seep and Columbia River data are adequate to assess impacts to the public.

**3.2.2     Sample Types and Monitoring Locations**

DOH and DOE contractor split water sample locations are shown in Figure 3.2.1.

*Groundwater*

DOH split 27 groundwater samples from 23 groundwater wells with the DOE contractor (CH2MHILL). Most well locations are on the Hanford Site, either within contaminated plumes, near waste sites, or along the Columbia River shoreline. A few of the co-sampled well locations are off the Hanford Site, located just south of Hanford in the northern part of Richland.

Groundwater sampling is conducted in the 100, 200, 300, 400, and 600 Areas of the Hanford Site. The 100 Area consists of nine retired reactors and support facilities located along the Columbia River. Tritium (H-3) and Sr-90 are contaminants commonly found in groundwater beneath the reactor facilities. A primary objective of the groundwater collection in the 100 Area is to monitor contaminants that may enter the Columbia River. At the 100K Area, groundwater is sampled to evaluate potential changes in radioactivity as spent nuclear fuel, shield water, and sludge are removed from the 100K East Fuel Storage Basin.

The 200 Area consists of retired reactor fuel processing facilities located in the center of the Hanford Site on the central plateau. Common groundwater contaminants include H-3, I-129, Sr-90, Tc-99, and isotopes of uranium. A primary objective of groundwater collection in the 200 Area is to track radioactive plume movement and monitor potential leaks from waste storage tanks.

The 300 Area consists of retired reactor fuel fabrication facilities located adjacent to the Columbia River. Groundwater contains tritium originating from the 200 Area and uranium originating from past 300 Area fuel fabrication activities. A primary objective of the groundwater collection in the 300 Area is to monitor contaminants at the southern boundary of the Hanford Site, which is close to the City of Richland's drinking water wells.

The 400 Area is the location of the Fast Flux Test Facility, a liquid sodium cooled test reactor that ceased operation in 1993. Tritium originating from the 200 Area is a common contaminant found in 400 Area groundwater. The primary objective of groundwater monitoring in this area is to assess impacts to the primary drinking water source for this part of Hanford. Note that the 400 Area is not shown on the map in Figure 3.2.1. It is located approximately four miles south and slightly west of the Columbia Generating Station (CGS).

The 600 Area includes all the land outside the operational areas of the Hanford Site (not specifically labeled on the map in Figure 3.2.1). The Old Hanford Town Site is within this region. Tritium originating from the 200 Area is a common contaminant found in 600 Area groundwater. The major objective of sampling 600 Area groundwater is to assess the nature and extent of radioactive plumes originating in the 200 Area that may be moving off-site.

*Riverbank Seeps*

DOH and the DOE contractor (MSA) split three Columbia River riverbank seep samples. Groundwater enters the Columbia River through riverbank seeps. Split samples are collected from the historically predominant areas for discharge of riverbank seep water to the Columbia River, which include the 100 Area (all three split samples in 2011), the Old Hanford Town Site (no split samples in 2011), and the 300 Area (no split samples in 2011).

*Surface Water*

DOH and the DOE contractor (MSA) split 16 surface water samples from 15 different locations (one location had two samples). Fourteen of the samples were collected from the Columbia River - two from near Priest Rapids Dam located upstream of Hanford, four from the 100N Area, four from the Old Hanford Town Site, and four from the 300 Area. Two of the samples were collected from irrigation canals, one located across the Columbia River at Riverview and the other at the southern boundary of the Hanford Site at the Horn Rapids Yakima River irrigation pumping station.

The Priest Rapids Dam location is upstream of the Hanford Site, while the remaining surface water sites are downstream of areas that may be impacted by Hanford. A comparison of contaminant concentrations at these sites gives an indication of Hanford's impact on the Columbia River.

Note that not all surface water sample locations are depicted in Figure 3.2.1. For example, the single surface water point on the map at the 100N Area is intended to represent the four samples collected from this general area. The scale of the map is not fine enough to show all four locations.

*Drinking Water*

Drinking water is supplied to DOE facilities on the Hanford Site by numerous water systems, most of which use water from the Columbia River. One of these systems, in the 400 Area at the Fast Flux Test Facility (FFTF), uses groundwater from the unconfined aquifer beneath the site. One drinking water sample, from a drinking water storage tank in the 400 Area, was split with MSA. In addition to the split 400 Area samples, DOH independently collected one drinking water sample from the Laser Interferometer Gravitational-Wave Observatory (LIGO) Facility and one from the Edwin Markham elementary school in Pasco, with both results presented in this report.

### 3.2.3    Monitoring Procedures

*Groundwater*

DOH groundwater samples were collected by DOE contractors who follow standard operating procedures that call for purging the well prior to sampling. Groundwater samples were collected from the upper, unconfined aquifer. The samples were analyzed for those radionuclides that are most likely present in the area, based on previous sampling and review of radiological contaminants present nearby. Most samples were analyzed for gross alpha, gross beta, tritium, and gamma emitting radionuclides. Specific analyses for C-14, I-129, Sr-90, Tc-99, and isotopes of uranium and plutonium were added where appropriate.

*Riverbank Seeps*

Columbia River riverbank seep samples are collected when the river flow is lowest, typically in the fall. This ensures that riverbank seep water contains primarily groundwater, instead of Columbia River water stored in the riverbank during high flow rates. The seeps have a very small flow rate and are collected with the aid of a small pump. All seep samples were split with MSA in the field and analyzed as unfiltered samples. Most samples were analyzed for gross alpha, gross beta, gamma emitting radionuclides, and H-3. Specific analyses for Sr-90, Tc-99, and isotopes of uranium were added where appropriate.

*Surface Water*

Columbia River surface water is monitored by collecting samples at several points spanning the width of the river. This technique is known as transect sampling. Columbia River samples are also collected from near the Hanford shoreline at locations where known groundwater plumes are near the river. Finally, surface water samples are collected from irrigation pumping stations located at Horn Rapids (Yakima River water) and Riverview (Columbia River water).

Samples were split in the field and analyzed unfiltered. Most samples were analyzed for isotopes of uranium, H-3, and Sr-90. Analyses for gross alpha, gross beta, gamma emitting radionuclides, and Tc-99 were added where appropriate.

*Drinking Water*

Drinking water is monitored by sampling either tap water, water from storage tanks, or groundwater wells that supply drinking water. The samples are typically analyzed for gross alpha, gross beta, gamma emitting radionuclides, Sr-90, and H-3.

## 3.2.4   Comparison of DOH and DOE Contractor Data

Table 3.2.1 summarizes the comparison of DOH and DOE contractor data. Section 2.2 discusses the methods for comparing split or collocated data. The table lists the analytes, the DOE contractor, and the number of split samples. The tables also list the quality of agreement for the split samples (see Section 2.2.4.1) and the range of concentrations measured by DOH. Finally, the "Anomalous Data ?" column denotes whether any of the DOH concentrations for the current year are anomalous compared to historical results (see Section 2.2.5).

The text following the table discusses cases in which 1) the agreement between DOH and DOE data is not good (i.e. is fair or poor), and 2) some of the DOH data are anomalous compared to historical results. A value for the "DOH Data Range" prefaced by the "less than" symbol (<) indicates that some or all DOH results are less than the listed detection limit.

| Analyte | Contractor | # Split Samples | Agreement | DOH Data Range (pCi/L) | Anomalous Data ? |
|---|---|---|---|---|---|
| C-14 | CH2MHILL[a] | 7 | **poor** | < 150 to 8100 | no |
| Co-60 | CH2MHILL | 10 | good | < 2 | no |
| Cs-134 | CH2MHILL | 9 | good | < 2 | no |
| Cs-137 | CH2MHILL | 10 | good | < 2 to 2,000 | no |
| Eu-152 | CH2MHILL | 9 | good | < 5 | no |
| Eu-154 | CH2MHILL | 9 | good | < 5 | no |
| Eu-155 | CH2MHILL | 9 | good | < 8 | no |
| Gross Alpha[c] | CH2MHILL | 19 | | | |
| Gross Beta[c] | CH2MHILL | 21 | | | |
| H-3 | CH2MHILL | 16 | **fair** | 73 to 740,000 | **yes** |
| I-129 | CH2MHILL | 11 | **fair** | < 0.5 to 17 | no |
| Pu-238 | CH2MHILL | 3 | good | < 0.04 to 0.26 | no |
| Pu-239/240 | CH2MHILL | 3 | good | 1 to 43 | no |
| Sr-90 | CH2MHILL | 12 | good | < 0.7 to 14,000 | no |
| Tc-99 | CH2MHILL | 8 | good | 6 to 2,700 | no |
| U-234 | CH2MHILL | 2 | **poor** | 32 to 1,100 | **yes** |
| U-235 | CH2MHILL | 2 | **poor** | 2 to 83 | **yes** |
| U-238 | CH2MHILL | 2 | **poor** | 28 to 1,200 | **yes** |
| Co-60 | MSA[b] | 4 | good | < 2 | no |
| Cs-134 | MSA | 4 | good | < 2 | no |
| Cs-137 | MSA | 5 | good | < 2 | no |
| Eu-152 | MSA | 5 | good | < 5 | no |
| Eu-154 | MSA | 5 | good | < 5 | no |
| Eu-155 | MSA | 5 | good | < 8 | no |
| Gross Alpha[c] | MSA | 7 | | | |
| Gross Beta[c] | MSA | 7 | | | |
| H-3 | MSA | 19 | **fair** | < 50 to 4,300 | no |
| Sr-90 | MSA | 19 | good | < 0.7 to 1.8 | no |
| Tc-99 | MSA | 6 | good | < 2 | no |
| U-234 | MSA | 16 | good | 0.1 to 8 | no |
| U-235 | MSA | 16 | good | < 0.1 to 0.5 | no |
| U-238 | MSA | 21 | good | 0.1 to 8 | no |

(a)  CH2MHILL samples include groundwater.
(b)  MSA samples include riverbank seep water, surface water, and drinking water.
(c)  DOH data not available at time of publishing. Results will be discussed in a future report.

Table 3.2.1     Summary of Water Samples Split with DOE Contractors.

The DOH and DOE contractor C-14 concentrations in groundwater are in poor agreement, as can be seen in Figure 3.2.2. Some of the concentrations are in agreement, while others differ significantly. Figure 3.2.3 shows a scatter plot of historical split C-14 groundwater data, where it can be seen that differences between the DOH and DOE contractor concentrations are common.

The DOH and DOE contractor H-3 concentrations in groundwater are in fair agreement, as can be seen in Figure 3.2.4. The data follow the same trend; however, the DOH concentrations are consistently higher than those reported by DOE. A scatter plot of this same data is shown in Figure 3.2.5, where it is easily seen that DOH reports higher concentrations. A regression analysis indicates the DOH concentrations are approximately 10% higher than those reported by DOE. Historically, the H-3 data are in good agreement. The disagreement of the data in 2010 and 2011 is anomalous. Note that each of these figures do not show two data points in the range of 700,000 pCi/L, as their inclusion in the graphs would obscure the details of all the other data at much lower concentrations.

The DOH and DOE contractor I-129 concentrations in groundwater are in fair agreement, as can be seen in Figure 3.2.6. The results are similar and follow the same trend, but there is a systematic bias in which DOE consistently reports higher concentrations than DOH. This systematic bias can be seen in the scatter plot shown in Figure 3.2.7. The preponderance of points to the left of the theoretical line where DOH and DOE concentrations are equal indicates that DOE consistently reports higher results. The regression analysis indicates that, on average, DOE reports concentrations 20% greater than those reported by DOH.

Historically, the DOH and DOE contractor isotopic uranium concentrations in groundwater are in good agreement. However, in June of 2011, DOH measured anomalously high concentrations at well 399-1-17A (U-234: 1,070 pCi/L, U-235: 83 pCi/L, U-238: 1,170 pCi/L) compared to average historical results (U-234: 62 pCi/L, U-235: 4 pCi/L, U-238: 55 pCi/L). Concentrations measured by DOH returned to normal for the sample collected in December of 2011, as can be seen in Figure 3.2.8. The DOE contractor concentrations for the June sample do not agree with DOH, as they are consistent with historical results.

The DOH and DOE contractor H-3 concentrations in surface and seep water are in fair agreement. The data follow the same trend; however, the DOH concentrations are consistently higher than those reported by DOE. This systematic bias can best be seen in a scatter plot of the data, shown in Figure 3.2.9. The regression analysis indicates a systematic bias in which, on average, DOE reports concentrations 73% lower than those reported by DOH. Historically, the H-3 data are in good agreement. The disagreement of the data in 2010 and 2011 is anomalous.

### 3.2.5    Other Discussion

In addition to the split water samples discussed above, DOH collected and analyzed drinking water samples from the LIGO Facility and the Edwin Markham elementary school in Pasco. DOH also independently analyzed many of the groundwater samples for analytes not included

as part of the oversight program split analysis. Any significant results from these additional DOH samples are included in the discussion below.

Isotopic uranium results are typically reported for U-234, U-235, and U-238. These isotopes occur in nature as well as in Hanford byproducts. Uranium-236 is an isotope that does not occur in nature, but rather is a byproduct of reactor operations. Uranium-236 is occasionally detected in Columbia River sediments and in water samples. DOH detected U-236 in groundwater and riverbank seep samples from the 300 Area. Concentrations ranged from 0.1 pCi/L to 45 pCi/L (groundwater well 399-1-17A). Concentrations for all uranium isotopes at well 399-1-17A are significantly higher than normal (see discussion above in Section 3.2.4).

Gross alpha and gross beta analyses are for the purpose of screening, and are generally indicative of the presence of uranium/plutonium isotopes and Sr-90/Tc-99, respectively. DOH checks samples to test if the gross concentrations are consistent with the sum of all the individual radionuclide contributions. No anomalous situations were found.

