

Environmental Radiation Monitoring and Assessment Program

*Hanford Environmental Radiation  
Oversight Program  
2009 Data Summary Report*

December 2010

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## **Acknowledgements**

Activities in the Hanford Environmental Radiation Oversight Program include sample schedule development, sample collection, radiochemical sample analyses, data entry, data review, data analysis, writing the annual report, technical review of the annual report, document preparation, database management, and overall program management. The Office of Radiation Protection and Public Health Laboratory staff that contribute to this program are:

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## Acronyms

ALARA	As Low As Reasonably Achievable
ALE	Arid Land Ecology Reserve
CFR	Code of Federal Regulations
CSB	Canister Storage Building
CVDF	Cold Vacuum Drying Facility
DOE	Department of Energy (United States)
DOH	Department of Health (Washington State)
DNR	Department of Natural Resources
DWS	Drinking Water Standard
EML	Environmental Measurement Laboratory
LLD	Lower Limits of Detection
MAPEP	Mixed Analyte Proficiency Evaluation Program
MDA	Minimum Detectable Activity
NCRP	National Council on Radiation Protection and Measurements
PHL	Public Health Laboratories
PNNL	Pacific Northwest National Laboratory
PUREX	Plutonium Uranium Extraction Facility
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
TWRS	Tank Waste Remediation System
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, and to assess the potential for public health impacts.

This report is a summary of the data collected for the Hanford Environmental Radiation Oversight Program in 2009.

The Oversight Program's objectives are met through collection and analysis of environmental samples and interpretation of results. DOH samples 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, discharge water, sediment, food and farm products, fish and wildlife, and vegetation are collected. In addition, ambient external radiation levels are measured using radiation dosimeters.

This report uses the categories of *good*, *fair*, and *poor* to qualitatively describe the agreement between DOH and DOE radioactivity concentrations in environmental media. Generally there is good agreement between data split between DOH and DOE contractors. The good agreement between the limited split data gives confidence that the remainder of the DOE environmental radiation data are valid.

The DOH and DOE contractor data are not expected to be in exact agreement for every sample because of the statistical nature of radioactive decay and the fact that samples collected from the field are not homogeneous. In addition to a few samples where the concentrations are similar but do not exactly match, there are a few categories of samples that display a systematic disagreement, and are categorized as fair agreement.

The agreement between DOH and DOE contractor results is fair for gross alpha, gross beta, Cs-137, H-3, uranium, and plutonium activity in air samples; gross beta, C-14, I-129, Sr-90, Tc-99, and U-235 activity in water samples; and Sr-90 activity in fish and vegetation samples. For the case of gross beta in air, the difference in sampling intervals and sampling equipment may contribute to the discrepancy. For the other

cases, the discrepancies are under investigation, and are likely related to differences in laboratory procedures and sample collection protocol.

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.

For example, C-14, H-3 (tritium), I-129, Sr-90, Tc-99, and isotopes of uranium were detected above background levels in some Hanford Site and Hanford boundary water samples. A variety of radionuclides, including Cs-137, Eu-152, Pu-239/240, Sr-90, and isotopes of uranium, were found above background levels in some Columbia River sediment samples. Most of the elevated concentrations are consistent with historical trends.

Anomalously elevated radionuclide concentrations were found in air samples from the 100K Area, groundwater samples from the 200 West Area, and TLD results at the 100KE Area.

While Hanford operations have resulted in radionuclides entering the environment, the data from the DOH Oversight Program indicate that public exposure to radioactivity from Hanford is far below regulatory limits.

## 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 use the DOH oversight data to assess impacts to the public by comparing 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<sup>3</sup>); 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 given as "2-sigma (two standard deviation)" uncertainty. 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 is 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 described above) 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 distinct 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 also assessed and incorporated into the qualitative assessment when appropriate.

The results of the assessment are discussed in the text of the report. When necessary or helpful to the reader, figures of the graphical representation of the data are included in the report.

#### 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  $\pm 1$  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 ([Section 3.4](#)); 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 gross alpha and gross beta results are in fair agreement. 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 fair agreement. The concentrations are similar and follow the same trends over time, but differences by up to a factor of five are observed.
- The DOH and DOE contractor quarterly composite results are in good agreement for gamma emitting radionuclides and isotopes of uranium. The agreement for tritium is only fair. In all cases, the concentrations are very small.
- The DOH and DOE contractor semiannual composite results are in fair agreement for most radionuclides, including Cs-137 and isotopes of uranium and plutonium.
- Most DOH concentrations are consistent with historical results. However, semiannual gross alpha, gross beta, Cs-137, Pu-238, and Pu-239/240 were anomalously elevated at one location near Hanford's 100K Area, likely due to nearby storage of radioactive material and consequences of cleanup activities.

#### 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. Mission Support Alliance (MSA) was the DOE contractor for this program. 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. Pacific Northwest National Laboratory (PNNL) was the DOE contractor for

this program. The two programs use different laboratories for analysis of the air samples, so each program is discussed separately in this report.

DOH collected air samples collocated with the Near Facilities and Operations program (MSA) 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 100 K 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 (PNNL) 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.

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.

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 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, 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 will change its collection schedule to match the four-week DOE contractor interval starting in 2010.

#### **3.1.4 Comparison of DOH and DOE Contractor Data**

Comparisons of DOH and DOE contractor data are summarized in [Tables 3.1.1](#) and [3.1.2](#). A discussion of how the data are interpreted is presented in [Section 2.2](#). 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](#)).

##### *Site-Wide and Offsite Monitoring Program - Samples Collocated with PNNL*

A summary of the Site-Wide and Offsite Monitoring Program collocated air samples is presented in [Table 3.1.1](#). Cases in which the agreement is not good are discussed in the text. DOH data range concentrations prefaced by the “less than” symbol indicate that some or all results are less than the listed detection limit. For all radionuclides, the concentrations reported by DOH are consistent with historical results, and no anomalous data were encountered.

Analyte	Collection Period	# Collocated Samples	Agreement	DOH Data Range (pCi/m <sup>3</sup> )	Anomalous Data ?
Gross Alpha	biweekly <sup>(a)</sup>	26	<b>fair</b>	0.0007 to 0.004	no
Gross Beta	biweekly <sup>(a)</sup>	129	<b>fair</b>	0.004 to 0.06	no
H-3	monthly	24	<b>fair</b>	< 2.5 to 23	no
Co-60	quarterly	16	good	< 0.001	no
Cs-137	quarterly	16	good	< 0.001	no
U-234	quarterly	8	good	< 0.00003 to 0.00008	no
U-235	quarterly	8	good	< 0.00001 to 0.00001	no
U-238	quarterly	8	good	< 0.00003 to 0.00008	no

(a) Biweekly at most sites, weekly at sites collocated with Columbia Generating Station.

Table 3.1.1 Summary of Samples Collocated with PNNL

The DOH and PNNL 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](#).

The scatter plot for historical DOH and PNNL gross alpha concentrations is shown in [Figure 3.1.3](#). This plot shows the data from all sites that are collocated with PNNL. There is significant scatter about the theoretical line in which the DOH and PNNL results are identical, with differences up to a factor of two being common. In addition, there is a small systematic bias between the DOH and PNNL results. The regression analysis of historical data indicates that DOH on average reports slightly higher concentrations.

The DOH and PNNL 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. As an example, the DOH and PNNL data at the Wye Barricade are shown in [Figure 3.1.4](#).

In part, the discrepancy in gross beta results is due to different sampling frequencies between DOH and the DOE contractor for some of the sites. DOH collects the air filters bi-weekly at most sites, but the collection frequency is weekly at sites collocated with the Columbia Generating Station. PNNL collects the samples bi-weekly at all sites. The effects can be seen in [Figure 3.1.4](#), where the PNNL data (collected every other week) appear “smoothed out” compared to the DOH data (collected every week). The bi-weekly integration period averages what would otherwise be two weekly data points.

The scatter plot for historical DOH and PNNL gross beta concentrations is shown in [Figure 3.1.5](#). This plot shows the data from all sites that are collocated with PNNL. There is significant scatter about the theoretical line in which the DOH and PNNL results are identical, with differences up to a factor of two being common. In addition, there is a small systematic bias between the DOH and PNNL results. The regression analysis of historical data indicates that PNNL on average reports slightly higher concentrations at the lower range of results, while DOH on average reports slightly higher concentrations at the mid and upper ranges.

The DOH and PNNL H-3 concentrations are in fair 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 data are shown in [Figure 3.1.6](#), and the scatter plot of historical data is shown in [Figure 3.1.7](#).

The DOH and PNNL isotopic uranium concentrations are in good agreement for this reporting year. Historically, however, the concentrations are only in fair agreement, as a discrepancy appears primarily for samples in which DOH measures U-238 concentrations greater than the detection limit of  $2.5E-5$  pCi/m<sup>3</sup>. In these cases, the corresponding PNNL data often do not confirm the slightly elevated DOH results. It should be noted, however, that the concentrations are very small, typically near the detection limit, and the differences between DOH and PNNL concentrations are also very small.

In addition to the analytes for the collocated sample analysis (listed in [Table 3.1.1](#)), most of the PNNL samples were also analyzed to determine concentrations of Am-241, Cs-134, Eu-152, Eu-154, Eu-155, Pu-238, Pu-239/240, Ru-106, Sb-125, and Sr-90. All results for these additional analyses were below the PNNL detection limits. DOH did not report results for these radionuclides in the quarterly composite air samples.

*Near Facilities and Operations Monitoring Program - Samples Collocated with Duratek*

A summary of the Near Facilities and Operations Monitoring Program collocated air samples is presented in [Table 3.1.2](#). Cases in which the agreement is not good are discussed in the text. DOH data range concentrations prefaced by the “less than” symbol indicate that some or all results are less than the listed detection limit. Some concentrations reported by DOH are outside the range of historical results, and these data are discussed in the text.

Analyte	Collection Period	# Collocated Samples	Agreement	DOH Data Range (pCi/m <sup>3</sup> )	Anomalous Data ?
Gross Alpha	biweekly	75	<b>fair</b>	0.0005 to 0.007	<b>yes</b>
Gross Beta	biweekly	135	<b>fair</b>	0.002 to 0.1	<b>yes</b>
Co-60	semiannual	6	good	< 0.0005	no
Cs-137	semiannual	6	<b>fair</b>	0.0005 to 0.2	<b>yes</b>
Pu-238	semiannual	6	<b>fair</b>	< 0.000005 to 0.0001	<b>yes</b>
Pu-239/240	semiannual	6	<b>fair</b>	< 0.000005 to 0.0009	<b>yes</b>
U-234	semiannual	6	<b>fair</b>	< 0.00001 to 0.00008	no
U-235	semiannual	6	good	< 0.000005	no
U-238	semiannual	6	<b>fair</b>	< 0.00001 to 0.00008	no

Table 3.1.2 Summary of Samples Collocated with Duratek

The DOH and MSA 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 discrepancy is prominent in

cases where the DOH concentration is greater than approximately 0.002 pCi/m<sup>3</sup>. The collocated data at 100K East Basin are shown in [Figure 3.1.8](#).

The scatter plot for historical DOH and MSA gross alpha concentrations is shown in [Figure 3.1.9](#). This plot shows the data from all collocated sites. There is significant scatter about the theoretical line in which the DOH and MSA results are identical, with differences up to a factor of two being common. In addition, there is a small systematic bias between the DOH and MSA results. The preponderance of points to the right of the theoretical ideal agreement line indicates that DOH on average reports slightly higher concentrations.