Radionuclides detected in drinking water samples include gross beta (12 pCi/L at Edwin Markam Elementary School), and H-3 (2,270 pCi/L at the 400 Area drinking water tank). All concentrations are below EPA drinking water standards (50 pCi/L for gross beta, and 20,000 pCi/L for H-3).
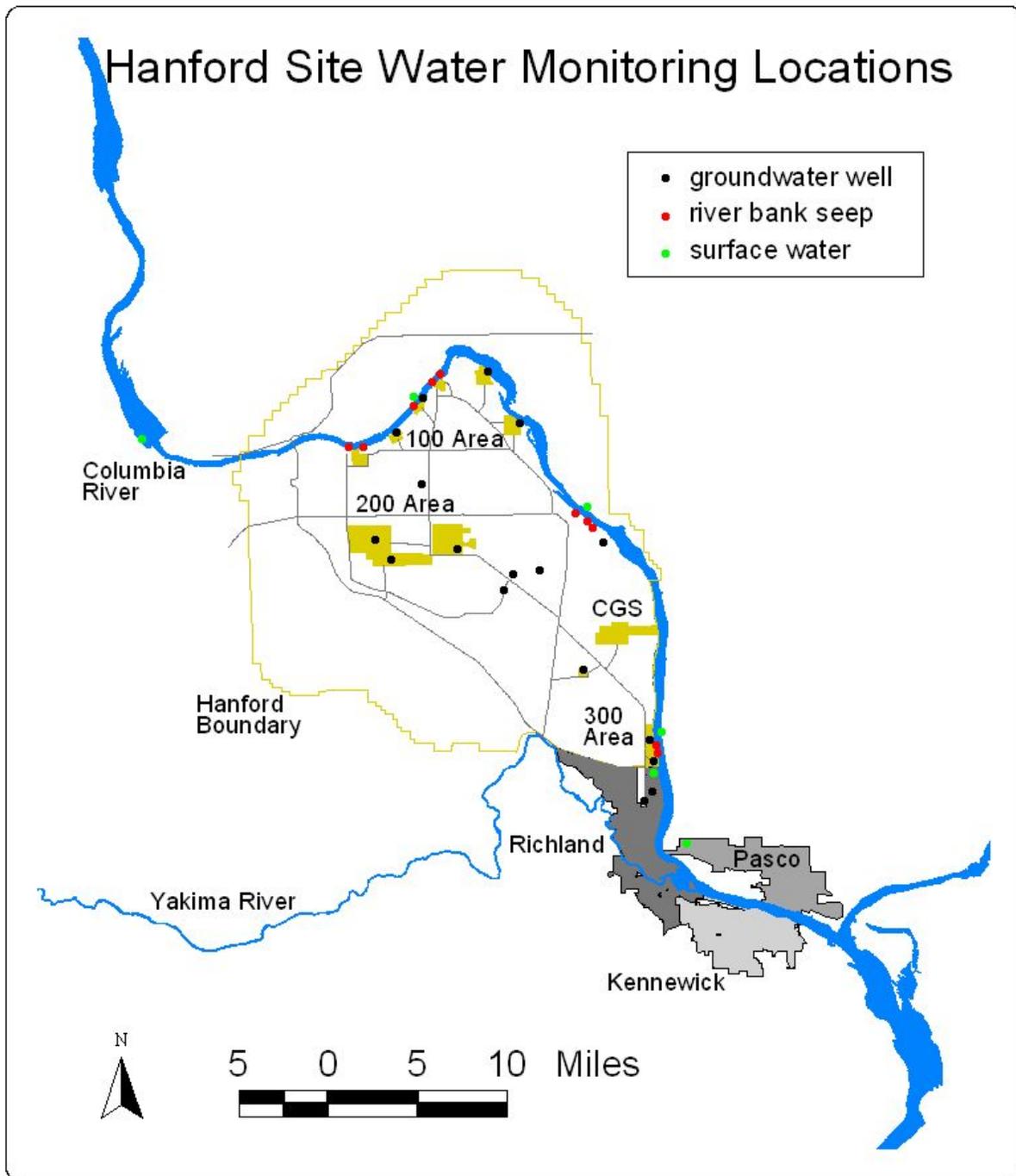
Figure 3.2.1    Historical Locations for Split Water Samples
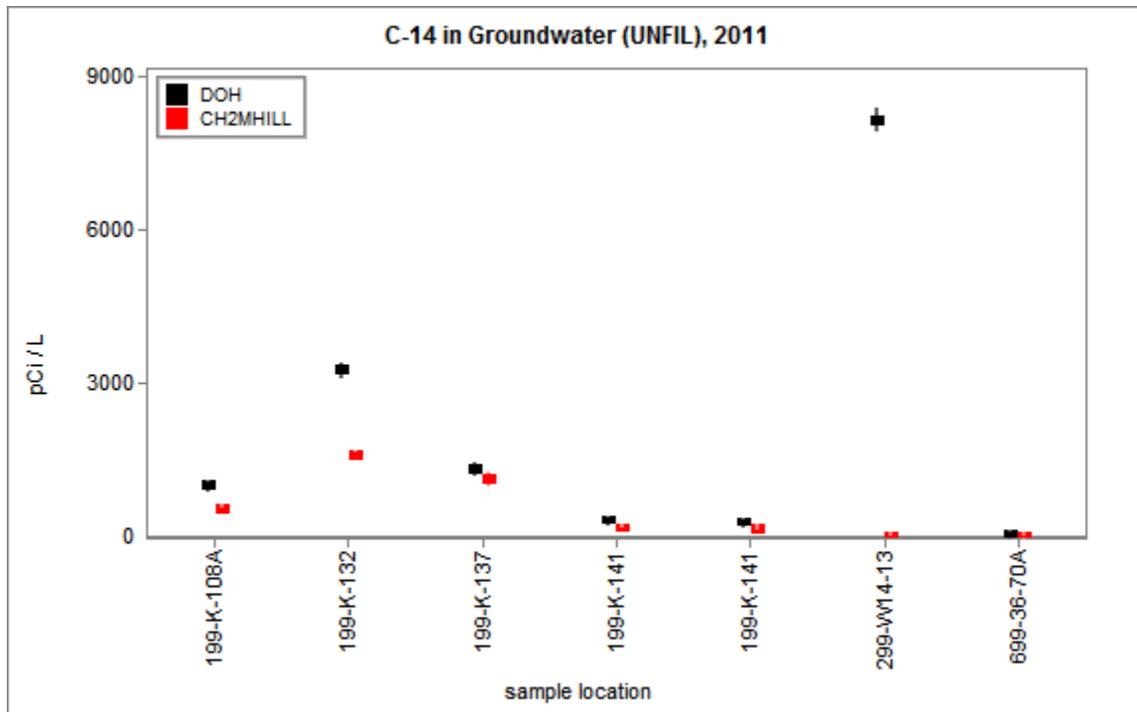
Figure 3.2.2    DOH and CH2MHILL C-14 Concentrations in Groundwater
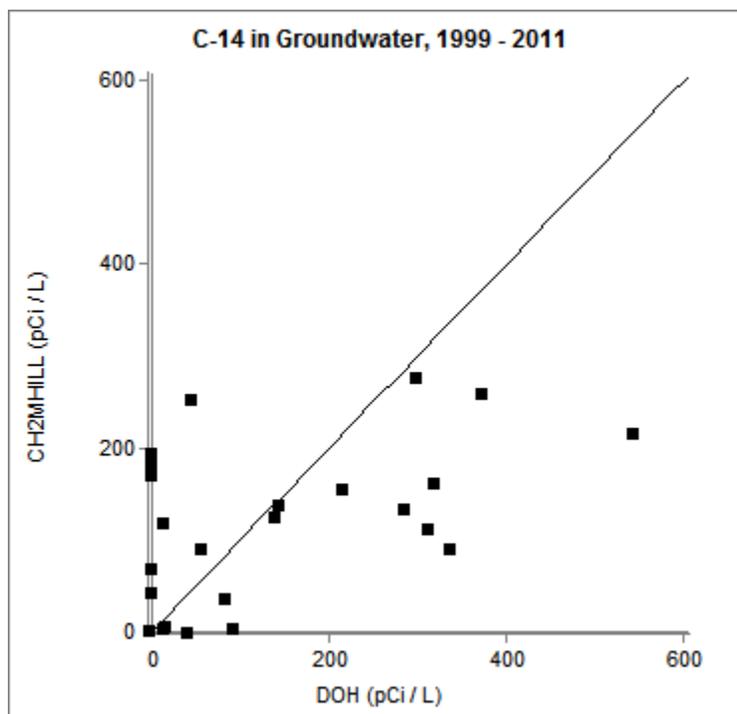


Figure 3.2.3    DOH and CH2MHILL Scatter Plot for Historical C-14 Concentrations in Groundwater

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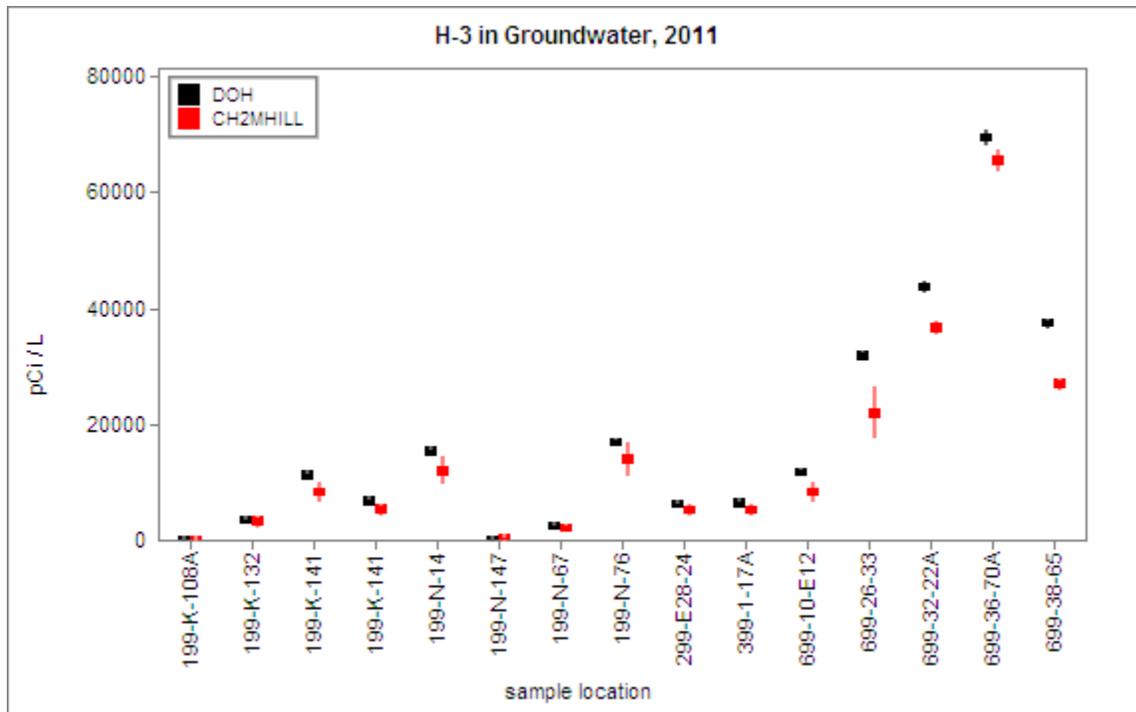
Figure 3.2.4    DOH and CH2MHILL H-3 Concentrations in Groundwater
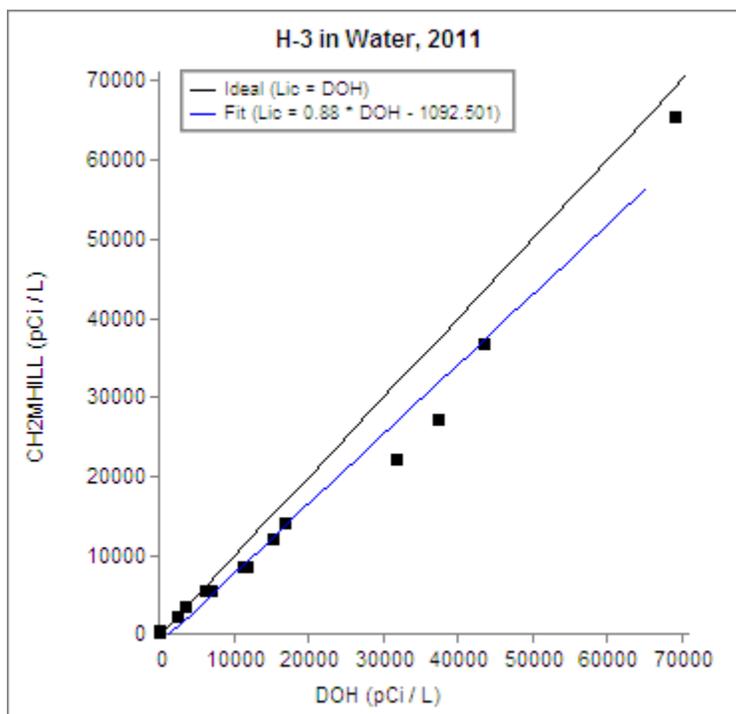


Figure 3.2.5  DOH and CH2MHILL Scatter Plot for H-3 Concentrations in Groundwater

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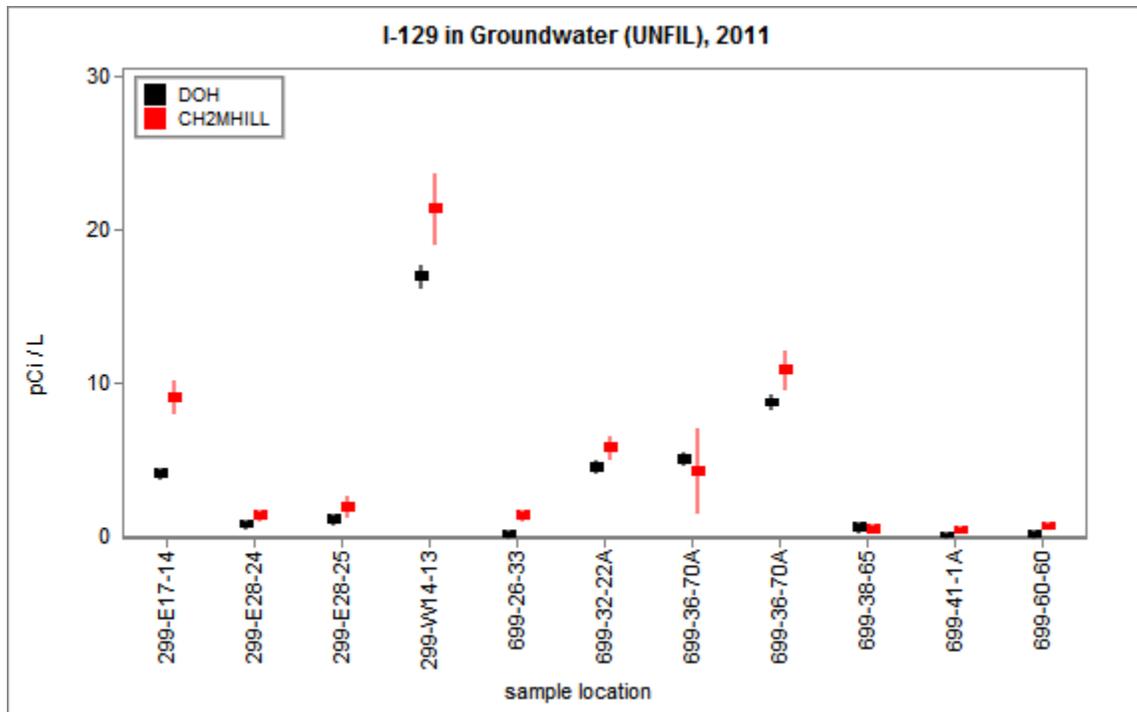
Figure 3.2.6    DOH and CH2MHILL I-129 Concentrations in Groundwater
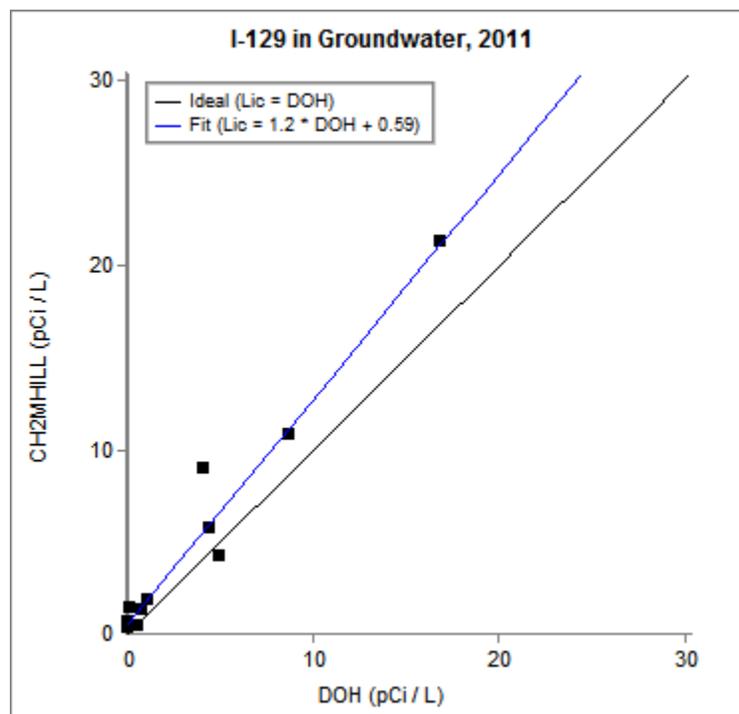


Figure 3.2.7   DOH and CH2MHILL Scatter Plot for I-129 Concentrations in Groundwater

33
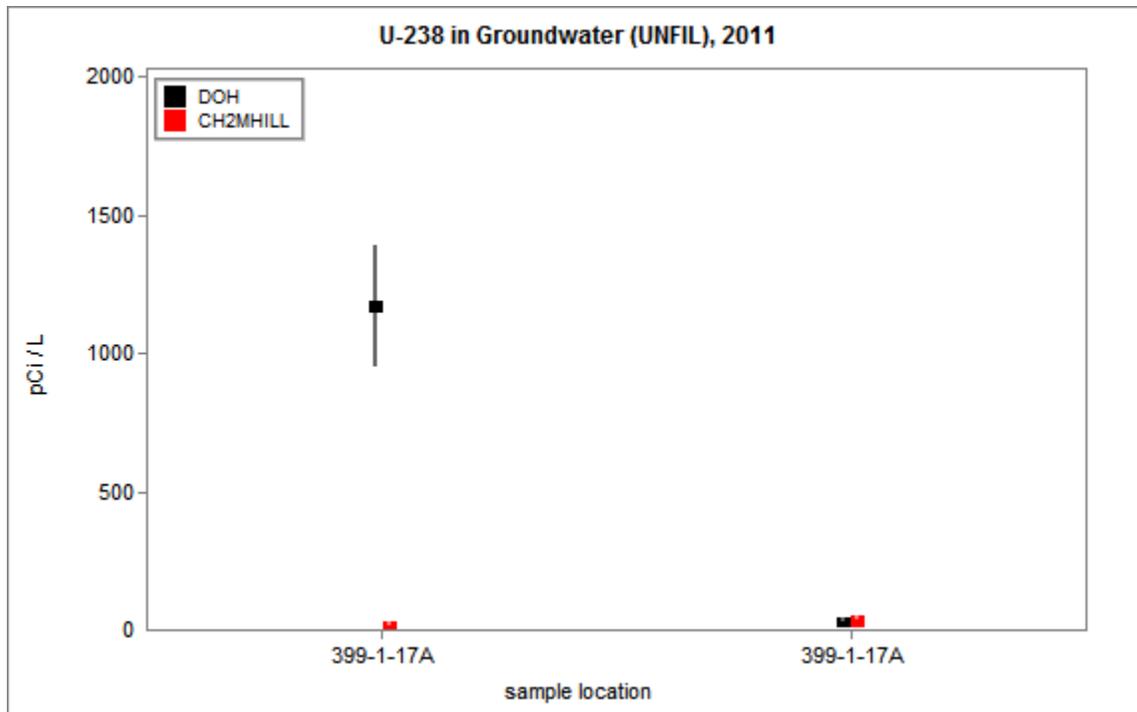
Figure 3.2.8    DOH and CH2MHILL U-238 Concentrations in Groundwater
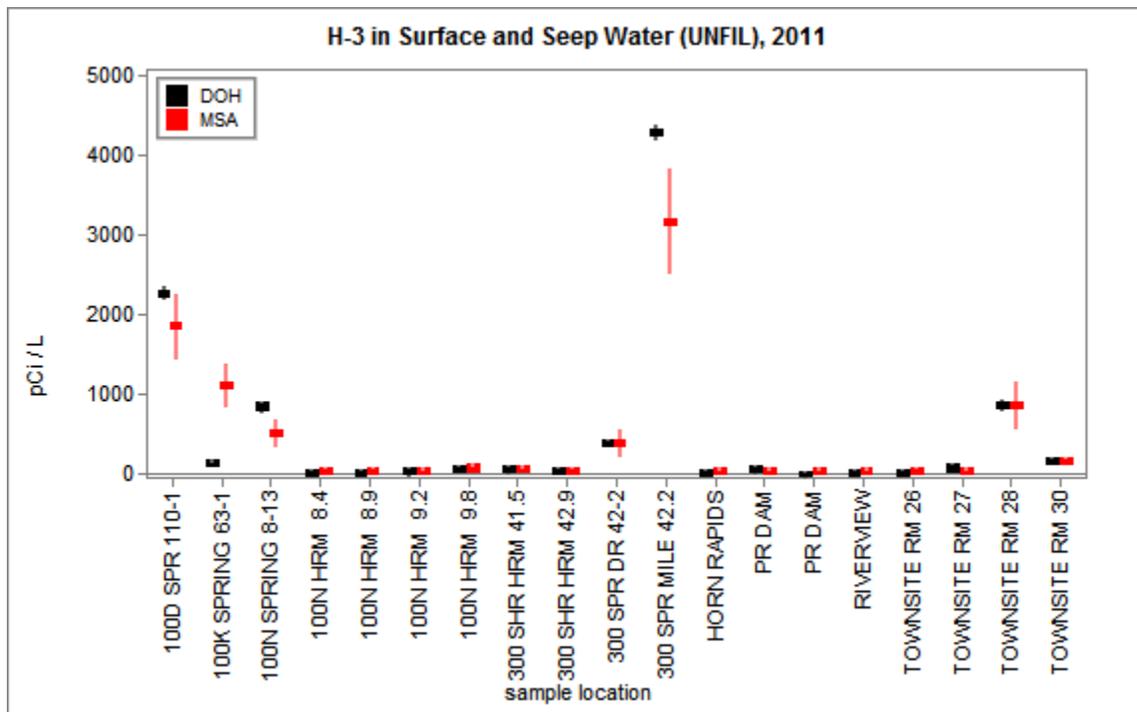


Figure 3.2.9    DOH and MSA H-3 Concentrations in Surface and Seep Water
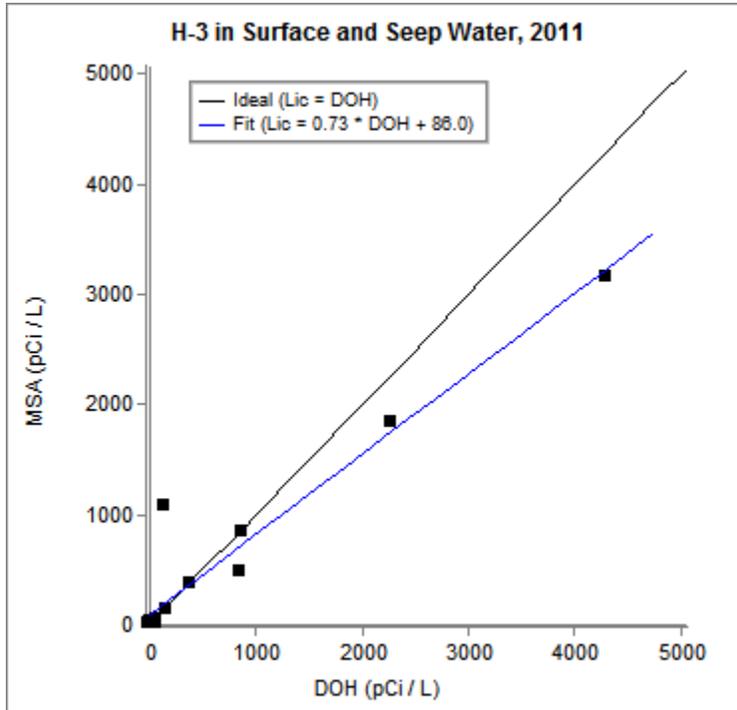
Figure 3.2.10  DOH and MSA Scatter Plot for H-3 Concentrations in Surface and Seep Water

## 3.3 External Radiation Monitoring

<table>
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Major Findings:

- The DOH and DOE contractor external radiation rates are in fair agreement.

- Radiation exposure rates at most DOH TLD locations on the Hanford Site are consistent with historical results and are similar to rates at locations along the Hanford perimeter and distant (background) from the Hanford Site.

- Exposure rates along the Columbia River are consistent with background.

- Exposure rates near the 100K East Basin at Hanford's 100K East Area have been anomalously high for several years, due to temporary outdoor storage of radioactive materials and the effects of cleanup activities.

- One exposure rate measurement at the 100N Outflow location was anomalously high compared to historical results.

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### 3.3.1 Purpose and General Discussion

DOH and DOE contractors monitor external radiation rates (also referred to as "exposure rates" in this report) with thermoluminescent dosimeters (TLDs). TLDs measure the time-integrated exposure to external radiation at their location. Sources of background external radiation include natural cosmic and terrestrial radiation as well as fallout from atmospheric testing of nuclear weapons. Contamination from the Hanford Site may contribute to man-made sources of external radiation. In addition to oversight of the DOE monitoring program, DOH compares on-site and off-site TLD results to determine if Hanford is impacting workers or the public.

External radiation levels can vary by up to 25% over the course of a year at any one location. This variation is primarily due to changes in soil moisture and snow cover, both of which affect shielding of natural radiation from the earth's crust.

DOH has historically maintained TLD monitoring sites collocated with the DOE Near-Facilities and Operations monitoring program, and the DOE Site-Wide and Offsite monitoring program. In 2006, the Site-Wide and Offsite TLD program was terminated by DOE. In response, DOH added 26 new TLD locations along the Columbia River to independently monitor locations that were previously monitored by DOE. In addition, DOH will continue to maintain its original TLD sites that were collocated with DOE. Therefore, from 2006 forward, the TLD section of this report will cover the sites collocated with the Near-Facilities and Operations program, as well as the sites operated independently by DOH.

**3.3.2        Sample Types and Monitoring Locations**

DOH operated 49 external radiation monitoring sites (TLD sites) that are relevant to the Hanford Site. Forty of these sites are operated under the Hanford Environmental Radiation Oversight Program, in which five sites are collocated with the Near-Facilities and Operations program currently run by Mission Support Alliance (MSA), and 35 sites are independently monitored by DOH. The remaining nine sites are part of the Columbia Generating Station Oversight Program, and they are included in this report because the sites are located along the Hanford perimeter.

The DOH TLD site locations are shown in Figure 3.3.1. Eight of the sites are near Hanford facilities with known, suspected, or potential radiation sources. Three sites (Yakima and Wye Barricades, and LIGO Facility) are located on the Hanford Site, but away from radiation sources. Twenty-six sites are along the Columbia River shoreline from the Vernita Bridge to downstream of Bateman Island at the mouth of the Yakima River. Nine sites are located around the Hanford Site perimeter. The remaining three sites (Othello, Yakima Airport, and Benton County Shops) are significantly distant from the Hanford Site. Many of the TLD sites are collocated with air monitoring sites.


**3.3.3        Monitoring Procedures**

Most collocated TLDs are deployed on a quarterly basis at each monitoring location, with the TLDs retrieved at the end of each calendar quarter. Some of the TLDs are deployed semi-annually, and others are deployed as weather and river conditions allow. The DOH TLDs are sent to the State Public Health Laboratory where the time-integrated external radiation exposure is determined for the deployment period. The results are then converted to an average daily radiation exposure rate and reported in units of milliroentgen per day (mR/day). At the same time the TLDs are retrieved, new TLDs are placed at each site.


**3.3.4        Comparison of DOH and DOE Contractor Data**

Table 3.3.1 summarizes the comparison of DOH and DOE contractor data. Section 2.2 discusses the methods for comparing split or collocated data. The table lists the analytes, the collection period, and the number of collocated samples. The table also lists the quality of agreement for the collocated samples (see Section 2.2.4.1) and the range of exposure rates measured by DOH. Finally, the "Anomalous Data ?" column denotes whether any of the DOH exposure rates for the current year are anomalous compared to historical results (see Section 2.2.5).

The text following the table discusses cases in which 1) the agreement between DOH and DOE data is not good (i.e. is fair or poor), and 2) some of the DOH data are anomalous compared to historical results. A value for the "DOH Data Range" prefaced by the "less than" symbol (<) indicates that some or all DOH results are less than the listed detection limit.

| Analyte | Collection Period | # Collocated Samples | Agreement | DOH Data Range (mR/day) | Anomalous Data ? |
|---------|-------------------|----------------------|-----------|-------------------------|------------------|
| TLD | quarterly | 20 | **fair** | 0.14 to 0.41 | **yes** |

Table 3.3.1    Summary of TLD Samples Collocated with MSA

Historically, the agreement between DOH and the DOE contractor TLD results has been fair, not good. The DOE contractor systematically reported slightly higher exposure rates (approximately 10% averaged over all data) than DOH. The discrepancy was primarily observed for third quarter results, and was not understood. Starting in 2009, a new contractor (MSA) took over this program, and the third quarter discrepancy still appears, as can be seen in Figure 3.3.2. Note that this graph shows the first, then second, then third, and finally fourth quarter results at each monitoring location. The agreement is good for first, second, and fourth quarter data, but the MSA exposure rate ranges from 15% to 35% higher than the DOH data for the third quarter. DOH is researching this discrepancy, and will discuss the findings in a future report.

Historically, DOH has measured elevated exposure rates at site 100N Spring, which is within Hanford's 100N Area (see Figure 3.3.3). The exposure rate at this site has steadily been decreasing with time, due to the natural decay of Co-60 surface contamination. With the recent cleanup of contaminated surface soil, exposure rates over the past several years now appear constant and are consistent with exposure rates from sites away from contaminated areas.

Elevated exposure rates have been observed since 2005 at location 100K East Basin, near a fuel storage basin within Hanford's 100K East Area. Figure 3.3.4 shows historical TLD data at this location. Radioactive material has been temporarily stored outside of the KE Basin facility since 2005, resulting in increased dose rates. The storage area was properly posted and access restricted. In addition, cleanup activities have resulted in temporary increased dose rates. Measurements along the Columbia River at the 100K Area (site location 100K Boat Ramp), the closest public access point, do not indicate elevated exposure rates.

### 3.3.5    Other Discussion

In addition to the five sites collocated with the DOE contractor discussed above, DOH independently monitors 35 TLD sites and monitors nine sites collocated with the Columbia Generating Station. The data from these 44 sites are summarized in Table 3.3.2.

The table lists the analytes, the collection period, and the number of samples. The table also lists the range of exposure rates measured by DOH. Finally, the "Anomalous Data ?" column denotes whether any of the DOH exposure rates for the current year are anomalous compared to historical results (see Section 2.2.5). The exposure rates reported by DOH are consistent with historical results, and no anomalous data were encountered.

| Analyte | Collection Period | # Samples | DOH Data Range (mR/day) | Anomalous Data ? |
|---------|-------------------|-----------|-------------------------|------------------|
| TLD | Quarterly / Semiannual | 117 | 0.12 to 0.52 | **yes** |

Table 3.3.2      Summary of Independent DOH TLD Samples

The DOH TLD sites are categorized by their location type, as described in Section 3.3.2. The average, minimum, and maximum dose rates for all of the sites in each location category are shown in the graph of Figure 3.3.5. This graph includes data from these 44 sites plus the five sites collocated with MSA discussed in Section 3.3.4 (all 49 DOH TLD sites). As can be seen, average dose rates are similar for all location categories. Generally, the maximum dose rate is highest for the sites that are onsite and near to contaminated or operational facilities. However, in 2011 there was an anomalously high exposure rate of 0.52 mR/day at the 100N Outflow TLD site. Normal exposure rates at this site range from 0.2 to 0.3 mR/day.

The average exposure rate at sites distant from Hanford is slightly lower than at other locations. The distant sites are located in areas covered by concrete or gravel, whereas most other sites are located directly over soil. For example, the Yakima Airport site is on a concrete tarmac. Concrete and gravel, like water in the Columbia River, shield the terrestrial component of natural radiation. Therefore, lower exposure rates are expected at these sites.

# Hanford Site TLD Locations

100D D Isl
100D DnRvr
100N Berm
100N Spr
100N Outflow
100K East Basin
100K BoatRamp
100B Ret Basin
100B Reactor
100B UpRvr
Vernita Bridge

Othello

100H
100H Locke Isl
White Bluff Ferry
100F DnRvr
100F FloodPlain
HTS Slough
HTS Powerline
Sta 53
HTS Railroad
Savage Isl Slough

**100 Area**

**200 Area**

Columbia
River

◄ to Yakima Airport

Yakima Barricade
WRAP
WSCF
200East North
200East East

Ringold Isl
Sta 45

**CGS**

Sta 43
CGS Powerline
Sta 8
Wooded Isl
Sta 40
300 TEDF
300 UpRvr Isl
313 Building
300 Isl
Byer's Landing
Port of Benton
Sta 4
North Richland