The DOH gross alpha concentrations are anomalously high at 100K East Basin compared to the other two sites (C Farm and PFP-N165). Average concentrations at 100K East Basin are 0.0025 pCi/m<sup>3</sup>, with a standard deviation of 0.0015 pCi/m<sup>3</sup> and maximum value of 0.007 pCi/m<sup>3</sup>, while the values at the C Farm and PFP-N165 are 0.0017, 0.0007, and 0.005 pCi/m<sup>3</sup>, respectively.

The DOH and MSA 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. As an example, the DOH and MSA data at C Farm are shown in [Figure 3.1.10](#).

The scatter plot for historical DOH and MSA gross beta concentrations is shown in [Figure 3.1.11](#). This plot shows the data from all collocated sites, except for 100K East Basin (see discussion below). The data from 100K East Basin are anomalously high, and are not shown in the figure because the scale would render the remaining data indiscernible. There is significant scatter about the theoretical line in which the DOH and MSA results are identical, with differences up to a factor of two being common. In addition, there is a small systematic bias between the DOH and MSA results. The regression analysis of historical data indicates that Duratek on average reports slightly higher concentrations at the lower range of results, while DOH on average reports slightly higher concentrations at the mid and upper range. The regression analysis for 100K East Basin (not shown) is similar.

The DOH gross beta concentrations in 2009 are anomalously high at 100K East Basin compared to the other four sites (C Farm, ERDF-SE, PFP-N165, and Wye Barricade). Average concentrations at 100K East Basin are 0.12 pCi/m<sup>3</sup>, with a standard deviation of 0.16 pCi/m<sup>3</sup> and maximum value of 0.7 pCi/m<sup>3</sup>, while the values for data combined at the other sites are 0.018, 0.01, and 0.06 pCi/m<sup>3</sup>, respectively. In addition, the 2009 concentrations at 100K East Basin are high compared to historical results at the same site, as can be seen in [Figure 3.1.12](#) which shows the data for the last three years.

The DOH and MSA concentrations for Co-60 and U-235 are in good agreement, as all results are below the detection limit. However, the concentrations for Cs-137, Pu-238, Pu-239/240, U-234, and U-238 are only in fair agreement. DOH and MSA report similar concentrations, most either below or only slightly above the detection limits. However, in cases where the isotope is detected, the uncertainty bars do not overlap. The results for Cs-137, Pu-239/240 (Pu-238 is similar), and U-238 (U-234 is similar) are shown in [Figures 3.1.13](#), [3.1.14](#), and [3.1.15](#), respectively. Historically, the agreement is only fair for these isotopes.

Anomalously high concentrations of Cs-137 (0.16 pCi/m<sup>3</sup>), Pu-238 (0.00013 pCi/m<sup>3</sup>), and Pu-239/240 (0.00086 pCi/m<sup>3</sup>) were reported by DOH in 2009 at 100K East Basin. Typical concentrations of these isotopes are 0.00003 pCi/m<sup>3</sup> for Cs-137, 0.000002 pCi/m<sup>3</sup> for Pu-238, and 0.000006 pCi/m<sup>3</sup> for Pu-239/240. As an example, historical concentrations of Cs-137 are shown in [Figure 3.1.16](#).

### 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 3.1.17](#), which shows gross beta activity at Wye Barricade over the last decade from 1999 through 2008.

DOH detected anomalously high concentrations of gross alpha, gross beta, Cs-137, Pu-238, and Pu-239/240 in 2009 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.

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.

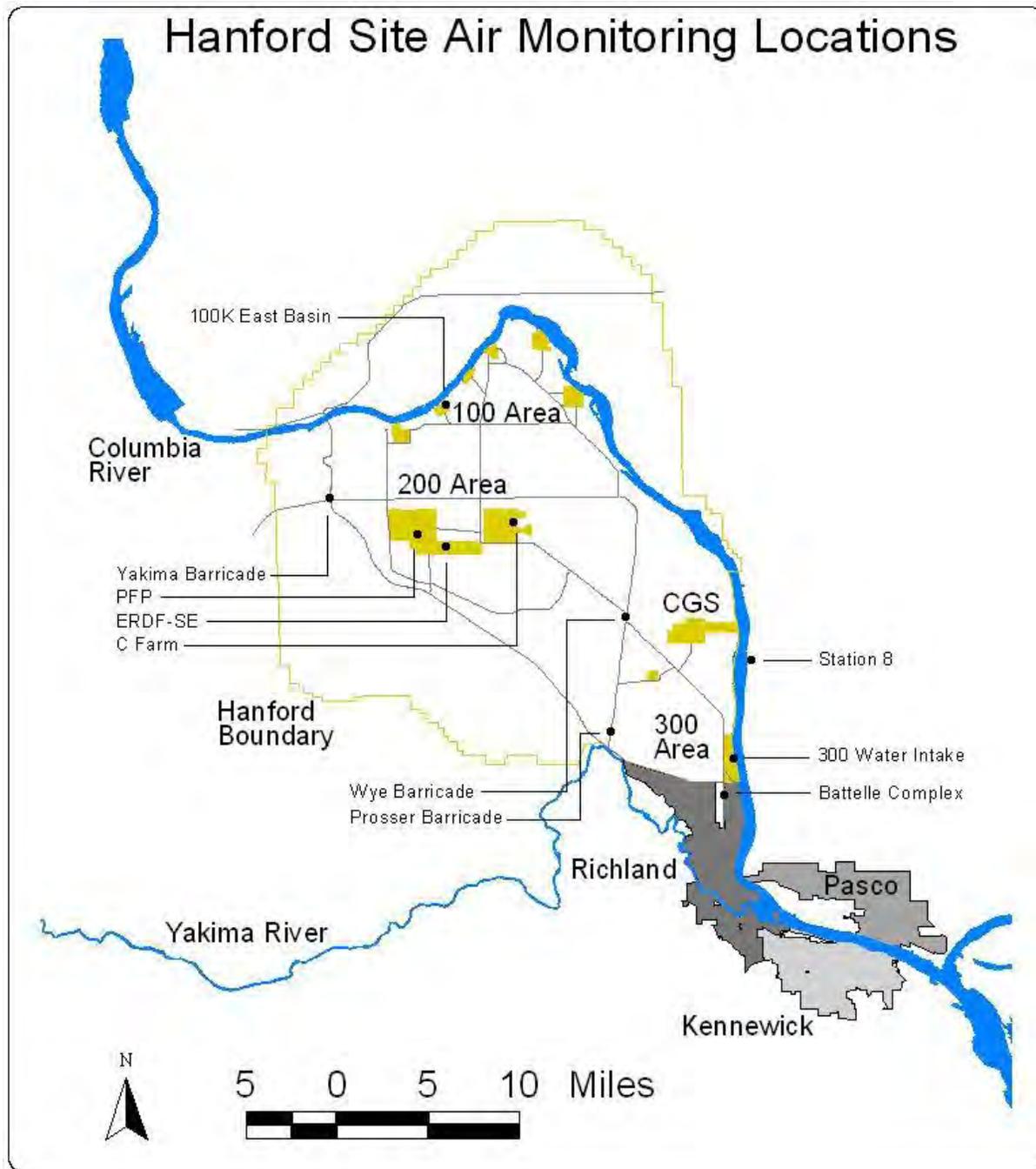


Figure 3.1.1 Collocated Air Monitoring Locations

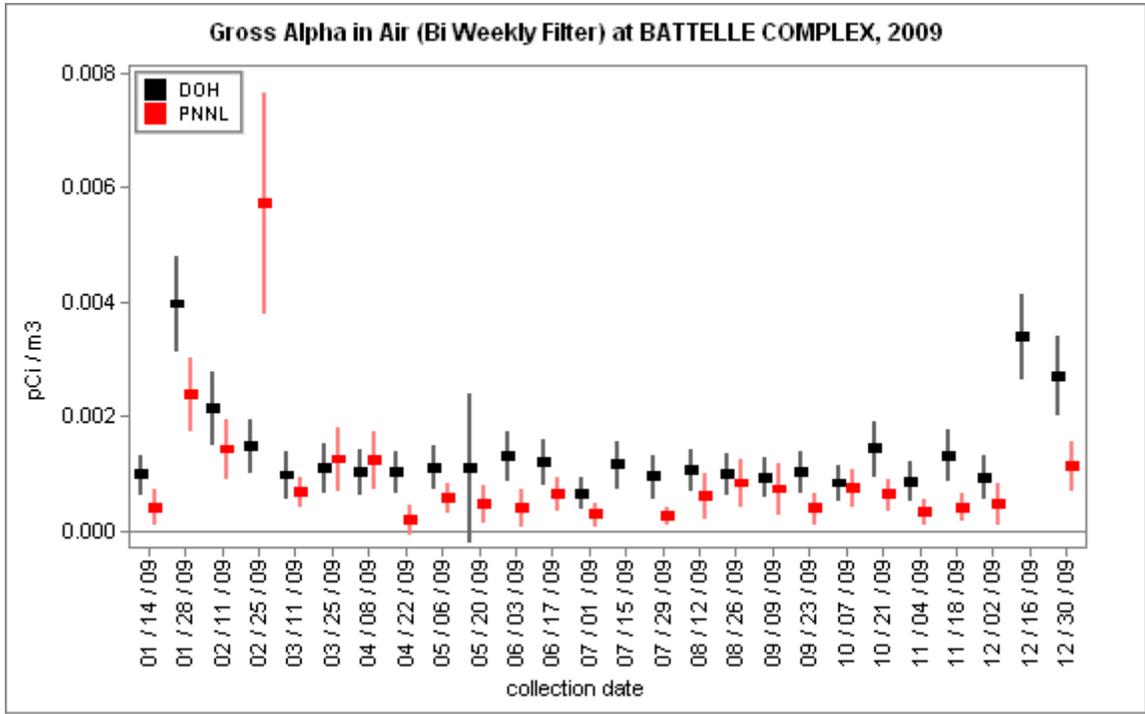


Figure 3.1.2 DOH and PNNL Gross Alpha Concentrations in Air at Battelle Complex

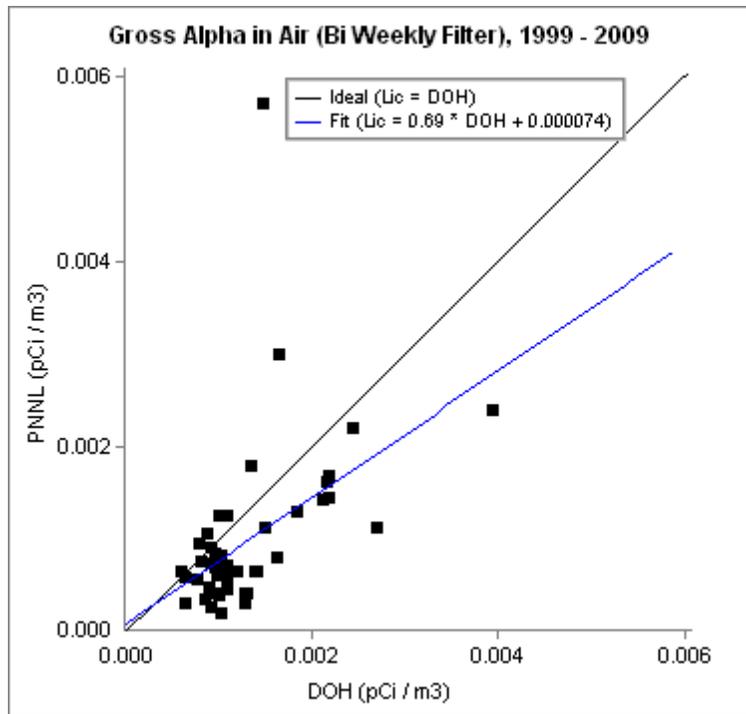


Figure 3.1.3 DOH and PNNL Scatter Plot for Historical Gross Alpha Concentrations in Air

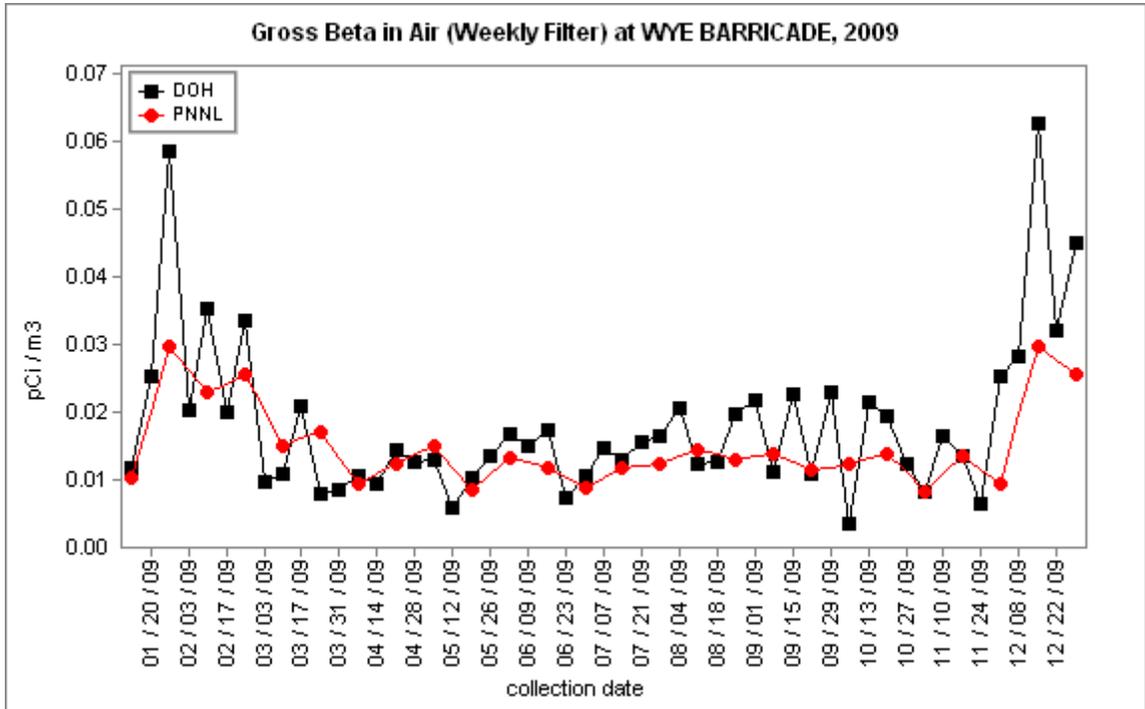


Figure 3.1.4 DOH and PNNL Gross Beta Concentrations in Air at Wye Barricade

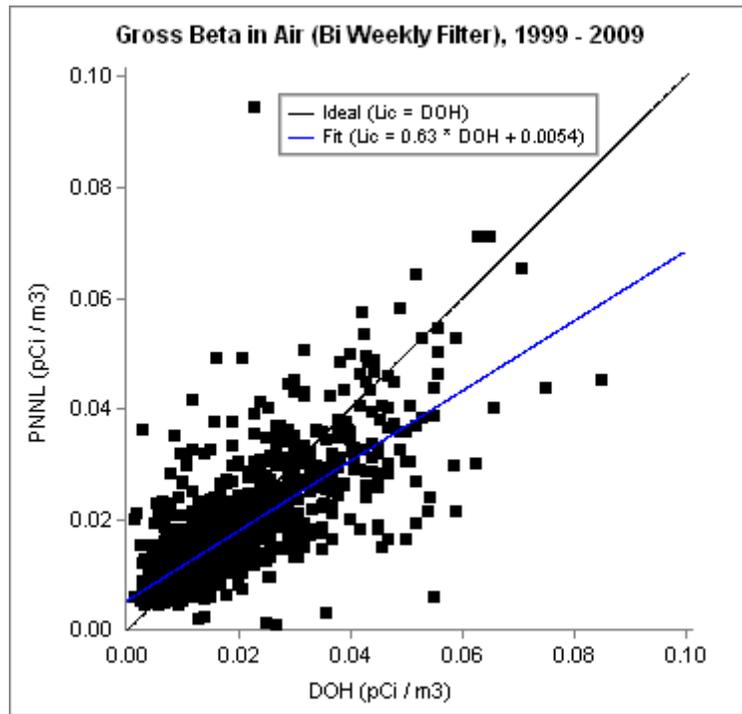


Figure 3.1.5 DOH and PNNL Scatter Plot for Historical Gross Beta Concentrations in Air