Wye Barricade
Ligo Facility
Sta 56
Sta 6

Hanford
Boundary

**300
Area**

Richland

Pasco

Yakima River

Columbia Park Isl

Benton County Shops

Kennewick

N

5    0    5    10  Miles

Figure 3.3.1    DOH External Radiation Monitoring (TLD) Locations

40
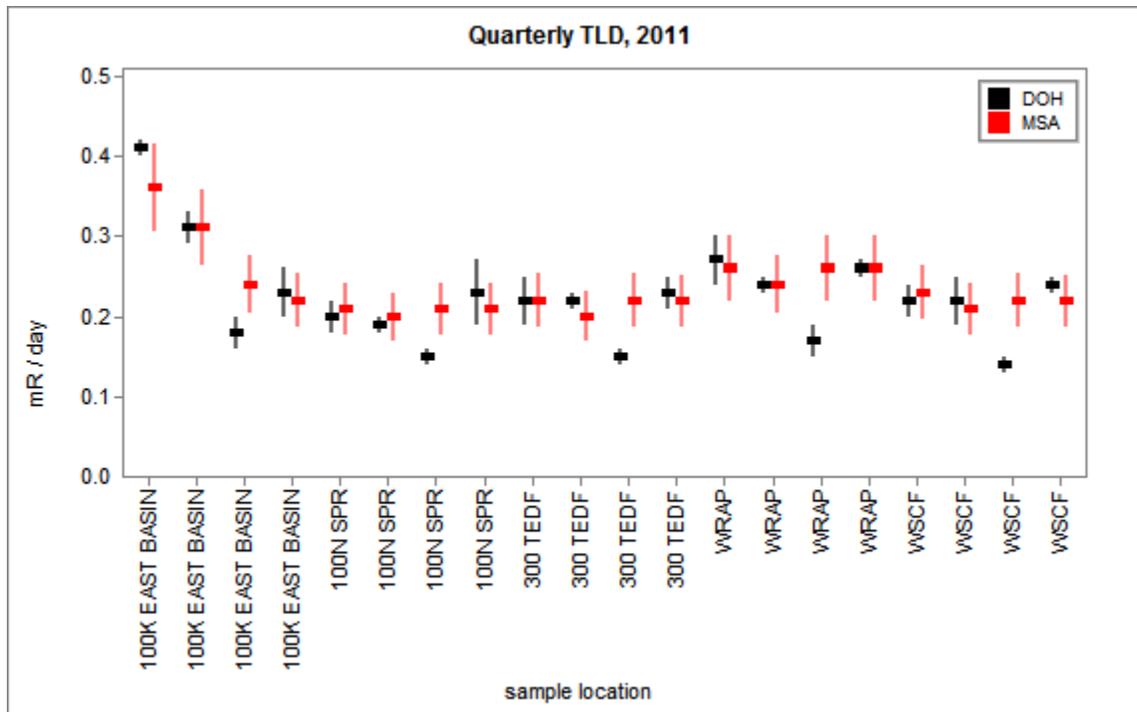
Figure 3.3.2    DOH and MSA Quarterly TLD Results
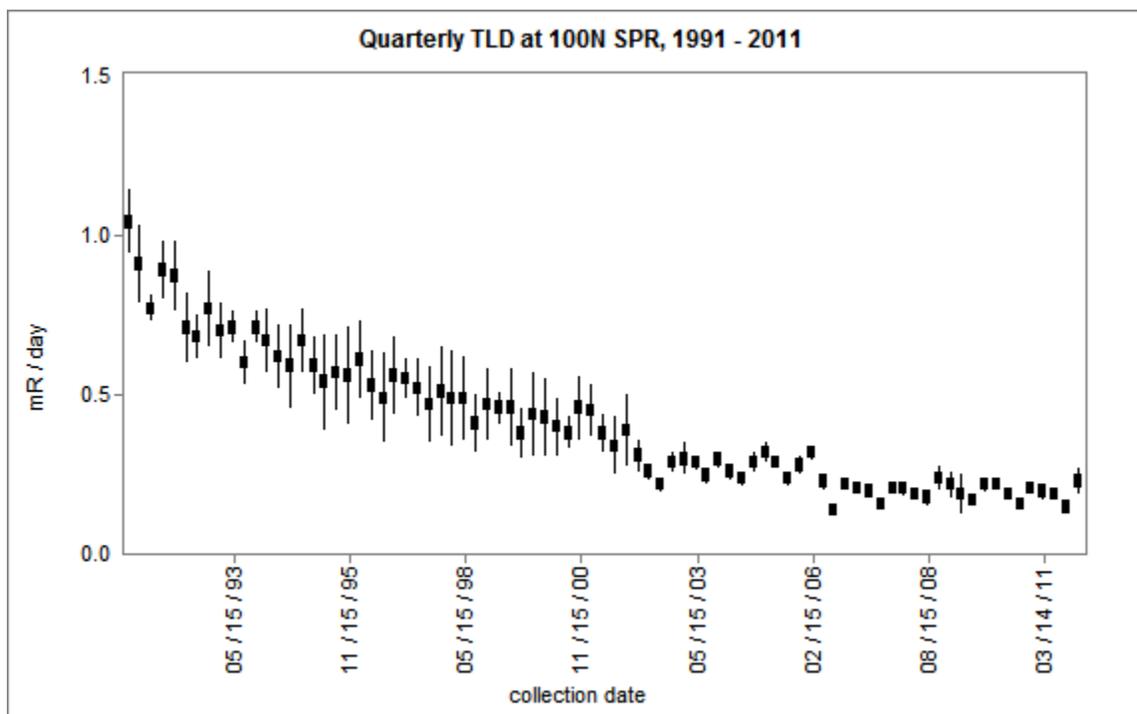


Figure 3.3.3    DOH Historical TLD Results at Location 100N SPR in the 100N Area

41
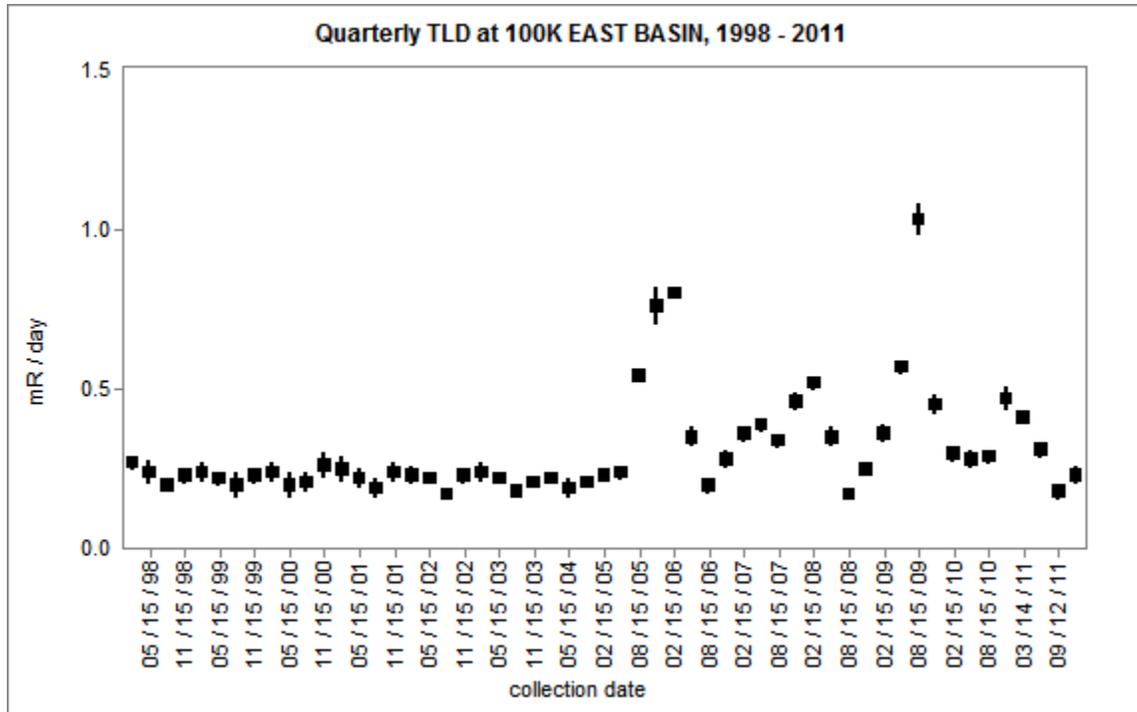
Figure 3.3.4    DOH Historical TLD Results at Location 100K East Basin in the 100K Area
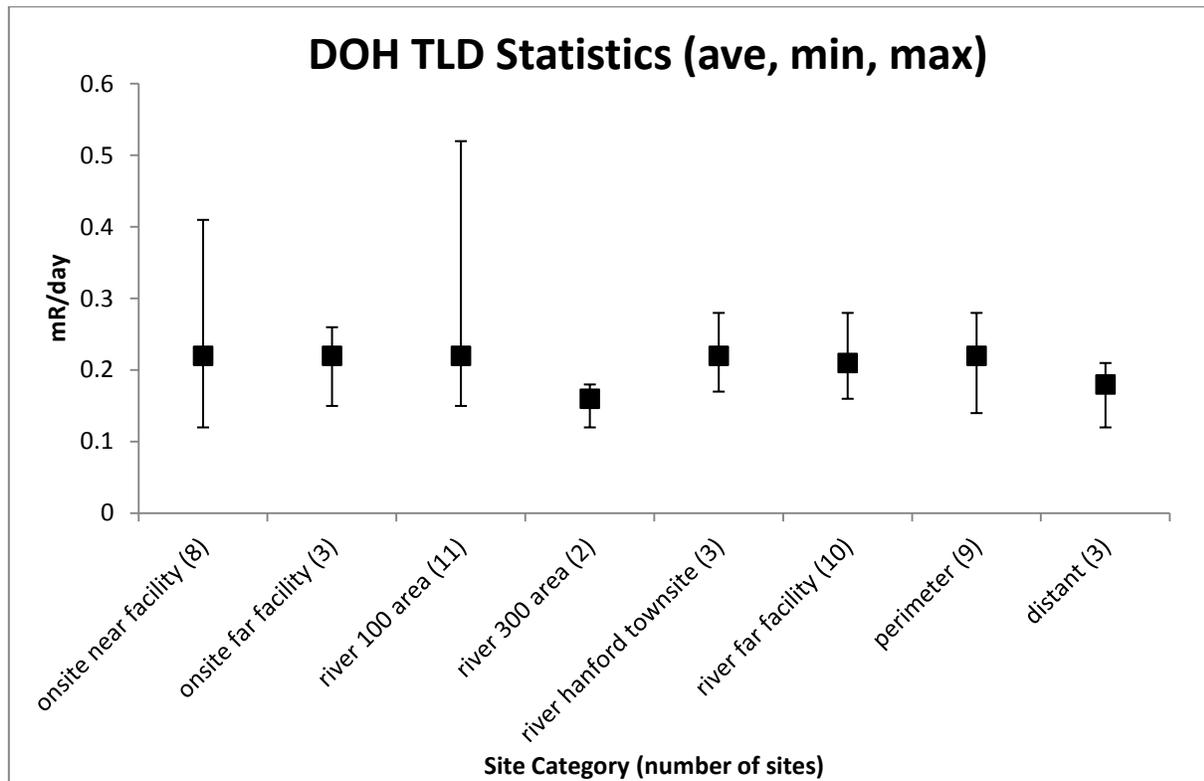


Figure 3.3.5    Statistical TLD Values for the Different DOH Site Location Types

42

## 3.4      Soil and Sediment Monitoring

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Major Findings:

- DOH and DOE contractor concentrations are in good agreement for all radionuclides except Pu-238.
- All DOH radionuclide concentrations are consistent with historical results. Concentrations of most radionuclides in sediment samples from locations adjacent to or downriver from Hanford are consistent with those from locations upriver from Hanford.

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### 3.4.1      Purpose and General Discussion

Contaminated soil and river sediments are a potential source of radiation exposure for people and biota in the environment. Human exposure may result from direct exposure to contaminated soil/sediment, ingestion of contaminated soil/sediment, ingestion of water contaminated by sediment resuspension, inhalation of contaminants resuspended in air, or ingestion of fish, animals, plants, or farm products exposed to contaminated soil and sediments.

Radionuclides in soil and sediment originate from many sources, including natural terrestrial sources, atmospheric fallout from nuclear weapons tests, and contaminated liquid and gaseous effluents. In addition, contaminants can reach Columbia River sediments from erosion of contaminated soil and flow of contaminated groundwater. Cesium-137, Sr-90, and plutonium isotopes are radionuclides consistently seen in soil or sediments because they exist in world-wide fallout, as well as potentially in effluents from the Hanford Site. Uranium isotopes, also consistently seen in soil and sediment, occur naturally in the environment in addition to being present from Hanford operations.

### 3.4.2      Sample Types and Monitoring Locations

Six sediment samples from the Columbia River were split with the DOE contractor (MSA in 2011). Soil samples were not included in this reporting period's oversight program. Two sediment samples were collected upriver from Hanford at Priest Rapids Dam, two along the Hanford Site at the 100K Area and the White Bluff Slough, and two downriver from Hanford at McNary Dam. These six sediment locations, along with four other historical locations, are shown in Figure 3.4.1.

Priest Rapids Dam, being upstream from Hanford, is considered a background location. McNary Dam is the first dam downstream from Hanford, and therefore is expected to have the highest radionuclide concentrations. Sediment locations within the Hanford boundary change from year to year. The locations are chosen to monitor areas where contaminants may be discharged into the river, areas where deposits could accumulate, or areas where the public may gain access to the shoreline.

### 3.4.3 Monitoring Procedures

Soil samples (none collected for this report) are collected by compositing four one-square foot areas, each excavated to a depth of one inch. The composited samples are split, and then dried prior to radiochemical analysis. Samples are analyzed for radionuclides that are most likely present in the area sampled, which at Hanford typically include gamma emitting radionuclides, Sr-90, isotopic uranium, and isotopic plutonium. Note that no soil samples were collected for this year's oversight program.

Sediment samples represent surface sediments and are collected with either a clam-shell style sediment dredge or, in the case of shoreline sediments, a plastic spoon. Sediment samples are collected by PNNL and then split with DOH. The samples are first dried, then analyzed for gamma emitting radionuclides, strontium-90, isotopic uranium, and isotopic plutonium. Radiochemical analysis methods for soil and sediment are identical. Soil and sediment concentrations are reported in units of pCi/g dry weight.

### 3.4.4 Comparison of DOH and DOE Contractor Data

Table 3.4.1 summarizes the comparison of DOH and DOE contractor data. Section 2.2 discusses the methods for comparing split or collocated data. The table lists the analytes, the collection period, and the number of split samples. The table also lists the quality of agreement for the split samples (see Section 2.2.4.1) and the range of concentrations measured by DOH. Finally, the "Anomalous Data ?" column denotes whether any of the DOH concentrations for the current year are anomalous compared to historical results (see Section 2.2.5).

The text following the table discusses cases in which 1) the agreement between DOH and DOE data is not good (i.e. is fair or poor), and 2) some of the DOH data are anomalous compared to historical results. A value for the "DOH Data Range" prefaced by the "less than" symbol (<) indicates that some or all DOH results are less than the listed detection limit.

| Analyte | Collection Period | # Split Samples | Agreement | DOH Data Range (pCi/g) | Anomalous DOH Data ? |
|---------|-------------------|-----------------|-----------|------------------------|----------------------|
| Co-60 | annual | 6 | good | < 0.02 | no |
| Cs-134 | annual | 4 | good | < 0.02 | no |
| Cs-137 | annual | 6 | good | 0.02 to 0.3 | no |
| Eu-152 | annual | 6 | good | < 0.05 to 0.1 | no |
| Eu-154 | annual | 6 | good | < 0.05 | no |
| Eu-155 | annual | 6 | good | < 0.08 | no |
| Pu-238 | annual | 5 | **fair** | < 0.005 | no |
| Pu-239/240 | annual | 5 | good | < 0.003 to 0.01 | no |
| Sr-90 | annual | 6 | good | < 0.008 to 0.02 | no |
| U-234 | annual | 6 | good | 0.8 to 2 | no |
| U-235 | annual | 6 | good | 0.03 to 0.07 | no |
| U-238 | annual | 6 | good | 0.8 to 1 | no |

Table 3.4.1    Summary of Split Columbia River Sediment Samples

The DOH and DOE contractor results for Co-60, Cs-134, Eu-154, and Eu-155 are all below detection limits.

The DOH and DOE contractor concentrations in sediment are in good agreement for all radionuclides except Pu-238. Typically, Pu-238 concentrations in sediment are below detection limits (generally near 0.01 pCi/g). In 2011, all DOH results are below the detection limit of 0.005 pCi/g. The DOE contractor concentrations are also undetected, except for a detected result (0.015 pCi/g with a detection limit of 0.007 pCi/g) in a McNary Dam sediment sample, as shown in Figure 3.4.2. This DOE contractor concentration is very small and is just slightly higher than the detection limit.

The Sr-90 concentrations are in good agreement, although the DOE contractor detection limit is approximately ten times greater than that of DOH. The DOH data vary in concentration from below the detection limit of 0.008 pCi/g to 0.015 pCi/g, while the DOE contractor reports all results are less than their detection limit of 0.04 pCi/g.

In 2008, higher than normal concentrations of uranium isotopes were measured by DOH at the background sediment location near Priest Rapids Dam, upstream of the Hanford Site. Since then (2009 onwards), the measured concentrations are consistent with historical values at this site.

Elevated concentrations of uranium isotopes are often found in Columbia River sediment samples collected from near the 300 Area, with U-234 and U-238 concentrations ranging from 1 to 4 pCi/g. However, in 2010, DOH measured isotopic uranium concentrations higher than typical values in 300 Area sediment. In 2011 (for this report), DOH did not split sediment samples from the 300 Area, and therefore DOH is not able to follow up on this issue.

### 3.4.5    Other Discussion

Radionuclides consistently identified by DOH in soil and sediment samples include Cs-137, Pu-239/240, U-234, U-235, and U-238. Uranium-233 (lower limit of detection approximately 0.1 pCi/g) has not been detected by DOH in any sediment samples. Other radionuclides identified in some sediment samples include Eu-152 and Sr-90.

Cesium-137, Sr-90, and plutonium isotopes exist in world-wide fallout as a result of nuclear weapons testing and may also exist in effluent from the Hanford Site. Uranium isotopes occur naturally in the environment and may also be present in Hanford Site effluent. All of these isotopes may transport through the environment into sediment.