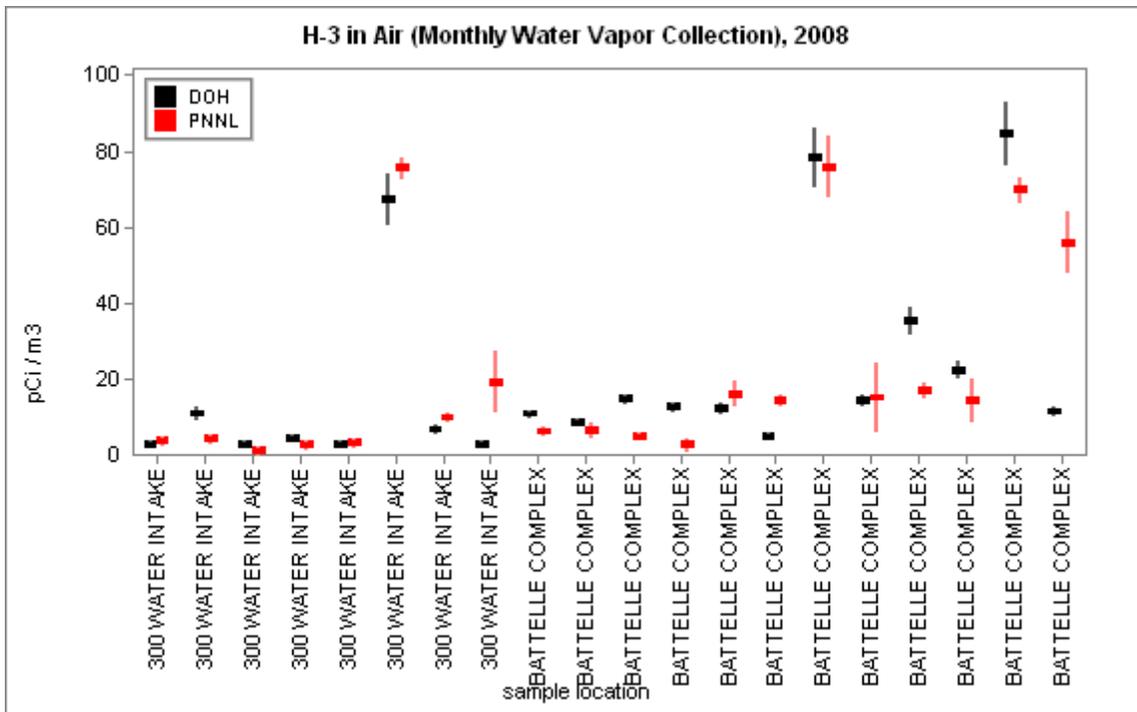


Figure 3.1.6 DOH and PNNL H-3 Concentrations in Air

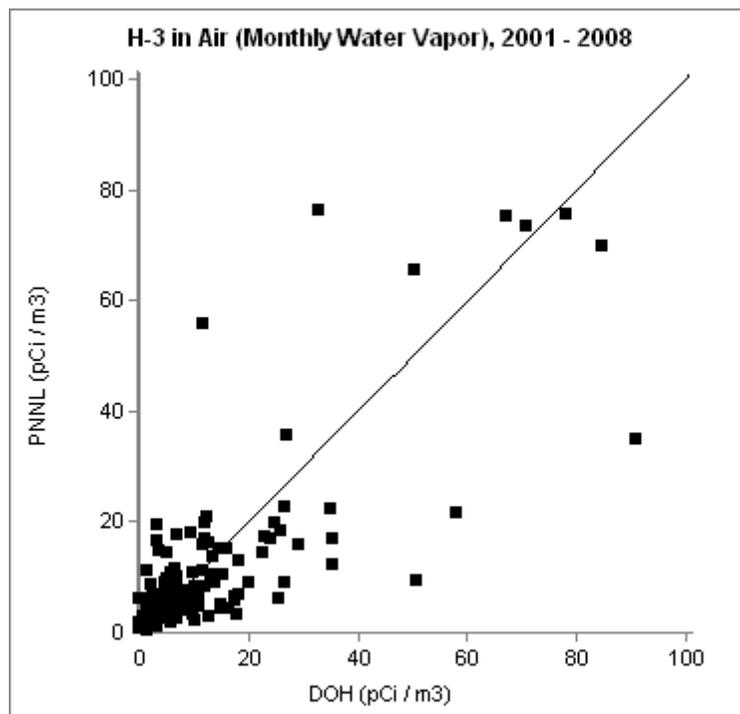


Figure 3.1.7 DOH and PNNL Scatter Plot for Historical H-3 Concentrations in Air

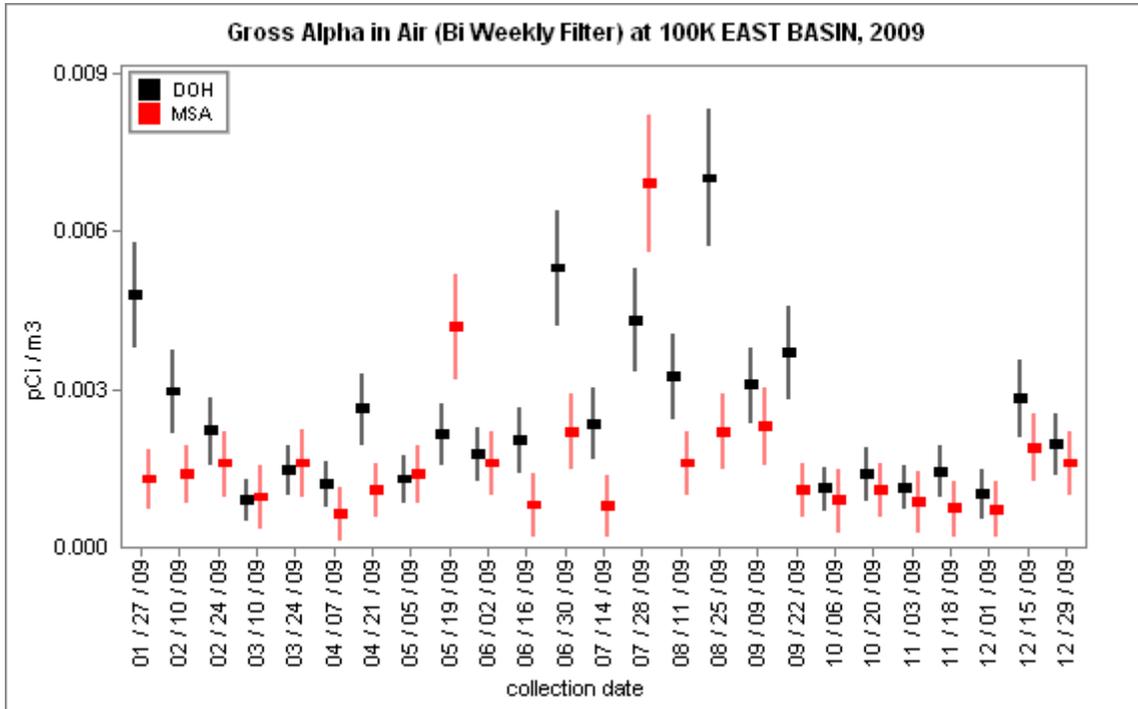


Figure 3.1.8 DOH and MSA Gross Alpha Concentrations in Air at 100K East Basin

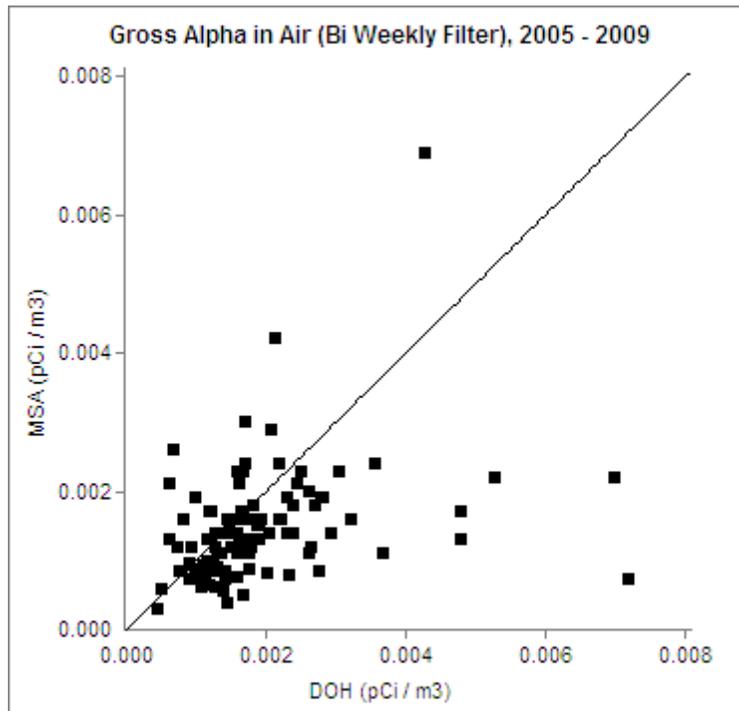


Figure 3.1.9 DOH and MSA Scatter Plot for Historical Gross Alpha Concentrations in Air

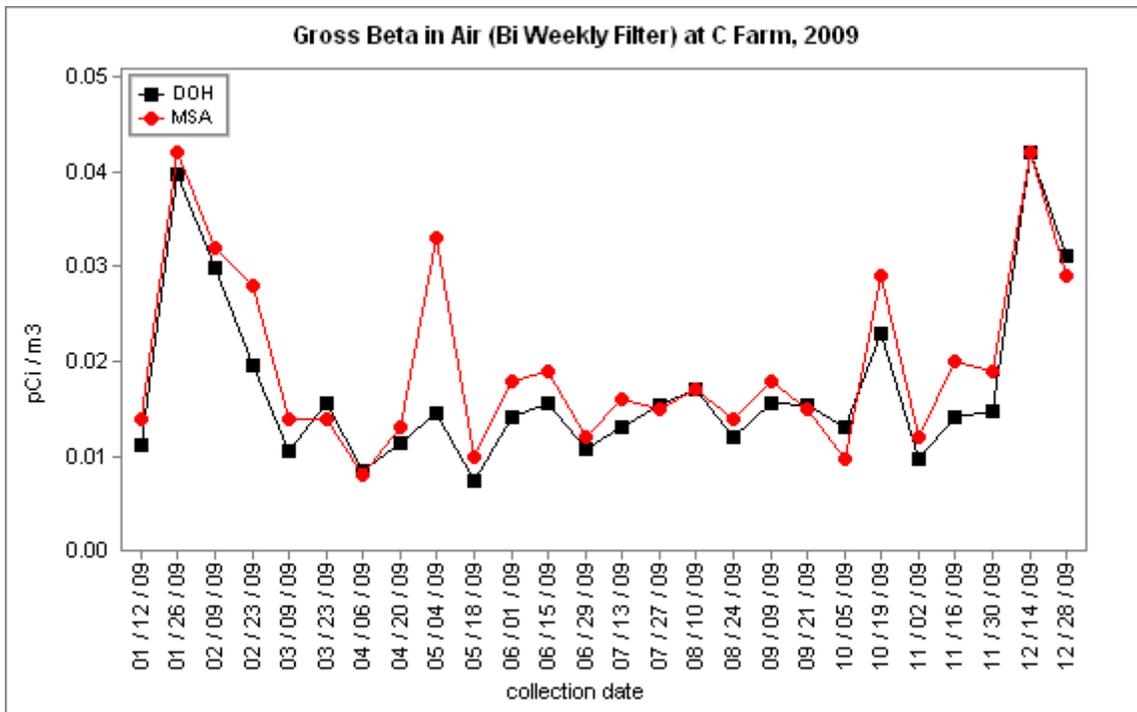


Figure 3.1.10 DOH and MSA Gross Beta Concentrations in Air at C Farm

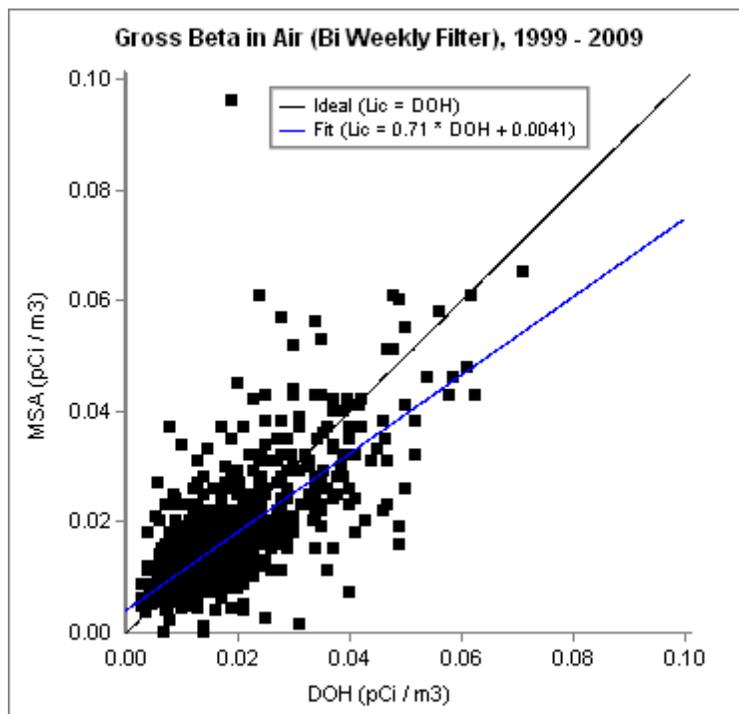


Figure 3.1.11 DOH and MSA Scatter Plot for Historical Gross Beta Concentrations in Air