Typically, radionuclide concentrations in sediment at most sites adjacent to and downriver from Hanford are not significantly different from those at the upstream background location at Priest Rapids Dam. Exceptions are elevated uranium concentrations from sediment adjacent to the 300 Area, and low-level Eu-152 concentrations downstream of Hanford at McNary Dam.
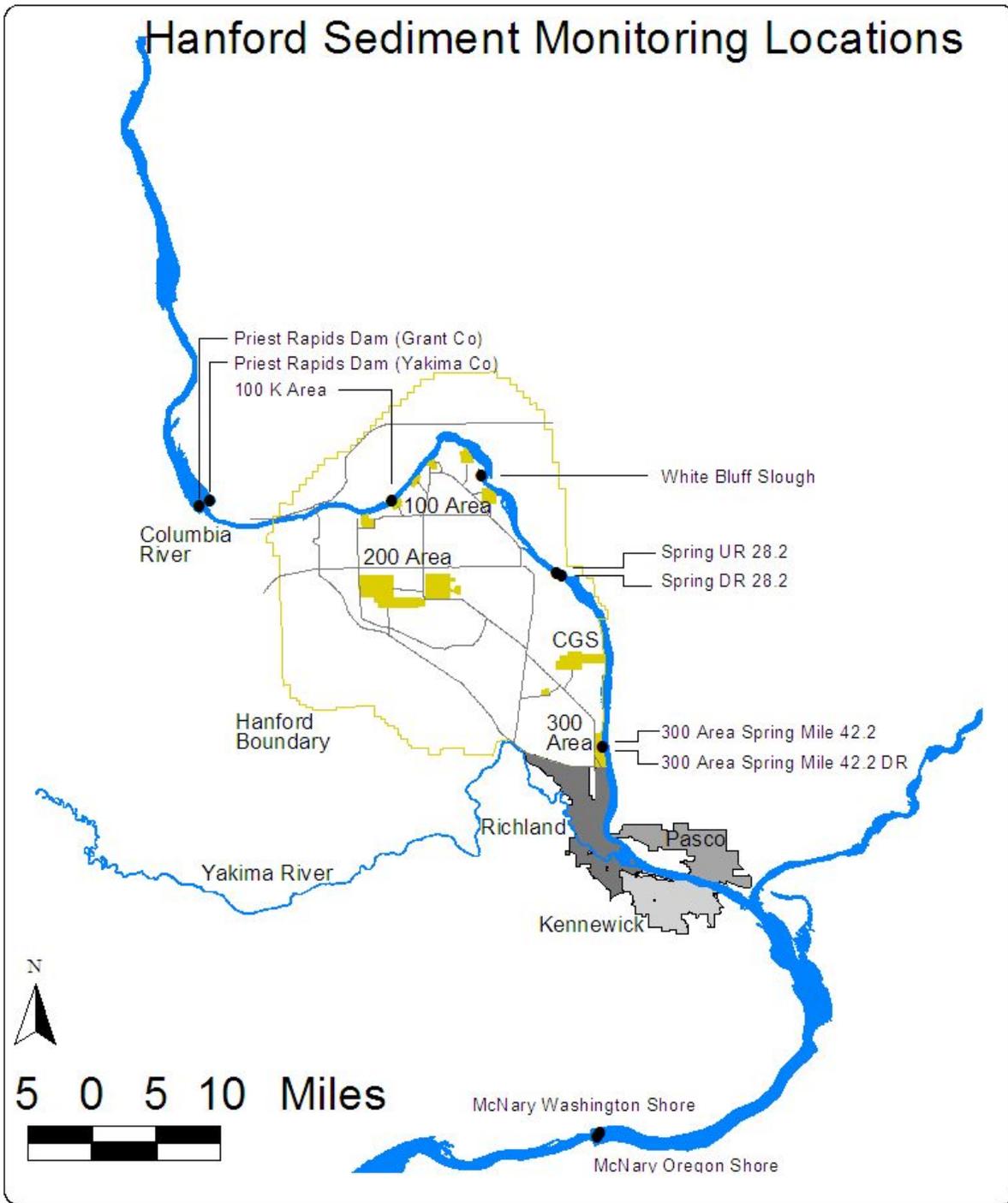
Figure 3.4.1    Historical Sediment Monitoring Locations
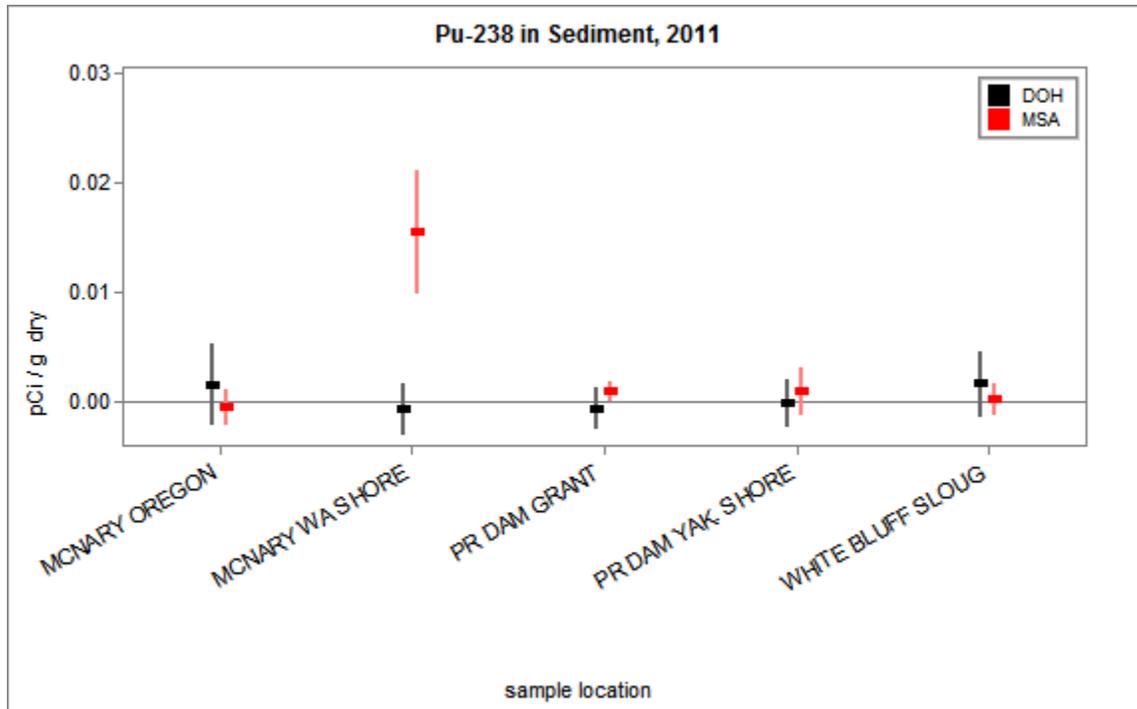
Figure 3.4.2  DOH and MSA Pu-238 Concentrations in Sediment

### 3.5 Farm Products Monitoring

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Major Findings:

- The DOH and DOE contractor concentrations for Sr-90 and gamma emitting radionuclides are all in good agreement.
- All DOH concentrations are below detection limits, and all concentrations are consistent with historical results.

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### 3.5.1 Purpose and General Discussion

The Department of Health and DOE contractors monitor farm products grown in Washington State; i.e., food and wine, to determine if contamination has migrated to plants that may be consumed by people.

### 3.5.2 Sample Types and Monitoring Locations

Farm product monitoring for the oversight program included four cherry samples, two leafy vegetable samples, three potato samples, and six wine samples.

All of the farm products were collected at locations which are nearby, but off-site of the Hanford Reservation. Samples are generally collected from farms located in the areas of Riverview, Sagemoor, Horn Rapids, East Wahluke, Ringold, Mattawa, Sunnyside, Yakima Valley, and the Columbia Valley.

### 3.5.3 Monitoring Procedures

Farm product samples are collected by the DOE contractor (MSA in 2011) and then split with DOH. Samples are generally collected once a year, at a time when the products are being harvested.

Fruits and vegetable samples are analyzed for Sr-90 and gamma emitting radionuclides, which include Co-60, Cs-134, Cs-137, Eu-152, Eu-154, Eu-155, Ru-106, and Sb-125. DOH reports Co-60 and Cs-137 results whether they are detectable or not, whereas the remaining gamma emitting radionuclides are only reported if they are detectable. Concentrations are reported in units of pCi/g (wet weight).

Wine is analyzed for gamma emitting radionuclides and tritium (H-3), and the concentrations are reported in units of pCi/L.

### 3.5.4   Comparison of DOH and DOE Contractor Data

Tables 3.5.1 and 3.5.2 summarize the comparison of DOH and DOE contractor data. Section 2.2 discusses the methods for comparing split or collocated data. The table lists the analytes, the collection period, and the number of split samples. The table also lists the quality of agreement for the split samples (see Section 2.2.4.1) and the range of concentrations measured by DOH. Finally, the "Anomalous Data ?" column denotes whether any of the DOH concentrations for the current year are anomalous compared to historical results (see Section 2.2.5).

The text following the table discusses cases in which 1) the agreement between DOH and DOE data is not good (i.e. is fair or poor), and 2) some of the DOH data are anomalous compared to historical results. A value for the "DOH Data Range" prefaced by the "less than" symbol (<) indicates that some or all DOH results are less than the listed detection limit.

| Analyte | Collection Period | # Split Samples | Agreement | DOH Data Range (pCi/g) | Anomalous Data ? |
|---------|-------------------|-----------------|-----------|------------------------|------------------|
| Co-60   | annual            | 9               | good      | < 0.01                 | no               |
| Cs-137  | annual            | 9               | good      | < 0.01                 | no               |
| Sr-90   | annual            | 7               | good      | < 0.005                | no               |

Table 3.5.1      Summary of Split Solid Farm Product Samples

| Analyte | Collection Period | # Split Samples | Agreement | DOH Data Range (pCi/L) | Anomalous Data ? |
|---------|-------------------|-----------------|-----------|------------------------|------------------|
| Co-60   | annual            | 6               | good      | < 7                    | no               |
| Cs-137  | annual            | 6               | good      | < 7                    | no               |
| Sr-90   | annual            | 6               | good      | < 100                  | no               |

Table 3.5.2      Summary of Split Wine Samples

All of the DOH and PNNL farm product concentrations are in good agreement. All of the DOH concentrations are below the DOH detection limit.

### 3.5.5      Other Discussion

DOH occasionally detects small concentrations of Sr-90 in farm products, with historical concentrations ranging from 0 to 0.1 pCi/g; however, all results in 2011 were below detection limits.

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**3.6**     **Fish and Wildlife Monitoring**

Major Findings:

- DOH and DOE contractor concentrations of Sr-90 and gamma emitting radionuclides are in good agreement.
- Concentrations of gamma emitting radionuclides are below detection limits, and concentrations of Sr-90 are consistent with those from background locations.

**3.6.1**     **Purpose and General Discussion**

DOH and DOE contractors monitor fish and wildlife to determine if contaminants have migrated into the food chain. Contaminants in fish arise from exposure to contaminated water, sediment, and aquatic biota. Contaminants in wildlife arise from ingestion of contaminated soil, vegetation, and water.

**3.6.2**     **Sample Types and Monitoring Locations**

Two collocated fish samples were collected from the Columbia River. A whitefish was collected from the area between Hanford's 100N and 100D areas, and a bass was collected adjacent to Hanford's 300 Area.

The oversight program did not collect collocated or split wildlife samples in 2011.

Strontium-90 results for fish and wildlife samples collected in 2010 were not available at publication time for the Oversight Program 2010 Data Summary Report (DOH 320-054). For 2010, three collocated fish samples were collected from the Columbia River; one from Hanford's 100N Area, one from Hanford's 300 Area, and one from a background location adjacent to the city of Vantage. Three split deer samples were collected; one from Hanford's 100N Area, and one from each background location in Olympia, WA and Winthrop, WA. Two split game bird samples were collected; one from Hanford's 100F/100H Area and one from a background location near Benton City, WA. The results of these samples are included in the analysis of Section 3.6.4 below.

**3.6.3**     **Monitoring Procedures**

For fish sampling, the DOE contractor (MSA in 2011) collects multiple samples at each location, one or more of which are analyzed by the contractor, and one analyzed by DOH. As such, fish results are from collocated samples, as opposed to split samples of the same fish. Since there is no control over the life history of the collocated fish, including their exposure to contaminants, differences in the DOH and PNNL results are expected.

Wildlife samples are collected by the DOE contractor. However, no wildlife samples were split with DOH in 2011.

Carcass and bone samples are analyzed for Sr-90, as this radionuclide accumulates in the bone, not the meat. Meat samples are analyzed for gamma emitting radionuclides, which include Co-60, Cs-134, Cs-137, Eu-152, Eu-154, Eu-155, Ru-106, and Sb-125. DOH reports Co-60 and Cs-137 results whether they are detectable or not, whereas the remaining gamma emitting radionuclides are only reported if they are detectable. Concentrations are reported in units of pCi/g (dry weight). Note that analysis for all radionuclides is not carried out at every sample location.

### 3.6.4    Comparison of DOH and DOE Contractor Data

Table 3.6.1 summarizes the comparison of DOH and DOE contractor data. Section 2.2 discusses the methods for comparing split or collocated data. The table lists the analytes, the collection period, and the number of split or collocated samples. The table also lists the quality of agreement for the collocated samples (see Section 2.2.4.1) and the range of concentrations measured by DOH. Finally, the "Anomalous Data ?" column denotes whether any of the DOH concentrations for the current year are anomalous compared to historical results (see Section 2.2.5).

The text following the table discusses cases in which 1) the agreement between DOH and DOE data is not good (i.e. is fair or poor), and 2) some of the DOH data are anomalous compared to historical results. A value for the "DOH Data Range" prefaced by the "less than" symbol (<) indicates that some or all DOH results are less than the listed detection limit.

The comparison of Sr-90 results includes samples collected both in 2010 and 2011.

| Analyte | Collection Period | # Collocated/Split Samples | Agreement | DOH Data Range (pCi/g) | Anomalous Data ? |
|---------|-------------------|----------------------------|-----------|------------------------|------------------|
| Co-60   | annual            | 2                          | good      | < 0.015                | no               |
| Cs-137  | annual            | 2                          | good      | < 0.015                | no               |
| Sr-90   | annual            | 8                          | good      | 0.014 to 1.4           | no               |

Table 3.6.1    Summary of Collocated Fish Samples

All of the DOH and DOE contractor results are in good agreement. Concentrations of gamma emitting radionuclides are below the detection limits, and concentrations of Sr-90 are consistent with historical data.

### 3.6.5    Other Discussion

Based on analysis of historical fish and wildlife samples collected at background locations not influenced by the Hanford Site, the Sr-90 concentrations in the 2010 and 2011 samples are most likely due to fallout from atmospheric weapons testing. Historical concentrations at background locations range from 0.02 to 2.8 pCi/g.

## 3.7    Vegetation Monitoring

Major Findings:

- DOH and DOE contractor concentrations of Sr-90 and gamma emitting radionuclides are in good agreement.
- All DOH concentrations are within the range of historical results and are consistent with concentrations from background locations.

### 3.7.1    Purpose and General Discussion

DOH and DOE contractors monitor vegetation to evaluate contaminants that are incorporated into plants, that in turn may be consumed by animals and potentially reach the public. Contaminants in vegetation primarily arise from airborne deposition, soil to plant transfer, and water to plant transfer.

Strontium-90 and isotopes of uranium are often detected in vegetation samples. In addition to the possibility that these radionuclides originate from Hanford-related contamination, Sr-90 is a product of fallout from atmospheric weapons testing, and uranium exists naturally in soil.

### 3.7.2    Sample Types and Monitoring Locations

Vegetation is typically collected from locations that could potentially be affected by contaminants from Hanford Site operations, as well as from background locations. The map in Figure 3.7.1 shows the vegetation sample locations for 2011, which include farms in the Horn Rapids and Riverview areas.

### 3.7.3    Monitoring Procedures

Vegetation samples are typically collected in late spring, and then split with the DOE contractor (historically with PNNL, currently with MSA). DOH and the DOE contractor independently analyze the samples. Samples are typically analyzed for Sr-90 and gamma emitting radionuclides, which include Co-60, Cs-134, Cs-137, Eu-152, Eu-154, Eu-155, Ru-106, and Sb-125. DOH reports Co-60 and Cs-137 results whether they are detectable or not, whereas the remaining gamma emitting radionuclides are only reported if they are detectable. Concentrations are reported in units of pCi/g (dry weight). Historically, the monitoring program also reported concentrations of uranium isotopes in vegetation, but this is no longer standard.

### 3.7.4　　　Comparison of DOH and DOE Contractor Data

Table 3.7.1 summarizes the comparison of DOH and DOE contractor data. Section 2.2 discusses the methods for comparing split or collocated data. The table lists the analytes, the collection period, and the number of split samples. The table also lists the quality of agreement for the split samples (see Section 2.2.4.1), and the range of concentrations measured by DOH. Finally, the "Anomalous Data ?" column denotes whether any of the DOH concentrations for the current year are anomalous compared to historical results (see Section 2.2.5).

The text following the table discusses cases in which 1) the agreement between DOH and DOE data is not good (i.e. is fair or poor), and 2) some of the DOH data are anomalous compared to historical results. A value for the "DOH Data Range" prefaced by the "less than" symbol (<) indicates that some or all DOH results are less than the listed detection limit.

| Analyte | Collection Period | # Split Samples | Agreement | DOH Data Range (pCi/g) | Anomalous Data ? |
|---------|-------------------|-----------------|-----------|------------------------|------------------|
| Co-60 | annual | 2 | good | < 0.02 | no |
| Cs-137 | annual | 2 | good | < 0.02 | no |
| Sr-90 | annual | 2 | good | 0.05 to 0.11 | no |

Table 3.7.1　　　Summary of Split Vegetation Samples

Historically, gamma emitting radionuclides are not detected in vegetation samples, and Sr-90 concentrations are found in the range from <0.02 pCi/g to 0.2 pCi/g. The concentrations for the samples collected in 2011 are consistent with historical results.

### 3.7.5　　　Other Discussion

Based on analysis of historical vegetation samples collected at background locations not influenced by the Hanford Site, the Sr-90 concentrations in the vegetation samples at Horn Rapids and Riverview are most likely due to fallout from atmospheric weapons testing.
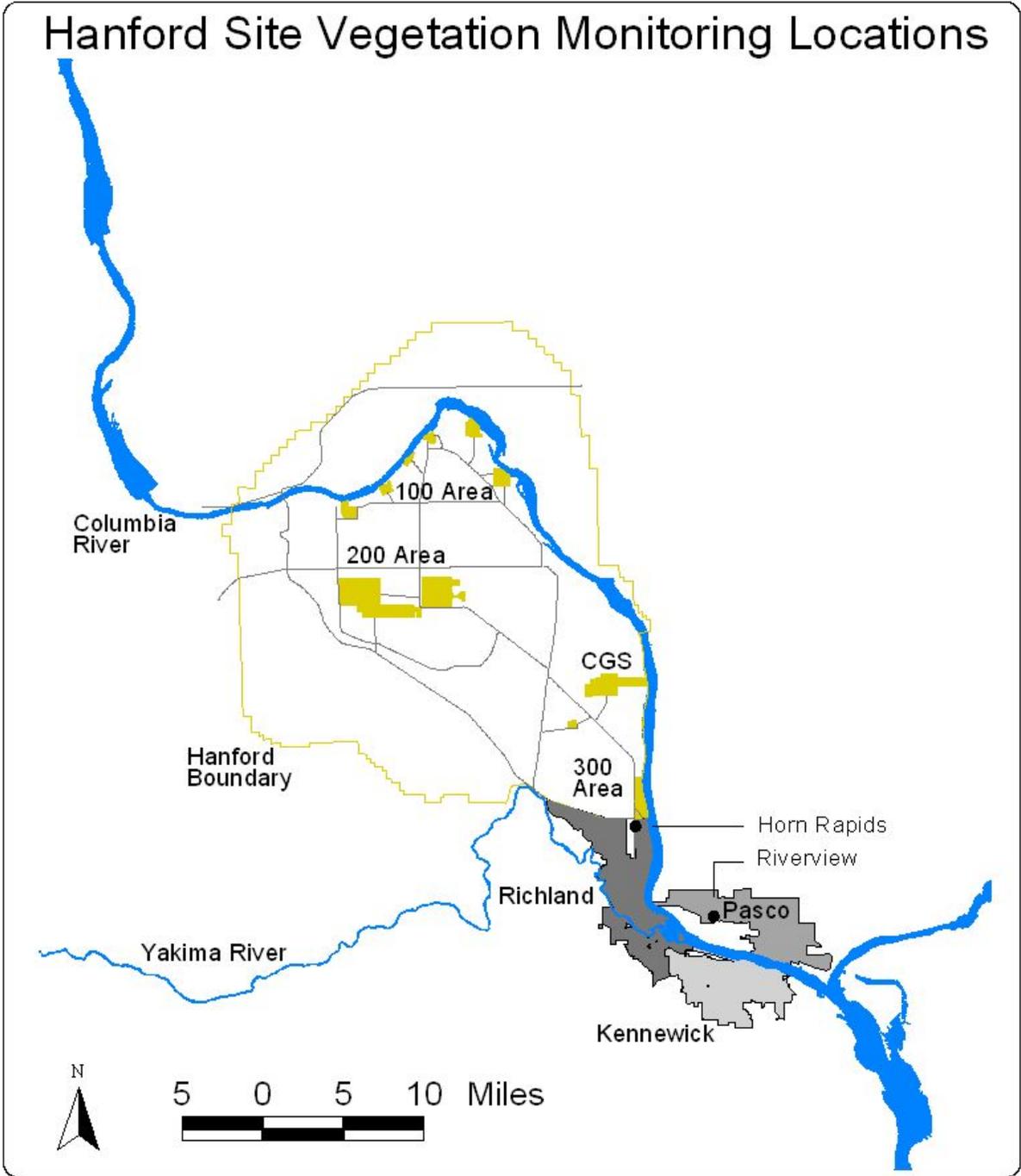
Figure 3.7.1    Vegetation Monitoring Locations

## 4.    Summary of Evaluation of DOH and DOE Contractor Results

The agreement between DOH and DOE contractor results is qualitatively described with the categories of *good*, *fair*, and *poor*. This section summarizes all data described as fair or poor.

The DOH and DOE gross alpha concentrations in biweekly air samples are in fair agreement. The collocated concentrations are similar and follow the same temporal trend at each of the monitoring locations, but many of the uncertainty bars do not overlap. This discrepancy is seen throughout historical data.

The DOH and DOE gross beta concentrations in biweekly air samples are in fair agreement. The collocated concentrations are similar and follow the same temporal trends. However, differences in concentration up to a factor of two are common, and there is a small systematic discrepancy between the two data sets in which DOE often reports slightly higher values than DOH. This discrepancy is seen throughout historical data.

The DOH and DOE H-3 concentrations in monthly air samples are in poor agreement. The two data sets are similar and follow the same temporal trend at each of the monitoring locations. However, many of the uncertainty bars do not overlap, and differences in concentration up to a factor of five occur. The discrepancy is not understood at this time, and is under investigation.

The DOH and DOE isotopic uranium concentrations in quarterly composite air samples are in fair agreement. The data generally follow the same trends; however, concentrations that differ by a factor of two are common. This discrepancy is seen throughout historical data.

The DOH and DOE Cs-137 concentrations in semiannual composite air samples are in fair agreement. The two data sets are similar, with most results below or only slightly above the detection limits. However, in cases where the isotope is detected, the uncertainty bars do not overlap. A systematic bias has been historically observed in which DOE on average reports concentrations approximately 60% lower than those reported by DOH.

The DOH and DOE contractor C-14 concentrations in water samples, all of which are groundwater, are in poor agreement. The discrepancy is not understood at this time, and is under investigation.

The DOH and DOE contractor H-3 concentrations in water samples are in fair agreement. The data follow the same trend; however, the DOH concentrations are consistently higher than those reported by DOE. Historically, the H-3 data are in good agreement. The disagreement of the data in 2010 and 2011 is anomalous.

Historically, the DOH and DOE contractor split I-129 results in water samples, most of which are groundwater, were in poor agreement. The agreement is fair for this reporting period, as the results are similar and follow the same trend. There remains a systematic bias, however, in which DOE consistently reports higher concentrations of this radionuclide than DOH.

Three problems have been previously identified with regard to the I-129 comparison. First, for samples in which I-129 is detected, DOH typically reports concentrations significantly lower than those reported by DOE. Secondly and perhaps related to the first problem, for samples in which I-129 is not detected, DOH reports a disproportionate number of negative results, more so than statistically expected. This suggests a negative bias in the DOH measurement process. Thirdly, some DOE results are reported at concentrations greater than the sample's minimum detectable activity (MDA), although the results are tagged as not detectable.

DOH has systematically investigated aspects of its I-129 measurement process with the potential to contribute to the differences noted. These investigations were initiated in 2006 and will continue until the issue is resolved. DOH will continue to document the process in this report.

The first step, which has been completed, was to review the DOH sampling, preservation, and shipment procedures. DOH identified potential sources of error with sample containers, preservation, sample holding times, and detector calibration. The detector calibration was investigated, and while some bias cannot be ruled out, has been determined to be too small to contribute meaningfully to the discrepancies observed in the split sample results.

For the second step, DOH reviewed sample collection practices and tested a revised sample collection procedure in 2009 that more immediately addresses sample preparation. In this procedure, iodine is converted to a more stable chemical form as soon as possible after sample collection. Previously, the collection practice called for samples to be acidified in the field or upon receipt at the laboratory. At the laboratory, a portion of the sample was pH neutralized and the I-129 was concentrated using an anion-exchange resin material with high specificity for I-129. This portion was taken after all other analyses were completed to ensure that sufficient sample was available for those tests. The problem with this collection practice is that the acid addition, which is good for keeping most radionuclides in solution, causes iodine to volatilize. Furthermore, iodine is strongly adsorbed by plastics, so that some quantity is likely lost to the walls of the container during transport and holding. Converting the iodine to a more stable chemical form and then trapping the iodine on ion-exchange resin as soon as the sample is collected minimizes these loss mechanisms. This work has also been completed.

In 2010, DOH conducted a set of experiments to evaluate the extent to which sample collection procedures and holding times have contributed to reported result bias in historic samples. These results have been completed and the data are currently being analyzed by DOH. Results of this study will be used to guide interpretation of historical results.

The third step in resolving the I-129 question is to target several groundwater wells with historically elevated concentrations of I-129 for split sample collection and analysis. This work, which is currently underway, will provide results over a wider range of activity with which to evaluate the degree to which the changes in DOH's measurement process have affected the observed bias between DOH and the DOE contractors.

Lastly, DOH will review the DOE contractor's laboratory procedures for I-129 analysis in an effort to identify any remaining differences between the DOH and DOE measurement processes. The findings will be discussed in future reports.

Historically, most DOH and DOE isotopic uranium concentrations in water samples are in good agreement. However, for this reporting period, DOH detected anomalously high concentrations of uranium isotopes from one groundwater well in the 300 Area. The DOH result was an order of magnitude greater than had been observed in the past. The DOE results did not confirm the high concentrations measured by DOH, as they were consistent with historical results. Upon investigation, DOE determined their original result was in error. The revised uranium concentration measured at well 399-1-17A was consistent with the DOH result.

DOE believes the spike in uranium levels was caused by remobilization of uranium in soil by the unusually high water table elevation. Uranium concentrations measured at the same well returned to normal values in 2012.

The DOH and DOE contractor external radiation dose rates, as measured with TLDs, are in fair agreement. The results generally follow the same trend, and the first and fourth quarter results are in good agreement. However, a systematic bias is observed for third quarter results, in which DOH reports concentrations slightly lower than those reported by DOE. The bias is also observed to a smaller degree for second quarter results. Inspection of the data suggests a seasonal influence on the DOH concentrations, which are lower in the heat of summer. This discrepancy is seen throughout historical data.

The DOH and DOE Pu-238 concentrations in sediment are in fair agreement. Historically, Pu-238 concentrations in sediment are below detection limits. This was the case in 2011 for the concentrations reported by DOH; however, DOE reported a positive detected concentration in a sediment sample from McNary Dam.

All discrepancies are under investigation, and findings will be discussed in future annual reports as issues are resolved.

## 5.    Special Events

Fukushima Daiichi Nuclear Plant Accident

This annual report spans the timeline of the catastrophic nuclear power plant accident that occurred in Japan. Washington State Department of Health's (DOH) environmental monitoring program provided a means to assess the public's health and ensure that it was not in danger. DOH monitored radioactive contaminants transported via air currents and later through the marine environment. The assessment included analysis of air, milk, rainwater, vegetation, shellfish, and fish.

On March 11, 2011, a 9.0 magnitude earthquake occurred off the eastern coast of Japan. This powerful earthquake triggered a tsunami which swept over the coast, causing loss of life and destruction of property. At the Fukushima Daiichi Nuclear Power Plant complex, the earthquake triggered automatic emergency actions to shut down the three operating nuclear reactors, Reactors 1, 2, and 3. Reactor 4 had been de-fueled and two others, Reactors 5 and 6, had already been shut down for routine maintenance.

Under emergency conditions, generators are brought online to provide power to critical emergency equipment, including pumps to provide reactor coolant water. These generators failed when the tsunami's 40-foot high wall of water washed over the complex and flooded the rooms where the generators were located. Without the generators providing power to circulate water needed to cool the reactors, the reactor cores overheated and fuel rods melted. Reactors 1, 2, and 3 experienced a full meltdown.

The high heat and pressure in the core caused a chemical reaction between the melting fuel rods and the residual water, producing explosive hydrogen gas. The hydrogen gas collected in the outer containment buildings and caused several explosions. These explosions and the intentional venting of gases to prevent further explosions released radioactive gases and particulates into the air. Air currents carried these contaminants away from the complex and across the Pacific Ocean.

Seawater was eventually used to cool the cores of Reactors 1, 2, and 3, but by the time it was applied, the cores had completely melted. Seawater used to flood the reactors washed radioactive contamination into the marine environment.

Upon learning of the earthquake and tsunami, DOH deployed environmental air samplers in Olympia and Seattle. These new samplers, along with continuous air monitoring on and near the U.S. Department of Energy Hanford Site, enabled DOH to monitor air quality across the state and determine that the temporarily increased concentrations of radioactivity in air were not due to Hanford activities.

All air monitoring results showed trace amounts of radiation, but not at harmful levels. Figure 5.1 shows iodine 131 concentrations in air measured by DOH in Seattle and Richland and by Columbia Generating Station (CGS) near Richland. Radioactivity peaked one week after the earthquake and tsunami, then quickly decreased followed by a smaller increase, and finally returned to pre-event levels. These air results in Washington State correspond to the

timing of releases at the reactor due to hydrogen explosions and gas venting. Increased concentrations of gross beta, gamma emitting radionuclides, and I-131 were found in Washington State air samples.

Many citizens were concerned about the safety of drinking water. The Columbia River is the source of drinking water for most people living near Hanford. In some parts of the state, people collect rainwater as their drinking water source. Therefore, DOH sampled both Columbia River water and rainwater. Rainwater, which can scavenge radioactive particulates from the air, showed radioactivity levels with a temporal pattern similar to that of I-131 in air (Figure 5.2), where concentrations returned to pre-Fukushima levels in a short time. No elevated radioactivity was found in Columbia River water. Trace radioactivity was also measured in milk and vegetation samples during the same timeframe; and, as with air and rain, concentrations returned to pre-accident levels quickly. At no time were the radiation readings in Washington State at harmful levels.

Other environmental monitoring groups offered their support during DOH's assessment of the Fukushima accident. The University of Washington (UW) Physics Department provided large volume air samplers allowing detection of more radionuclides than what could be seen with a small volume of air. The UW Atmospheric Sciences Department shared air particulate samples collected from the summit of Mt. Bachelor, helping DOH understand how the air was moving from Japan to Washington. The nuclear power plant in Washington, Columbia Generating Station, added air and rainwater sampling to its routine monitoring. Monitoring results from the USDOE contractors at Hanford was likewise shared. The results of the latter are presented as part of our split sample analysis in other parts of this report.

More monitoring data related to Fukushima were available to DOH from the U.S. Environmental Protection Agency's (EPA) environmental radiation ambient monitoring system. A link to EPA's nationwide network, RadNet, for sampling air, rain, and milk, can be found at http://www.epa.gov/radnet/.