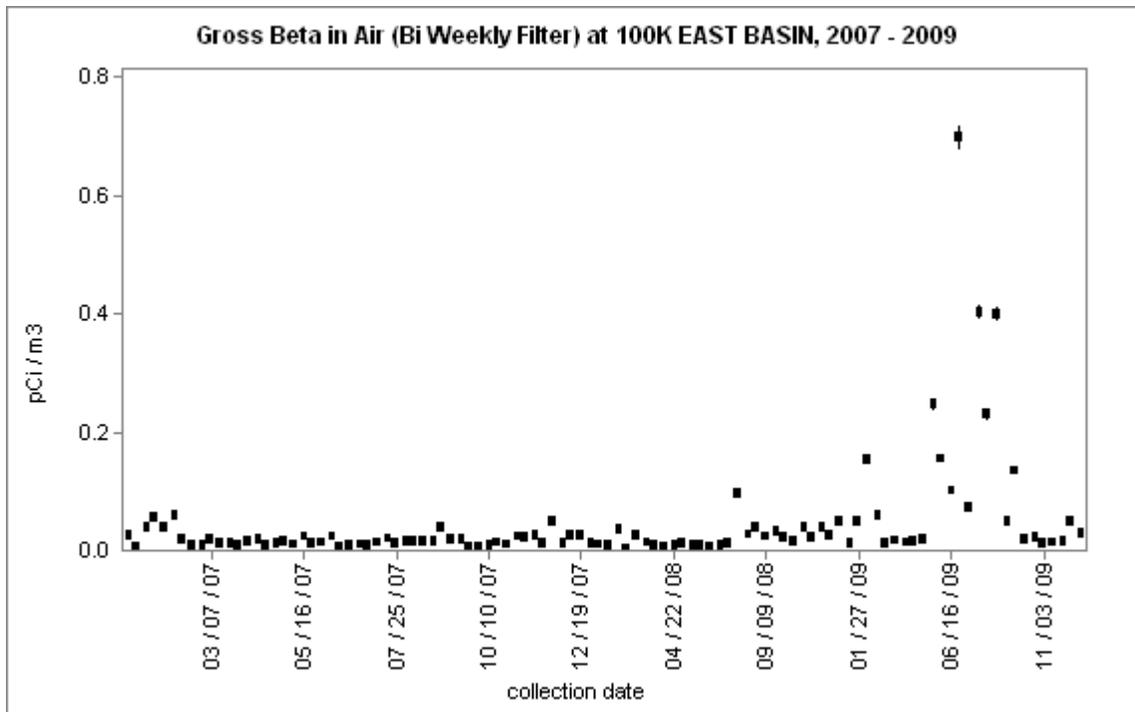


Figure 3.1.12 DOH and MSA Gross Beta Concentrations in Air at 100K East Basin

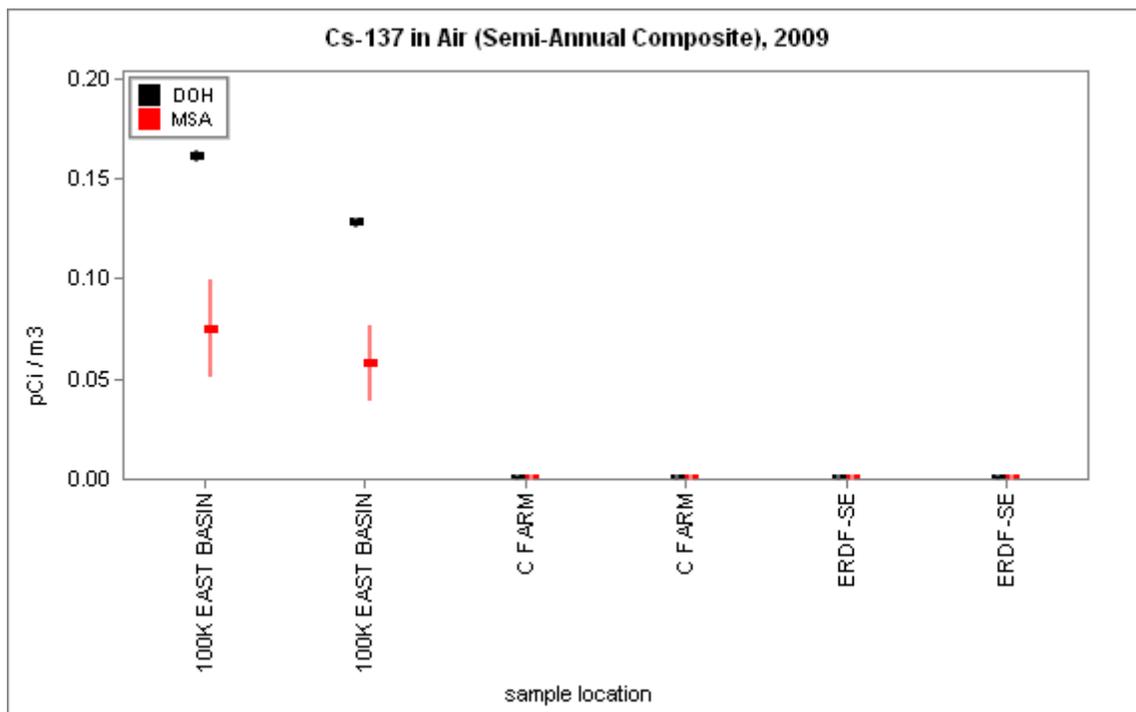


Figure 3.1.13 DOH and MSA Cs-137 Concentrations in Air

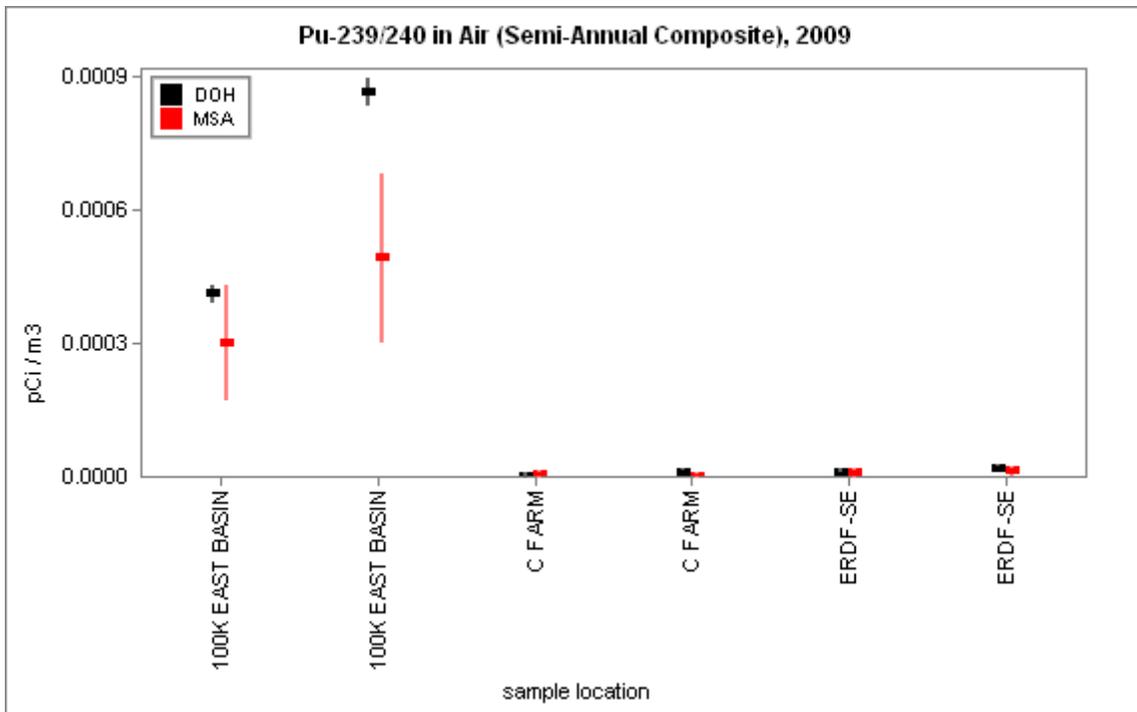


Figure 3.1.14 DOH and MSA Pu-239/240 Concentrations in Air

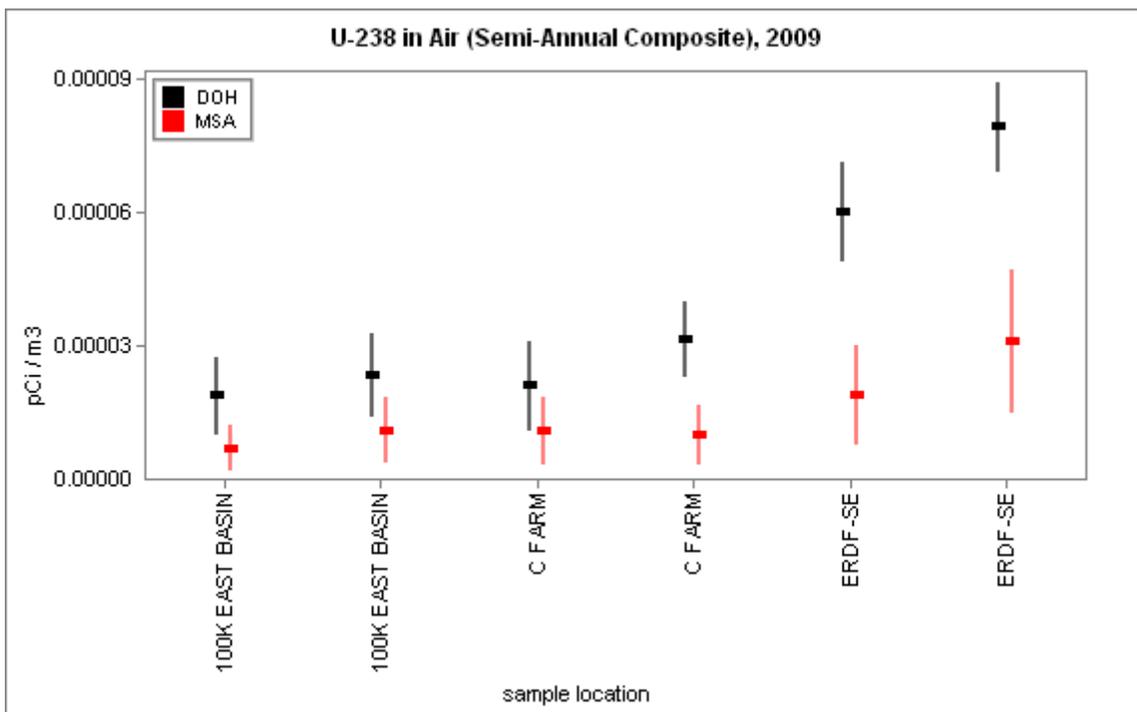


Figure 3.1.15 DOH and MSA U-238 Concentrations in Air

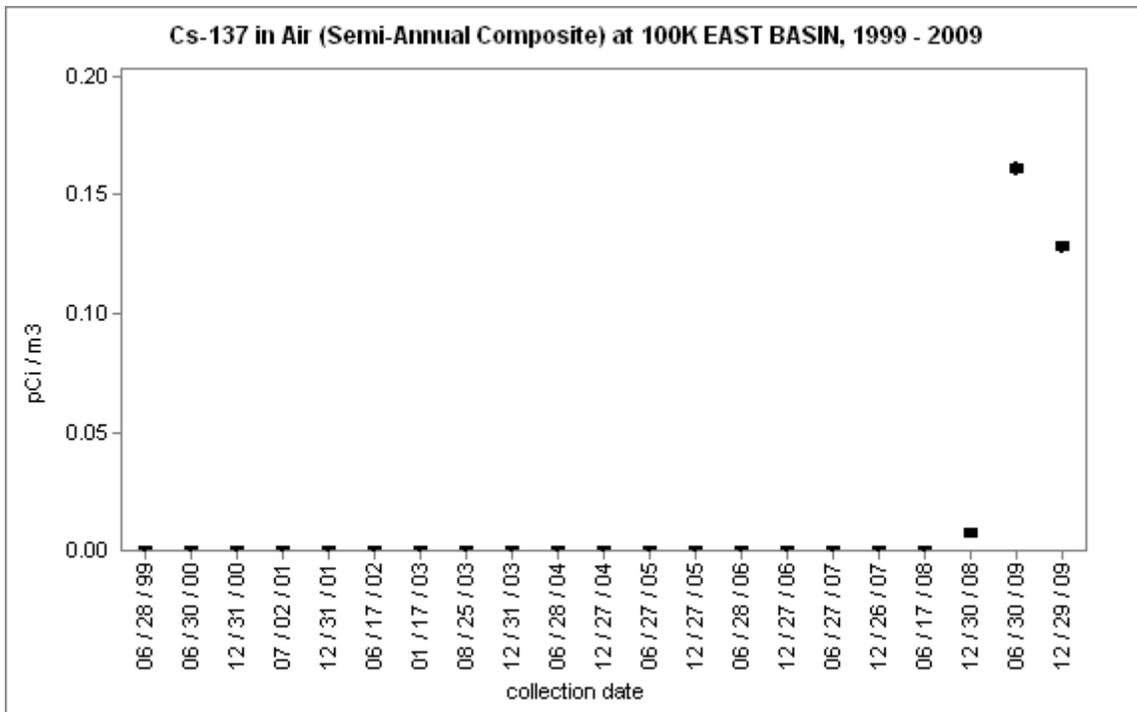


Figure 3.1.16 DOH Historical Cs-137 Concentrations in Air at 100K East Basin

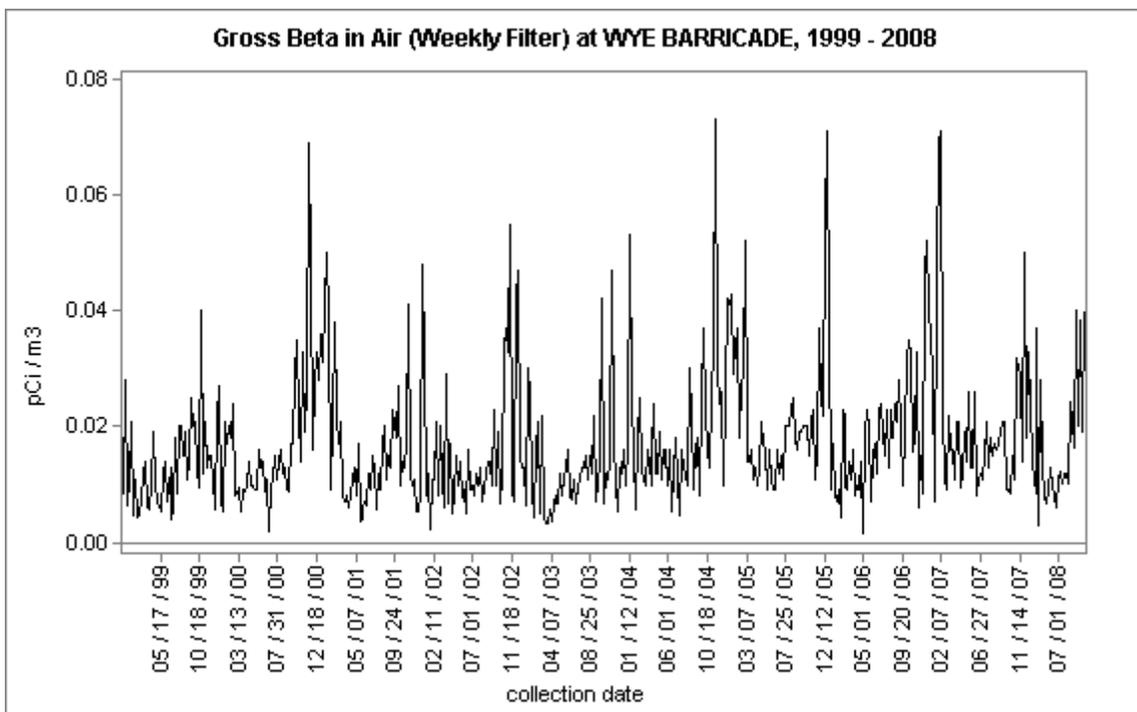


Figure 3.1.17 DOH Historical Gross Beta Concentrations in Air at Wye Barricade

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

### Major Findings:

- The DOH and Fluor Hanford split water concentrations are in fair agreement for C-14, gross beta, I-129, and Tc-99, and are in good agreement for all other radionuclides.
- The DOH and PNNL split water concentrations are in fair agreement for gross beta, Sr-90, and U-235, and are in 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, 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.
- Elevated concentrations of C-14, H-3, I-129, and Tc-99 were found at groundwater well 299-W14-13. Elevated isotopic uranium concentrations were found in groundwater well and Columbia River surface water samples adjacent to the 300 Area.
- Radionuclide concentrations in drinking water samples analyzed by DOH are all below federal standards.
- Radionuclide concentrations in TEDF discharge water samples are all below Washington State 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 to 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, effluent treatment discharge 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 20 groundwater samples from 18 groundwater wells with Fluor Hanford (two wells had two samples). 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 100 KE 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 PNNL split 10 Columbia River riverbank seep samples. Groundwater enters the Columbia River through riverbank seeps. Samples are collected from the historically predominant areas for discharge of riverbank seep water to the Columbia River, which include the 100 Area (five samples), the Old Hanford Town Site (three samples), and the 300 Area (two samples).

### *Surface Water*

DOH and PNNL 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.

### *Discharge Water*

DOH conducts discharge effluent monitoring at the 310 Treated Effluent Disposal Facility (TEDF) as acknowledged in the Aquatic Lands Sewer Outfall Lease No. 20-013357. This agreement between the Department of Natural Resources (DNR) and DOE requires DOH to provide oversight of the discharge effluent monitoring program by splitting approximately 15% of the 12 annual samples (collected monthly). DOH and Fluor split two discharge water samples.

The TEDF was constructed as part of a Tri-Party Agreement milestone to cease discharges to the 300 Area Process Trenches. The facility began operation in December 1994, and effluent sampling has been conducted since that time.

### *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. Two drinking water samples from the 400 Area were split with PNNL, one from a drinking water storage tank, the other from a groundwater well that supplies drinking water.

In addition to the split 400 Area samples, DOH independently collected a drinking water sample from the Laser Interferometer Gravitational-Wave Observatory (LIGO) Facility and 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 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 PNNL in the field and analyzed as unfiltered samples. All 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 and Discharge 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. All samples were analyzed for isotopes of uranium and for H-3. Analyses for gross alpha, gross beta, gamma emitting radionuclides, Sr-90, and Tc-99 were added where appropriate. Discharge samples from the TEF were analyzed for gross alpha, gross beta, gamma emitting radionuclides, and H-3.

#### *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

Comparisons of DOH and DOE Contractor data are summarized in [Table 3.2.1](#). A discussion of how the data are interpreted is presented in [Section 2.2](#). 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](#)).

Cases in which the agreement is not good are discussed in the text. DOH data range concentrations prefaced by the “less than” symbol indicate that some or all results are less than the listed detection limit. For all radionuclides, the concentrations reported by DOH are consistent with historical results, and no anomalous data were encountered.

Analyte	Contractor	# Split Samples	Agreement	DOH Data Range (pCi/g)	Anomalous Data ?
C-14	Fluor <sup>(a)</sup>	3	<b>fair</b>	< 150 to 370	no
Co-60	Fluor	10	good	< 3	no
Cs-137	Fluor	10	good	< 3	no
Gross Alpha	Fluor	17	good	< 4 to 18	no
Gross Beta	Fluor	18	<b>fair</b>	< 1 to 3,400	no
H-3	Fluor	20	good	< 50 to 900,000	no
I-129	Fluor	6	<b>fair</b>	< 0.5 to 18	no
Sr-90	Fluor	6	good	< 0.7 to 1,300	no
Tc-99	Fluor	6	<b>fair</b>	< 5 to 4,100	no
Co-60	PNNL <sup>(b)</sup>	10	good	< 3	no
Cs-137	PNNL	11	good	< 3	no
Gross Alpha	PNNL	14	good	< 4 to 80	no
Gross Beta	PNNL	14	<b>fair</b>	< 1 to 43	no
H-3	PNNL	28	good	< 50 to 22,000	no
Sr-90	PNNL	24	<b>fair</b>	< 0.7 to 1	no
Tc-99	PNNL	11	good	< 5 to 24	no
U-234	PNNL	21	good	< 0.08 to 32	no
U-235	PNNL	21	<b>fair</b>	< 0.04 to 0.9	no
U-238	PNNL	21	good	< 0.07 to 33	no

(a) Fluor Hanford samples include groundwater and discharge water.

(b) PNNL samples include riverbank seep water, surface water, and drinking water.

Table 3.2.1 Summary of Water Samples Split with Fluor and PNNL.

The DOH and Fluor C-14 concentrations in groundwater are in fair agreement, as can be seen in [Figure 3.2.2](#). The results follow the same trend, but the uncertainty bars do not overlap. The DOH detection limit is 150 pCi/L, while the Fluor detection limit is a factor of ten lower.

This fact is reflected in the size of the uncertainty bars in the graph, where the Fluor uncertainty bars are much smaller than those of DOH.

Most of the DOH and Fluor gross beta concentrations in water samples are in good agreement. However, one result, at groundwater well 699-26-33, is in poor agreement, as can be seen in [Figure 3.2.3](#). Historical data at this well is shown in [Figure 3.2.4](#), where it can be seen that the Fluor result for 2009 (third set of data in the figure) is not consistent with all the other data. Furthermore, the Fluor gross beta result is not consistent with measured concentrations of other beta emitters such as Sr-90 or Tc-99.

The DOH and Fluor I-129 concentrations in groundwater are in fair agreement, as can be seen in [Figure 3.2.5](#). The results are similar and follow the same trend, but there is a systematic bias in which Fluor consistently reports higher concentrations than DOH. This systematic bias can be seen in the scatter plot of historical split I-129 concentrations in groundwater, shown in [Figure 3.2.6](#). The preponderance of points to the left of the theoretical line where DOH and Fluor concentrations are equal indicates that Fluor consistently reports higher results.

The DOH and Fluor Tc-99 concentrations in groundwater are in fair agreement. The historical results are shown in [Figure 3.2.7](#). Most concentrations are below 200 pCi/L, and these results are in good agreement. However, the higher concentration results are only in fair agreement, as they are similar and follow the same trend, but the uncertainty bars do not overlap.

The DOH and PNNL gross beta concentrations in water samples (riverbank seep and surface water samples) are in fair agreement. The results are similar, but the uncertainty bars do not overlap for several of the samples, as can be seen in [Figure 3.2.8](#). The scatter plot for historical results, [Figure 3.2.9](#), shows that when concentrations are below 25 pCi/L, the DOH and PNNL results are in good agreement. However, for higher concentrations, there is a systematic bias in which DOH consistently reports higher values than PNNL. In some cases, the DOH results are three times greater than those reported by PNNL. This systematic bias at higher concentrations is evident in the plot of historical gross beta concentrations at riverbank seep location 300 Spr DR 42-2 shown in [Figure 3.2.10](#).

Historically, most DOH and PNNL Sr-90 concentrations in water are in good agreement. For this reporting period, most of the Sr-90 results are below the detection limit. However, two detected results do not agree (100B Spr 39-2 and 100D Spr 099), as can be seen in [Figure 3.2.11](#).

Historically, most of the DOH and PNNL U-235 concentrations in water are in good agreement, as typically the results are below detection limits. However, for cases where U-235 is detected, primarily in 300 Area riverbank seep water, there is a systematic bias in which PNNL often reports higher concentrations than DOH. This trend is evident in the scatter plot of historical results for 300 Area riverbank seep water shown in [Figure 3.2.12](#).

Several of the DOH results at groundwater well 299-W14-13, in the 200 West Area, are higher than typically measured in Hanford groundwater. The upper values for the range of DOH concentrations listed in [Table 3.2.1](#) for H-3, I-129, and Tc-99 come from this well.

DOH also measured C-14 at 13,000 pCi/L from this well, although the DOE contractor did not provide a result for this radionuclide. All the concentrations measured in 2009 at this well are consistent with historical results.

For the prior reporting period (2008), the isotopic uranium concentrations measured by DOH in Columbia River surface water at one of the sites along the 100N Area, 100N HRM 9.8, were higher than typically measured. For example, U-238 concentrations are typically near 0.2 pCi/L, while at HRM 9.8 the concentration was 3 pCi/L. For this reporting period, uranium concentrations at all surface water locations are typical. It appears the 2008 result was an anomaly.

### **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 0.3 to 1.7 pCi/L, and these concentrations are consistent with historical results.

DOH detected elevated isotopic uranium at a 300 Area groundwater well (399-1-17A). Uranium-234 and U-238 concentrations are each near 30 pCi/L, and these results are consistent with those reported over the last several years. The EPA drinking water standard for the sum of all uranium isotopes is 21 pCi/L.

DOH detected elevated C-14 in groundwater well 299-W14-13 (13,000 pCi/L). DOE contractors did not report C-14 results at this well. Similar concentrations were detected by DOH in 2007 and 2008. This well, located in the 200 West Area, had elevated concentrations of several other radionuclides, as discussed in [Section 3.2.4](#). The EPA drinking water standard for C-14 is 2,000 pCi/L.

DOH detected both Bi-214 and Pb-214 in several groundwater samples (one well in the 100 Area, one in the 300 area, and four in the 600 Area), with Bi-214 concentrations ranging up to 59 pCi/L, and Pb-214 concentrations ranging up to 63 pCi/L. DOH analyzed groundwater from two 100K Area wells for Pu-238 and Pu-239/240, and all results were below detection limits.

Gross alpha and gross beta analyses are for the purpose of screening, and are generally indicative of the presence of uranium isotopes and Sr-90, respectively. For samples where both gross alpha and uranium concentrations were analyzed, the gross alpha concentrations were typically consistent with the sum of concentrations from all uranium isotopes.

For example, at groundwater well 399-1-17A, the sum of isotopic uranium concentrations is 63 pCi/L, while the gross alpha concentration is 53 pCi/L. These results are consistent when consideration of the uncertainty range is included.

For samples where both gross beta and Sr-90 concentrations were analyzed, gross beta concentrations were typically consistent with twice the Sr-90 concentrations (gross beta analysis detects the beta emissions from both Sr-90 and its daughter, Y-90). As an example, DOH detected Sr-90 at groundwater well 199-N-14, at a concentration of 1,320 pCi/L. The gross beta result at the same well is 2,710 pCi/L. These results are consistent when consideration of the uncertainty range is included.