The Fukushima accident was classified a Level 7 Nuclear and Radiological Event because it caused a major release of radiation and had widespread health and environmental effects in Japan. Results from our augmented and routine monitoring programs, along with data shared by other monitoring groups, provided a basis to determine that the public's health was not harmed by the low levels of contamination in Washington State. Additionally, the data collected by DOH and other scientists determined that temporary increases in radiation levels were due to events in Japan and not from operations at the Hanford Site.
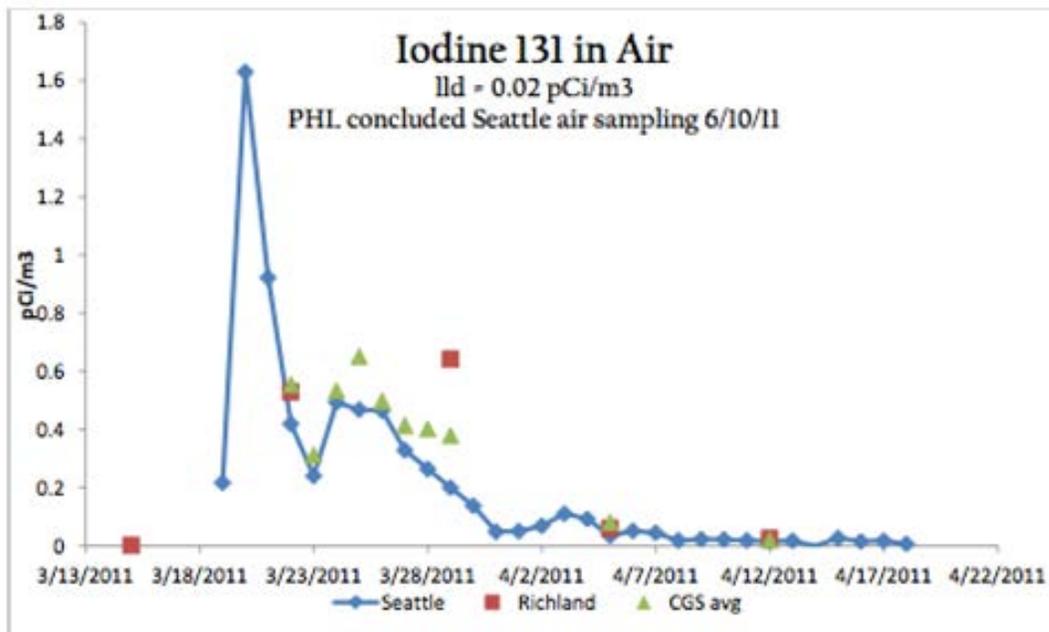
Figure 5.1     Iodine 131 in Air
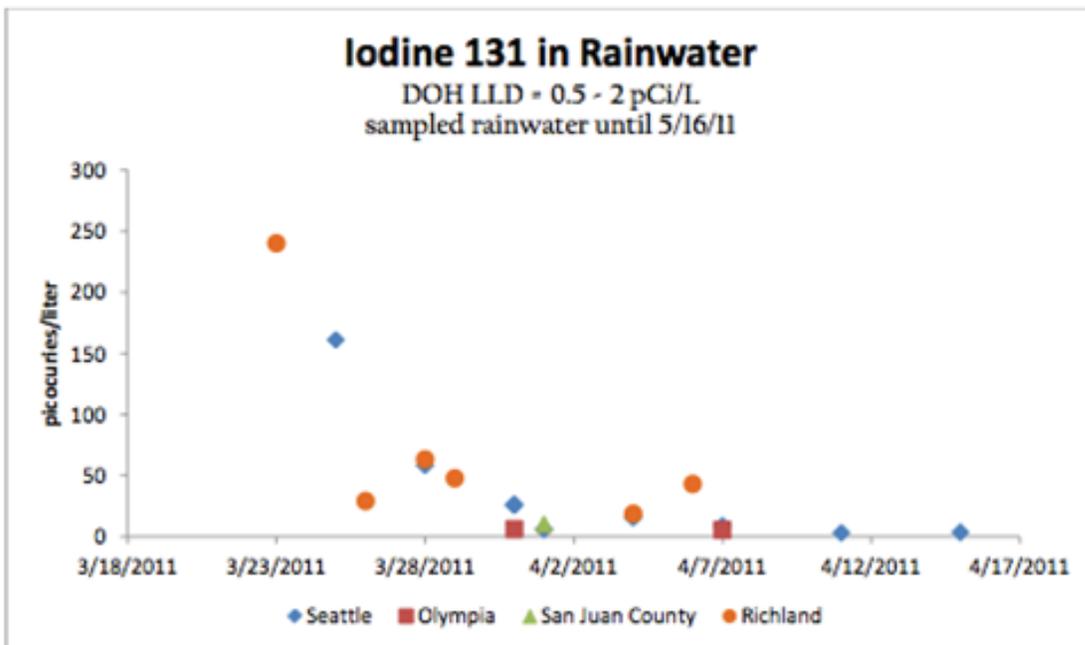


Figure 5.2     Iodine 131 in Rainwater

# Appendix A - Radiation Tutorial

A.1     Radiation and Radioactivity

Radioactivity from natural sources is found throughout nature, including in air, water, soil, within the human body, and animals. Naturally occurring radioactivity originates from the decay of primordial terrestrial sources such as uranium and thorium. Other sources are continually produced in the upper atmosphere through interactions of atoms with cosmic rays. These naturally occurring sources of radiation produce the background levels of radiation to which humans are unavoidably exposed.

Radioactivity is the name given to the phenomenon of matter emitting ionizing radiation. Radiation emitted from the nucleus of an atom is termed nuclear radiation. Atoms that emit radiation are termed *radioactive*. The three most common types of radiation are:

- Alpha – A particle consisting of two protons and two neutrons emitted from the nucleus of an atom. These charged particles lose their energy very rapidly in matter and are easily shielded by small amounts of material, such as a sheet of paper or the surface layer of skin. Alpha particles are only hazardous when they are internally deposited.

- Beta – An electron emitted from the nucleus of an atom. These charged particles lose their energy rapidly in matter, although less so than alpha radiation. Beta radiation is easily shielded by thin layers of metal or plastic. Beta particles are generally only hazardous when they are internally deposited.

- Gamma – Electromagnetic radiation, or photons, emitted from the nucleus of an atom. Gamma radiation is best shielded by thick layers of lead or steel. Gamma energy may cause an external or internal radiation hazard. (X-rays are similar to gamma radiation but originate from the outer shell of the atom instead of the nucleus.)

In the past century, exposure of people to radiation has been influenced by the use and manufacture of radioactive materials. Such uses of radioactive materials include the healing arts, uranium mining and milling operations, nuclear power generation, nuclear weapons manufacturing and testing, and storage and disposal of nuclear wastes. Radiation levels were most altered by residual fallout from nuclear weapons testing.
The United States ceased atmospheric testing following adoption of the 1963 Nuclear Test Ban Treaty, and exposure has been decreasing since then.

*Radioisotope* and *radionuclide* are interchangeable terms used to refer to radioactive isotopes of an element. An element is delineated by its chemical name followed by its atomic number, which is the sum of its number of protons and neutrons. For example, carbon-12, which is the most naturally abundant form of carbon, consists of six protons and six neutrons for a total of twelve. Carbon-13 and carbon-14, which consist of six protons and seven and eight neutrons respectively, are also found in nature. These forms of carbon are called isotopes of carbon.

If an isotope is radioactive it is called a radioisotope. In the example given, carbon-12 and carbon-13 are non-radioactive isotopes of carbon. Carbon-14 is radioactive, and is therefore a radioisotope of carbon.

All radioisotopes will eventually decay, by emitting radiation, and will become non-radioactive isotopes. For example, carbon-14 decays to nitrogen-14. An important property of any radioisotope is the half-life. Half-life is the amount of time it takes for a quantity of any radioisotope to decay to one-half of its original quantity.

In the example above, carbon-14 has a half-life of 5,730 years. Thus, one gram of pure carbon-14 would transform into 1/2 gram of carbon-14 and 1/2 gram of nitrogen-14 after 5,730 years. After another 5,730 years, for a total of 11,460 years, 1/4 gram of carbon-14 and 3/4 grams of nitrogen-14 would remain. This decay process would continue indefinitely until all of the carbon-14 had decayed to nitrogen-14.

Heavier radioisotopes often decay to another radioisotope, which decays to another radioisotope, and so on until the decay process culminates in a non-radioactive isotope. This sequence of decays is called a decay chain. Each of the isotopes produced by these decays is called a decay product. For example, uranium-238 decays to thorium-234, which decays to protactinium-234, and so on, until the decay chain ends with non-radioactive lead-206.

A.2     Radiological Units and Measurement

From the perspective of human health, exposure to radiation is quantified in terms of radiation dose. Radiation dose measures the amount of energy deposited in biological tissues. Commonly, units of the roentgen, rad, and rem are used interchangeably to quantify the radiation energy absorbed by the body. The international scientific units (SI) for rad and rem are gray and sievert, respectively. There is no SI unit for roentgen.

The roentgen is a measure of radiation exposure in air, rad is a measure of energy absorbed per mass of material, and rem is a unit that relates radiation exposure to biological effects in humans. See the glossary (Appendix D) for more complete definitions of these terms.

The quantity of radioactivity in material is measured in curies. A curie (Ci) is a quantity of any radionuclide that undergoes an average transformation rate of 37 billion transformations per second. One curie is the approximate activity of 1 gram of radium. The SI unit for activity is the becquerel which is equal to one disintegration per second.

Human radiation doses are expressed in units of rems or seiverts. Since radiation doses are often small, units of millirem (mrem) or milliseivert (mSv) are commonly used. A mrem is one-thousandth of a rem. Table A.1 shows the average annual dose for the United States from both natural and artificial sources. Natural sources account for 82% of the annual dose to the U.S. population, with radon being the dominant natural dose contributor at 55%.

| Source | | Dose (mrem/yr) | Dose (mSv/yr) | Percent of Total |
|---|---|---|---|---|
| Natural | Radon | 200 | 2.0 | 55 |
| | Cosmic | 27 | 0.27 | 8 |
| | Terrestrial | 28 | 0.28 | 8 |
| | Internal | 39 | 0.39 | 11 |
| | Total Natural | 300 | 3 | 82% |
| Artificial | Medical X-Ray | 39 | 0.39 | 11 |
| | Nuclear Medicine | 14 | 0.14 | 4 |
| | Consumer Products | 10 | 0.1 | 3 |
| | Total Artificial | 63 | 0.63 | 18% |
| Other | Occupational | 0.9 | < 0.01 | < 0.3 |
| | Nuclear Fuel Cycle | < 1 | < 0.01 | < 0.03 |
| | Fallout | < 1 | < 0.01 | < 0.03 |
| | Miscellaneous | < 1 | < 0.01 | < 0.03 |
| | Grand Total | 363 | 3.63 | 100% |

Table A.1    Annual Effective Dose Equivalent (NCRP 93)

It is well established that very high radiation doses, in the neighborhood of 300,000 to 500,000 mrem, are fatal. At lower, but still high doses (above approximately 20,000 mrem), the primary biological impact is an increased risk of cancer.

The health effects of radiation are substantially better known than those of most other carcinogens because, in addition to animal data, there is a wealth of human data. However, virtually all the evidence on the harmful effects of radiation comes from observations of the effects from high doses or high dose rates. The primary source of information on the health effects of radiation comes from studies of the survivors of the Japanese atomic bombings. Other sources include radiation accidents, occupational exposures, and medical exposures.

Most exposures to radiation workers and the general public, however, involve low doses; i.e., lifetime doses of less than approximately 20,000 mrem above natural background. The health effects of exposure to low doses of radiation are too small to unambiguously measure. In the absence of direct evidence of the harmful effects of radiation at low doses, estimates of health effects are made by extrapolation from observations at high doses. There is much controversy and disagreement about the procedure for such an extrapolation. The conventional procedure traditionally has hypothesized a linear extrapolation of the high dose health effects data to a point of zero dose, zero risk.

Typically, radiation doses associated with exposure to environmental contamination are very small, and the health effects from these exposures are not known with a reasonable degree of certainty.

## Appendix B - Laboratory a priori Lower Limits of Detection

Air Cartridge (pCi/m$^3$)

|  | Nuclide | Volume (m$^3$) | Method* | Standard LLD (100 min.) |
|---|---|---|---|---|
| Gamma | I-131* | 450 | INGe | 2.00E-02 |

Air Filter (pCi/m$^3$)

|  | Nuclide | Volume (m$^3$) | Method | Standard LLD (100 min.) |
|---|---|---|---|---|
| Beta | Gross | 450 | $\alpha\beta$ Cntr | 1.00E-03 |

Quarterly Composite Air Filter (pCi/m$^3$)

|  | Nuclide | Volume (m$^3$) | Method | Standard LLD (400 min.) |
|---|---|---|---|---|
| Gamma | Be-7 | 5200 | INGe | 8.00E-02 |
|  | Co-60 | 5200 | INGe | 1.00E-03 |
|  | Cs-134 | 5200 | INGe | 2.00E-03 |
|  | Cs-137 | 5200 | INGe | 1.00E-03 |

|  | Nuclide | Volume (m$^3$) | Method | Standard LLD (1000 min.) |
|---|---|---|---|---|
| Alpha | Nat U | 5200 | Alpha Spec | 2.50E-05 |
|  | U-234 | 5200 | Alpha Spec | 2.50E-05 |
|  | U-235 | 5200 | Alpha Spec | 1.00E-05 |
|  | U-238 | 5200 | Alpha Spec | 2.50E-05 |

Semi-Annual Composite Air Filter (pCi/m$^3$)

|  | Nuclide | Volume (m$^3$) | Method | Standard LLD (400 min.) |
|---|---|---|---|---|
| Gamma | Be-7 | 10400 | INGe | 4.00E-02 |
|  | Co-60 | 10400 | INGe | 5.00E-04 |
|  | Cs-134 | 10400 | INGe | 1.00E-03 |
|  | Cs-137 | 10400 | INGe | 5.00E-04 |

Semi-Annual Composite Air Filter (pCi/m$^3$) Continued

|       | Nuclide    | Volume (m3) | Method     | Standard LLD (1000 min.) |
|-------|------------|-------------|------------|--------------------------|
| Alpha | Nat U      | 10400       | Alpha Spec | 1.25E-05                 |
|       | U-234      | 10400       | Alpha Spec | 1.25E-05                 |
|       | U-235      | 10400       | Alpha Spec | 5.00E-06                 |
|       | U-238      | 10400       | Alpha Spec | 1.25E-05                 |
|       | Pu-238     | 10400       | Alpha Spec | 5.00E-06                 |
|       | Pu-239/240 | 10400       | Alpha Spec | 5.00E-06                 |

Food (pCi/g)

|       | Nuclide  | Mass (g) | Method           | Standard LLD (1000 min.) |
|-------|----------|----------|------------------|--------------------------|
| Alpha | Nat U    | 20       | Alpha Spec       | 2.00E-03                 |
|       | U-234    | 20       | Alpha Spec       | 1.50E-02                 |
|       | U-235    | 20       | Alpha Spec       | 1.00E-03                 |
|       | U-238    | 20       | Alpha Spec       | 2.00E-03                 |
|       | Pu-238   | 20       | Alpha Spec       | 3.00E-03                 |
|       | Pu-239   | 20       | Alpha Spec       | 2.00E-03                 |
|       | Th-230   | 20       | Alpha Spec       | 5.00E-03                 |
|       | Th 232   | 20       | Alpha Spec       | 2.00E-03                 |
|       | Am-241   | 20       | Alpha Spec       | 2.00E-03                 |
|       | Ra – 226 | 20       | $\alpha\beta$ Cntr | 6.00E-04               |

Milk (pCi/L)

|       | Nuclide | Volume (L) | Method   | Standard LLD (400 min.) |
|-------|---------|------------|----------|-------------------------|
| Gamma | K-40    | 3          | INGe     | 3.00E+01                |
|       | I-131   | 3          | INGe     | 2.00E+00                |
|       | Cs-134  | 3          | INGe     | 2.00E+00                |
|       | Cs-137  | 3          | INGe     | 2.00E+00                |
|       | Ba-140  | 3          | INGe     | 9.00E+00                |

|       |       |   |          | Standard LLD (1000 min.) |
|-------|-------|---|----------|--------------------------|
|       | I-131 | 4 | IXR/INGe | 7.00E-01                 |

|      |       |   |                         | Standard LLD (100 min.) |
|------|-------|---|-------------------------|-------------------------|
| Beta | Sr-90 | 1 | Nitric Acid/ $\alpha\beta$ Cntr | 7.00E-01        |

Meat (pCi/g)

| | Nuclide | Mass (g) | Method | Standard LLD (1000 min.) |
|---|---|---|---|---|
| Gamma | K-40 | 400 | INGe | 1.40E-01 |
| | Mn-54 | 400 | INGe | 7.00E-03 |
| | Co-58 | 400 | INGe | 7.00E-03 |
| | Co-60 | 400 | INGe | 8.00E-03 |
| | Cs-137 | 400 | INGe | 6.00E-03 |
| | I-131 | 400 | INGe | 2.00E-02 |
| | Ra-226(DA) | 400 | INGe | 2.50E-01 |
| | Am-241(GA) | 400 | INGe | 2.00E-02 |
| | | | | |
| Alpha | Nat U | 10 | Alpha Spec | 4.00E-03 |
| | U-234 | 10 | Alpha Spec | 3.00E-03 |
| | U-235 | 10 | Alpha Spec | 2.00E-03 |
| | U-238 | 10 | Alpha Spec | 3.00E-03 |
| | Pu-238 | 10 | Alpha Spec | 5.00E-03 |
| | Pu-239 | 10 | Alpha Spec | 4.00E-03 |
| | Am-241 | 10 | Alpha Spec | 4.00E-03 |
| | | | | |
| Beta | Sr-90 (bone) | 5 | Nitric Acid/ $\alpha\beta$ Cntr | 2.00E-01 |

Shellfish (pCi/g)

| | Nuclide | Mass (g) | Method | Standard LLD (400 min.) |
|---|---|---|---|---|
| Gamma | I-131 | 400 | INGe | 6.00E-03 |
| | Co-60 | 400 | INGe | 6.00E-03 |
| | K-40 | 400 | INGe | 1.00E-01 |