Radionuclides detected in drinking water samples include gross alpha (10 pCi/L at Edwin Markham), gross beta (12 pCi/L at Edwin Markham), and H-3 (2,300 and 2,600 pCi/L at 400 Area locations). All concentrations are below EPA drinking water standards (15 pCi/L for gross alpha, 50 pCi/L for gross beta, and 20,000 pCi/L for H-3).

Radionuclides detected in discharge water include H-3 (150 pCi/L). All concentrations were below limits set by the Department of Natural Resources. These limits are 15 pCi/L for gross alpha, 50 pCi/L for gross beta, and 20,000 pCi/L for H-3.

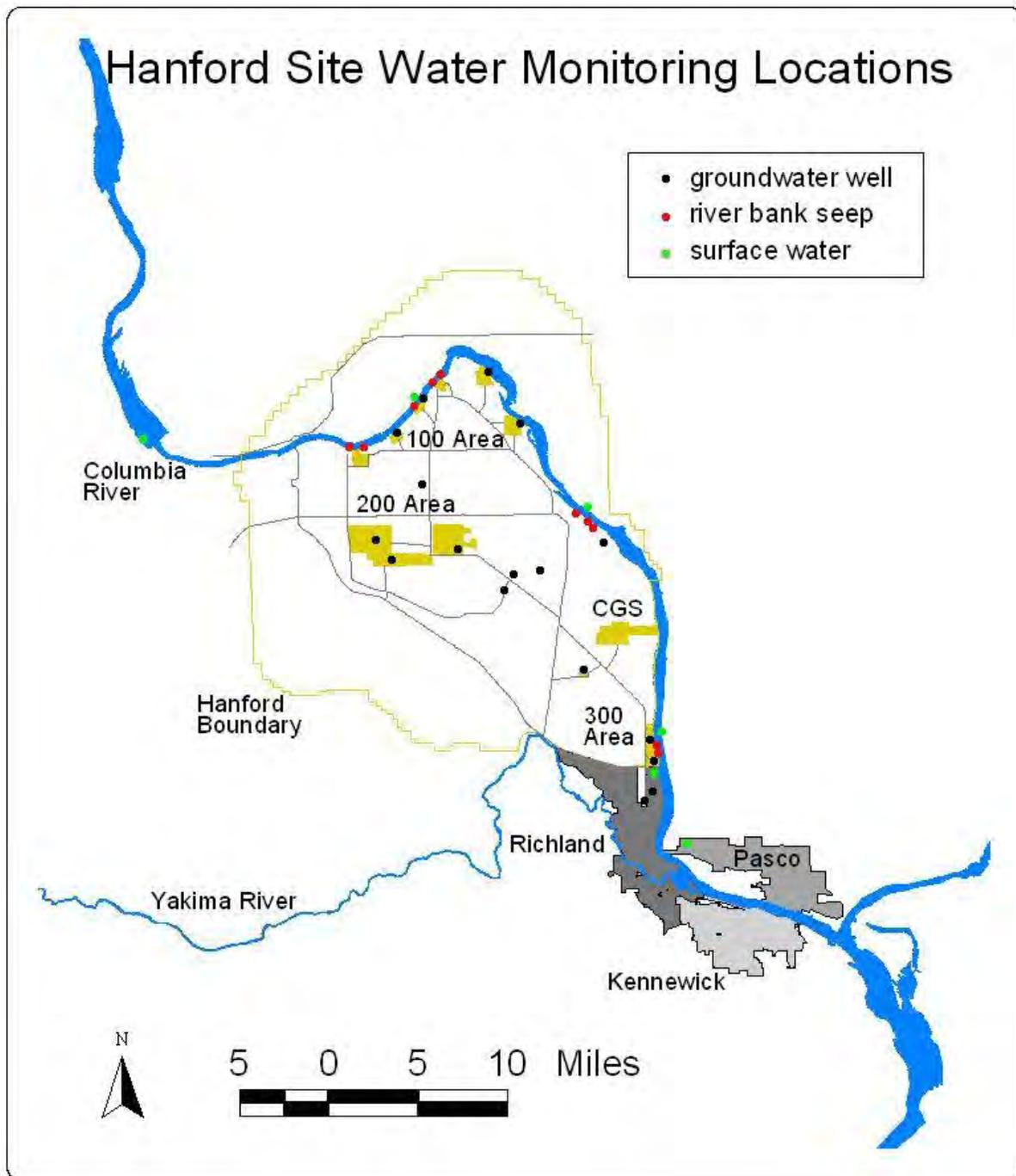


Figure 3.2.1 Split Water Sample Locations

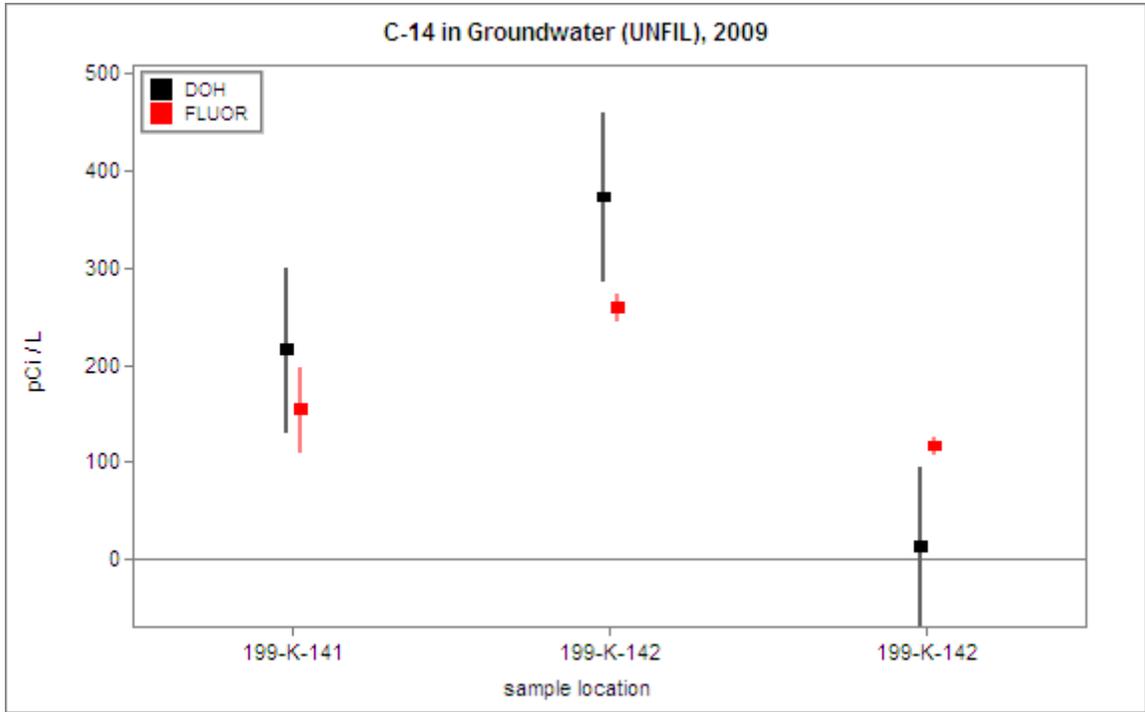


Figure 3.2.2 DOH and Fluor C-14 Concentrations in Groundwater

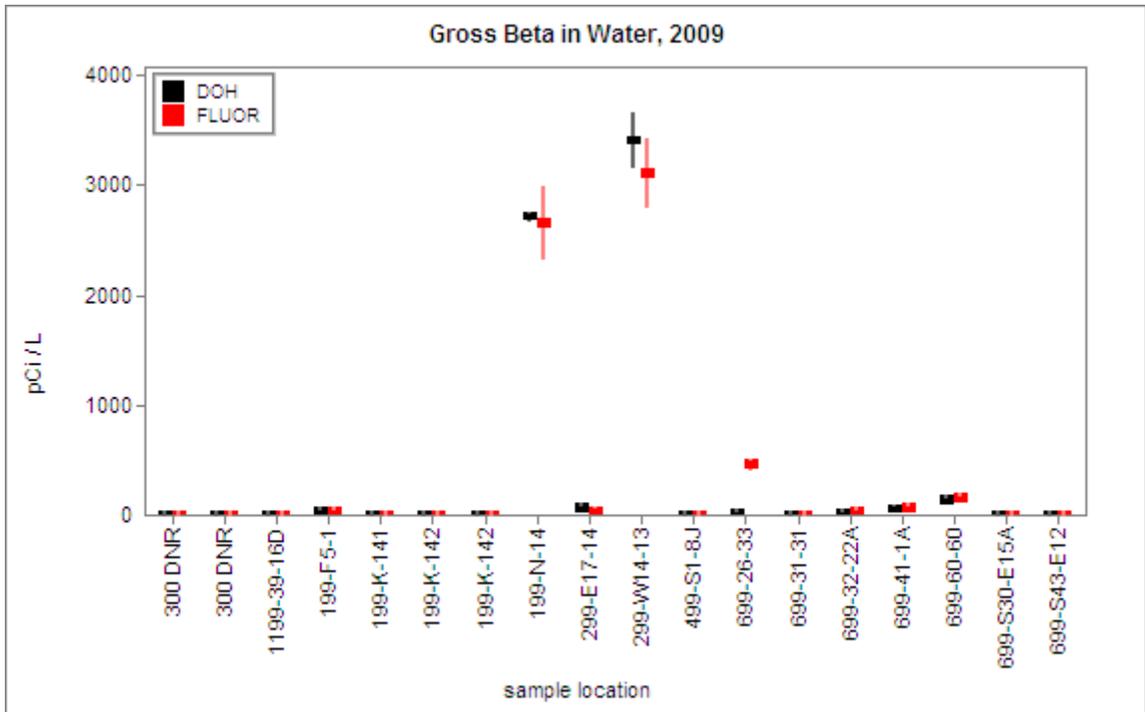


Figure 3.2.3 DOH and Fluor Gross Beta Concentrations in Water Samples

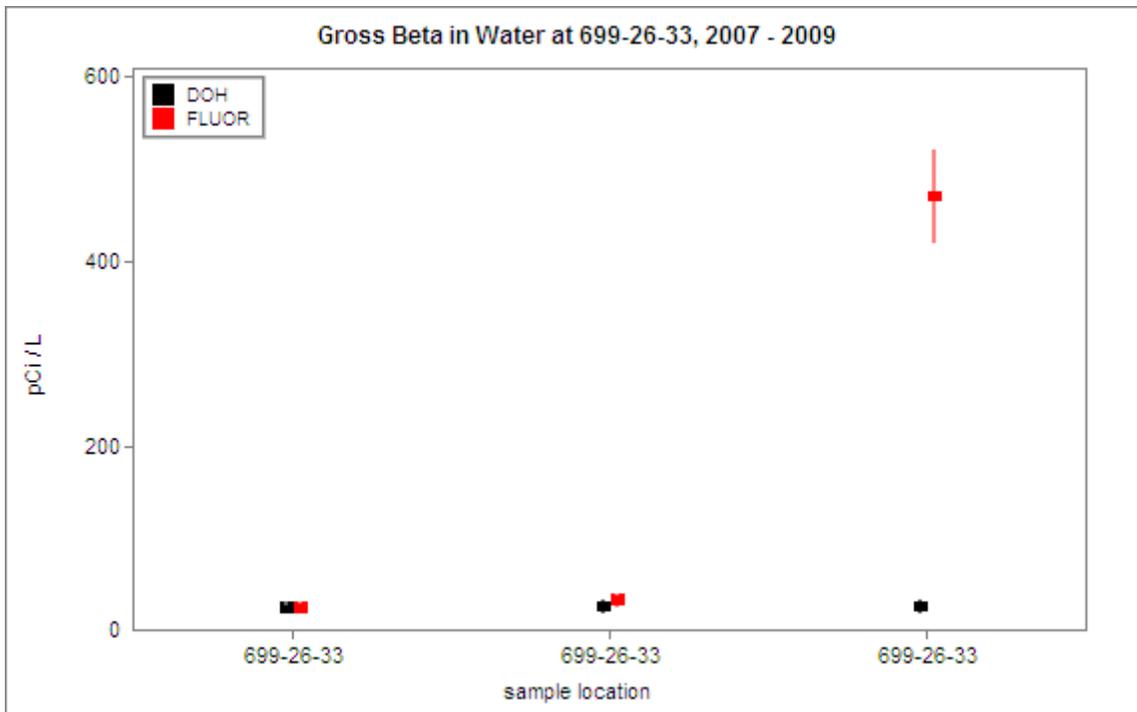


Figure 3.2.4 DOH and Fluor Historical Gross Beta Concentrations at Groundwater Well 699-26-33