Soil/Sediment (pCi/g)

| | Nuclide | Mass (g) | Method | Standard LLD (1000 min.) |
|---|---|---|---|---|
| Alpha | Nat U | 1 | Alpha Spec | 4.00E-02 |
| | U-234 | 1 | Alpha Spec | 3.00E-02 |
| | U-235 | 1 | Alpha Spec | 2.00E-02 |
| | U-238 | 1 | Alpha Spec | 3.00E-02 |
| | Pu-238 | 10 | Alpha Spec | 5.00E-03 |
| | Pu-239 | 10 | Alpha Spec | 4.00E-03 |
| | Th-230 | 1 | Alpha Spec | 4.00E-02 |
| | Th 232 | 1 | Alpha Spec | 4.00E-02 |
| | Am-241 | 10 | Alpha Spec | 4.00E-03 |
| | Ra - 226 | 1 | $\alpha\beta$ Cntr | 1.00E-01 |
| | Ra-226(DA) | 600 | INGe | 2.00E-02 |

| | | | | Standard (100 min.) |
|---|---|---|---|---|
| Alpha | Gross | 0.1 | $\alpha\beta$ Cntr | 4.00E+01 |

| | | | | Standard LLD (1000 min.) |
|---|---|---|---|---|
| Gamma | K-40 | 600 | INGe | 1.50E-01 |
| | Mn-54 | 600 | INGe | 1.00E-02 |
| | Co-60 | 600 | INGe | 1.00E-02 |
| | Zn-65 | 600 | INGe | 2.00E-02 |
| | Zr-95 | 600 | INGe | 1.00E-02 |
| | Ru-103 | 600 | INGe | 1.50E-02 |
| | Ru-106 | 600 | INGe | 1.00E-02 |
| | Sb-125 | 600 | INGe | 2.00E-02 |
| | Cs-134 | 600 | INGe | 1.20E-02 |
| | Cs-137 | 600 | INGe | 1.50E-02 |
| | Ce-144 | 600 | INGe | 5.00E-02 |
| | Eu-152 | 600 | INGe | 1.50E-02 |
| | Eu-154 | 600 | INGe | 1.50E-02 |
| | Eu-155 | 600 | INGe | 2.00E-02 |
| | Ra-226(DA) | 600 | INGe | 1.00E-01 |
| | Am-241(GA) | 600 | INGe | 2.00E-02 |
| | Tot U(GA) | 600 | INGe | 2.00E-01 |

| | | | | Standard (100 min.) |
|---|---|---|---|---|
| Beta | Sr-90 | 150 | Nitric Acid/ | 1.80E-03 |
| | Tc-99 | 10 | 3M/LS | 2.00E-01 |

|  | Gross beta | 0.4 | $\alpha\beta$ Cntr | 1.50E+00 |

Vegetation (pCi/g except H-3 which is expressed as pCi/L)

|  | Nuclide | Mass (g) | Method | Standard LLD (1000 min.) |
|---|---|---|---|---|
| Alpha | Nat U | 10 | Alpha Spec. | 8.00E-03 |
|  | U-234 | 10 | Alpha Spec. | 6.00E-03 |
|  | U-238 | 10 | Alpha Spec. | 6.00E-03 |
|  | Pu-238 | 10 | Alpha Spec. | 5.00E-03 |
|  | Pu-239 | 10 | Alpha Spec. | 4.00E-03 |
|  | Am-241 | 10 | Alpha Spec. | 4.00E-03 |
|  |  |  |  |  |
| Gamma | K-40 | 100 | INGe | 3.00E-01 |
|  | Mn-54 | 100 | INGe | 4.00E-02 |
|  | Co-60 | 100 | INGe | 4.00E-02 |
|  | Zn-65 | 100 | INGe | 1.50E-01 |
|  | Zr-95 | 100 | INGe | 2.00E-01 |
|  | Ru-106 | 100 | INGe | 4.00E-01 |
|  | Cs-137 | 100 | INGe | 4.00E-02 |
|  | I-131 | 100 | INGe | 4.00E-02 |
|  | Am-241(GA) | 100 | INGe | 2.00E-01 |

|  | Nuclide | Mass (g) | Method | Standard LLD (100 min.) |
|---|---|---|---|---|
| Beta | Gross | 0.4 | $\alpha\beta$ Cntr | 1.50E+00 |
|  | Sr-90 | 20 | Nitric Acid/ $\alpha\beta$ Cntr | 5.00E-02 |
|  | Tc-99 | 5 | 3M/LS | 1.50E+00 |

|  | Nuclide | Volume (L) | Method | Standard LLD (200 min.) |
|---|---|---|---|---|
|  | C-14 | 0.0002 | Oxid/LS | 3.00E+02 |
|  | H-3 | 0.002 | LS | 5.00E+02 |

| Water (pCi/L) | | | | Standard LLD | Standard LLD |
|---|---|---|---|---|---|
| | Nuclide | Volume (L) | Method | (1000 min.) | (100 min.) |
| Alpha | Nat U | 0.5 | Alpha Spec | 1.30E-01 | |
| | U-234 | 0.5 | Alpha Spec | 8.00E-02 | |
| | U-235 | 0.5 | Alpha Spec | 6.00E-02 | |
| | U-238 | 0.5 | Alpha Spec | 8.00E-02 | |
| | Ra-226 | 0.5 | αβ Cntr | | 2.00E-01 |
| | Pu-238 | 0.5 | Alpha Spec | 8.00E-02 | |
| | Pu-239 | 0.5 | Alpha Spec | 6.10E-02 | |
| | Th-230 | 0.5 | Alpha Spec | 1.00E-01 | |
| | Th 232 | 0.5 | Alpha Spec | 1.00E-01 | |
| | Am-241 | 0.5 | Alpha Spec | 8.00E-02 | |

| | | | | Standard LLD (1000 min.) |
|---|---|---|---|---|
| Gamma | Am-241 | 3 | INGe | 1.00E+01 |
| | Ba-140 | 3 | INGe | 9.00E+00 |
| | Ce-144 | 3 | INGe | 1.30E+01 |
| | C0-58 | 3 | INGe | 1.50E+00 |
| | Co-60 | 3 | INGe | 2.00E+00 |
| | Cr-51 | 3 | INGe | 1.60E+01 |
| | Cs-134 | 3 | INGe | 2.00E+00 |
| | Cs-137 | 3 | INGe | 2.00E+00 |
| | Eu-152 | 3 | INGe | 5.00E+00 |
| | Eu-154 | 3 | INGe | 5.00E+00 |
| | Eu-155 | 3 | INGe | 8.00E+00 |
| | Fe-59 | 3 | INGe | 3.00E+00 |
| | I-129 | 3 | IXR/LEP | 8.00E-01 |
| | I-131 | 3 | INGe | 2.00E+00 |
| | K-40 | 3 | INGe | 3.00E+01 |
| | Mn-54 | 3 | INGe | 1.50E+00 |
| | Nb-95 | 3 | INGe | 2.00E+00 |
| | Ru-103 | 3 | INGe | 2.00E+00 |
| | Ru-106 | 3 | INGe | 1.50E+01 |
| | Sb-125 | 3 | INGe | 5.00E+00 |
| | Sn-113 | 3 | INGe | 2.00E+00 |
| | Zn-65 | 3 | INGe | 3.00E+00 |
| | Zr-95 | 3 | INGe | 2.00E+00 |

Water (pCi/L) Continued

|  | Nuclide | Volume (L) | Method | Standard LLD (200 min.) | Standard LLD (100 min.) |
|---|---|---|---|---|---|
| Beta | H-3 | 0.010 | Dist/LS | 6.00E+01 | |
| | C-14 | 0.010 | LS | 1.50E+02 | |
| | Sr-90 | 1 | Nitric Acid/ $\alpha\beta$ Cntr | | 7.00E-01 |
| | Tc-99 | 0.5 | 3M/LS | | 4.00E+00 |
| Gross | Alpha | 0.1 | $\alpha\beta$ Cntr | | 4.00E+00 |
| | Beta | 0.5 | $\alpha\beta$ Cntr | | 1.00E+00 |

*LLD for Air Cartridge is 3 days

METHOD
 Preparation Methods

   IXR = Ion Exchange Resin
   Nitric Acid
   3M = 3M Ion Exchange Disks
   Oxid = Oxidation

 Counting Methods

   INGe = Intrinsic Germanium Detector
   $\alpha\beta$ Cntr = Alpha, Beta Counter
   Alpha Spec = Alpha Spectrometry
   LS = Liquid Scintillation
   LEP = Low Energy Photon Detector

Formulas

A.   Lower line: <u>Random Uncertainty</u>

RU = 1.96((gross sample cpm/$T_1$) + (BKGCPM/$T_2$))$^{1/2}$/((E)(2.22)(V)(Y)(D))

B.   <u>Uncertainty (standard error) of the sample mean (U)</u>

U = s/(n)$^{1/2}$

C.   <u>Lower Limit of Detection (LLD)</u>

LLD = 4.66S/((2.22)(E)(V)(Y)(D))

D.   <u>Definitions</u>

| | | |
|---|---|---|
| 2.22 | = | conversion factor from dpm to picocuries |
| BKGCPM | = | background counts per minute |
| D | = | decay factor = $e^{-(\ln 2/T_{1/2})(t)}$ |
| E | = | counting efficiency: counts per disintegration |
| LLD | = | the a priori determination of the smallest concentration of radioactive material sampled that has a 95 percent probability of being detected, with only five percent probability that a blank sample will yield a response interpreted to mean that radioactivity is present above the system background |
| n | = | number of samples analyzed (number of data points) |
| RU | = | random uncertainty at the 95 percent confidence level (sometimes referred to as counting error) |
| s | = | sample standard deviation |
| S | = | one standard deviation of the background count rate (which equals (BKG/$T_2$)$^{1/2}$) |
| sample cpm | = | counts per minute of sample |
| t | = | elapsed time between sample collection and counting |
| $T_1$ | = | sample count time |
| $T_2$ | = | background count time |
| $T_{1/2}$ | = | half-life of radionuclide counted |
| U | = | uncertainty (standard error) of the sample mean |
| V | = | volume in liters (or mass in grams) of sample |
| Y | = | fractional radiochemical yield (when applicable) |

# Appendix C - Glossary of Terms

Alpha Particle

A heavy particle emitted from the nucleus of an atom. It consists of two protons and two neutrons, which is identical to the nucleus of a helium atom without orbital electrons. These heavy charged particles lose their energy very rapidly in matter. Thus, they are easily shielded by paper or the surface layer of skin. Alpha particles are only hazardous when they are internally deposited.

Analyte

The specific radioisotope measured in a radiochemical analysis. For example, tritium, Sr-90, and U-238 are analytes.

Background
(Background Radiation)

Radiation that occurs naturally in the environment. Background radiation consists of cosmic radiation from outer space, radiation from the radioactive elements in rocks and soil, and radiation from radon and its decay products in the air we breathe.

Baseline Samples

Environmental samples taken in areas unlikely to be affected by any facilities handling radioactive materials.

Becquerel

A unit, in the International System of Units (SI), of measurement of radioactivity equal to one transformation per second.

Beta Particle

A high-speed particle emitted from the nucleus, which is identical to an electron. They can have a -1 or +1 charge and are effectively shielded by thin layers of metal or plastic. Beta particles are generally only hazardous when they are internally deposited.

| | |
|---|---|
| Curie | The basic unit of activity. A quantity of any radionuclide that undergoes an average transformation rate of 37 billion transformations per second. One curie is the approximate activity of 1 gram of radium. Named for Marie and Pierre Curie, who discovered radium in 1898. |
| Decay, Radioactive | The decrease in the amount of any radioactive material with the passage of time, due to the spontaneous emission from the atomic nuclei of either alpha or beta particles, often accompanied by gamma radiation. |
| Detection Level | The minimum amount of a substance that can be measured with a 95% confidence that the analytical result is greater than zero. |
| DOH | Department of Health or Washington State Department of Health |
| Dose | A generic term that means absorbed dose, equivalent dose, effective dose, committed equivalent dose, committed effective dose, or total effective dose. |
| Fallout | Radioactive materials that are released into the earth's atmosphere following a nuclear explosion or atmospheric release and eventually fall to earth. |
| Gamma Ray | Electromagnetic waves or photons emitted from the nucleus of an atom. They have no charge and are best shielded by thick layers of lead or steel. Gamma energy may cause an external or internal radiation hazard. (X-rays are similar to gamma radiation but originate from the outer shell of the atom instead of the nucleus.) |

| | |
|---|---|
| Gross Alpha / Gross Beta | A screening test that reports alpha particle activity in a sample. The test is not intended to identify specific radioisotopes. The tests are primarily used to evaluate trends. In addition, screening tests are used to determine if further radioisotope specific analysis is necessary; and if radioisotope analysis has been carried out, to determine if the activities from specific radioisotopes account for all of the activity found in the screening test. |
| Half-life | The time in which half the atoms of a particular radioactive substance disintegrate to another nuclear form. Measured half-lives vary from millionths of a second to billions of years. Also called physical half-life. |
| ICRP | International Commission on Radiation Protection |
| Ionizing Radiation | Any radiation capable of displacing electrons from atoms or molecules, thereby producing ions. Examples: alpha, beta, gamma, x-rays, and neutrons. |
| Isotope | One of two or more atoms with the same number of protons, but different numbers of neutrons, in the nuclei. |
| Lower Limit of Detection (LLD) | The smallest amount or concentration of a radioactive element that can be reliably detected in a sample. |
| NCRP | National Council for Radiation Protection |
| PHL | Public Health Laboratory |
| pCi (picocurie) | $10^{-12}$ curies (one trillionth of a curie) |
| PNNL | Pacific Northwest National Laboratory |
| QATF | Quality Assurance Task Force |

| | |
|---|---|
| Quality Assurance | All those planned and systematic actions necessary to provide adequate confidence that a facility, structure, system, or component will perform satisfactorily and safely in service. |
| Quality Control | A component of Quality Assurance; comprises all those actions necessary to control and verify that a material, process, or product meets specified requirements. |
| Quality Factor (Q) | A numerical factor assigned to describe the average effectiveness of a particular kind (and sometimes energy) of radiation in producing biological effects on humans. |
| Rad | The special unit of absorbed dose. It is a measure of the energy absorbed per mass of material. One rad is equal to an absorbed dose of 0.01 J kg$^{-1}$ (1 rad = 0.01 gray). |
| Radioactivity | The process of undergoing spontaneous transformation of the nucleus, generally with the emission of alpha or beta particles, often accompanied by gamma rays. The term is also used to designate radioactive materials. |
| Radioisotope | A radioactive isotope; i.e., an unstable isotope that undergoes spontaneous transformation, emitting radiation. Approximately 2500 natural and artificial radioisotopes have been identified. |
| Radionuclide | A radioactive nuclide. |
| Rem | The special unit of dose equivalent. The dose equivalent in rem is equal to the absorbed dose in rad multiplied by a quality factor that accounts for the biological effect of the radiation (1 rem = 0.01 sievert). |
| Replicate Sample | Two or more samples from one location that are analyzed by the same laboratory. |

| | |
|---|---|
| Roentgen | A unit of exposure to ionizing radiation. It is that amount of gamma or x-rays required to produce ions carrying 1 electrostatic unit of electrical charge in 1 cubic centimeter of dry air under standard conditions. Named after Wilhelm Roentgen, German scientist who discovered x-rays in 1895. |
| Split Sample | A sample from one location that is divided into two samples and analyzed by different laboratories. |
| TLD | Thermoluminescent Dosimeters |
| U.S. DOE | United States Department of Energy |
| WAC | Washington Administrative Code |
| X-ray | Electromagnetic waves or photons emitted from the outer shell of the atom instead of the nucleus. They have no charge and are best shielded by thick layers of lead or steel. X-ray energy may cause an external or internal radiation hazard. |

# Appendix D - List of Analytes

| | |
|---|---|
| Am-241 | Americium-241 |
| Be-7 | Beryllium-7 |
| C-14 | Carbon-14 |
| Cm-244 | Curium-244 |
| Co-60 | Cobalt-60 |
| Cs-137 | Cesium-137 |
| Eu-152 | Europium-152 |
| Eu-154 | Europium-154 |
| Eu-155 | Europium-155 |
| H-3 | Hydrogen-3 |
| I-129 | Iodine-129 |
| K-40 | Potassium |
| NO2+NO3 | Nitrite + Nitrate |
| Pu-238 | Plutonium-238 |
| Pu-239/240 | Plutonium-239/240 |
| Ru-106 | Ruthenium-106 |
| Sb-125 | Antimony-125 |
| Sr-90 | Strontium-90 |
| Tc-99 | Technetium-99 |
| Total U | Total Uranium |
| U-234 | Uranium-234 |
| U-235 | Uranium-235 |
| U-236 | Uranium-236 |
| U-238 | Uranium-238 |