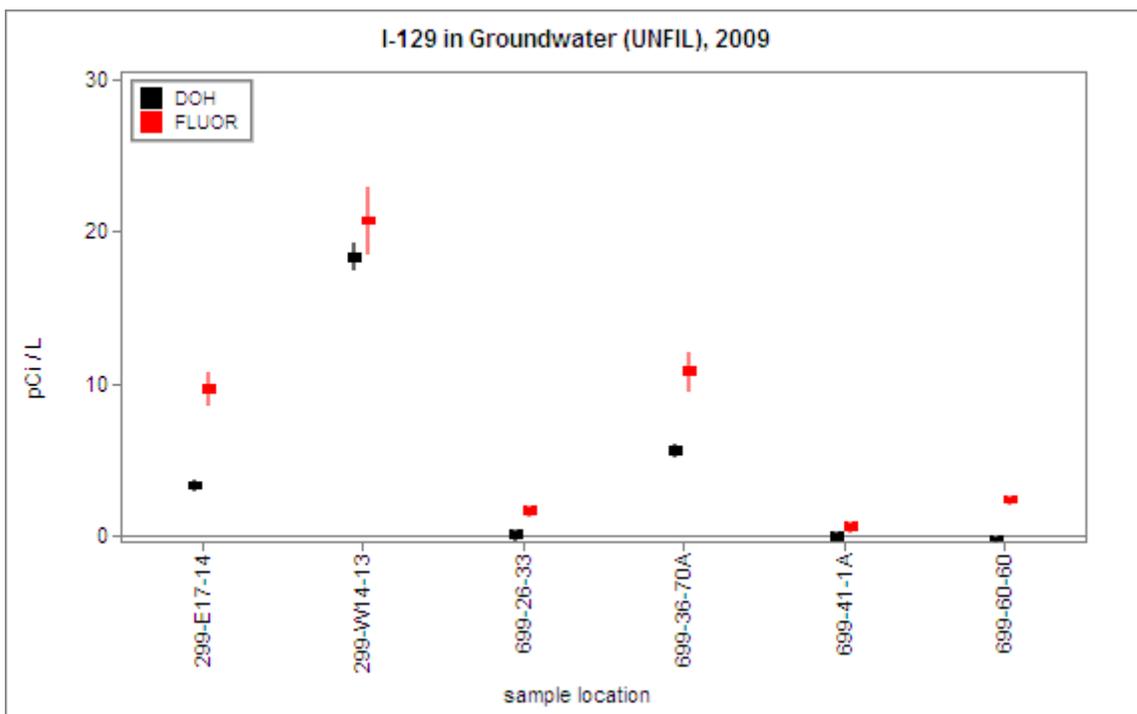


Figure 3.2.5 DOH and Fluor I-129 Concentrations in Groundwater

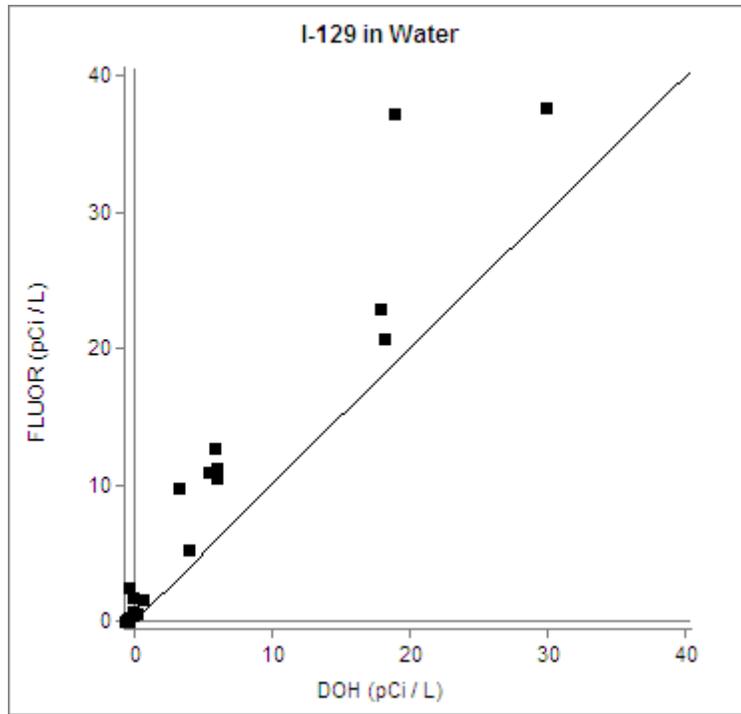


Figure 3.2.6 DOH and Fluor Scatter Plot for Historical I-129 Concentrations in Groundwater

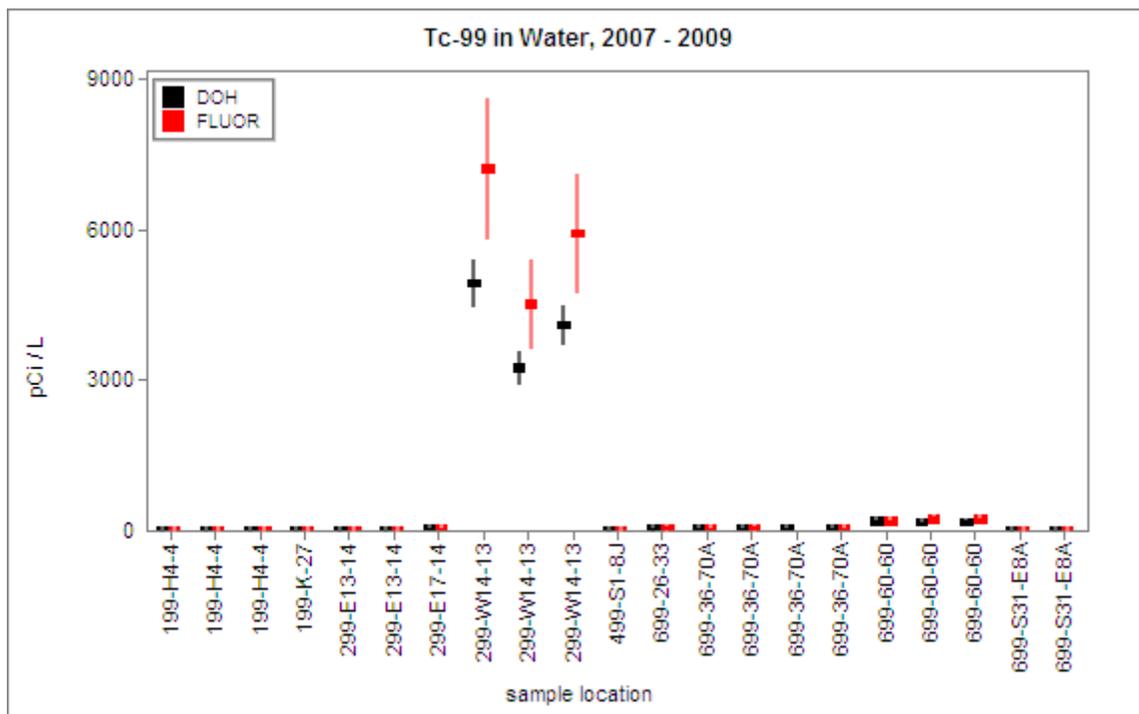


Figure 3.2.7 DOH and Fluor Historical Tc-99 Concentrations in Groundwater

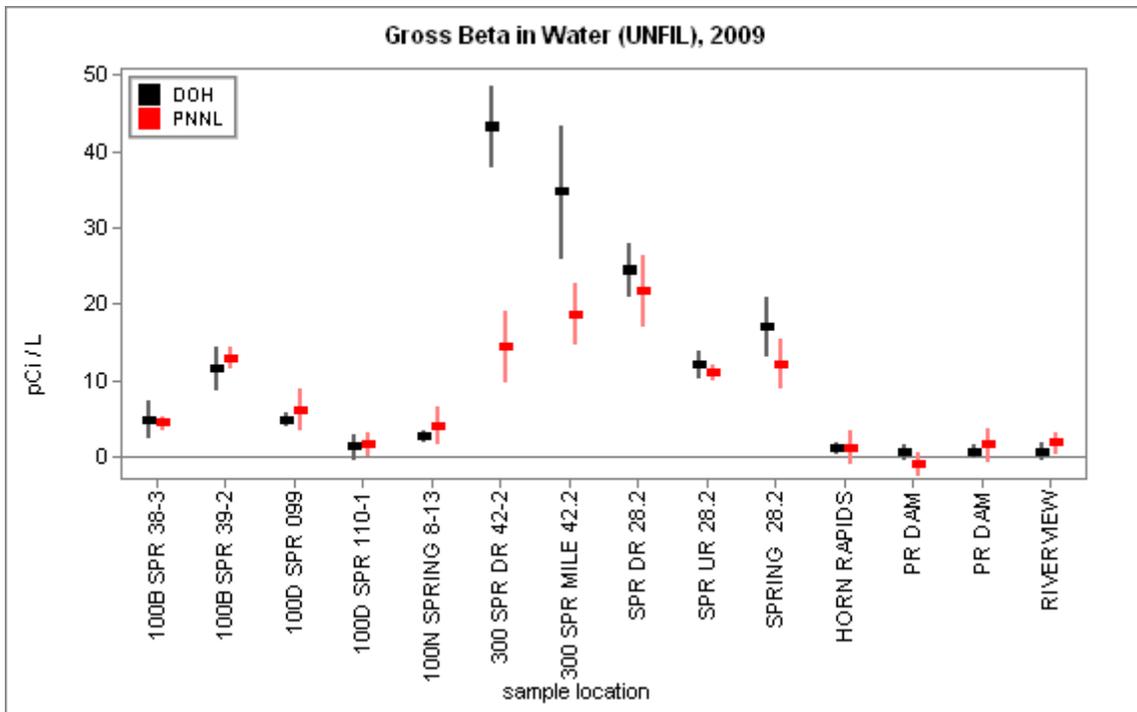


Figure 3.2.8 DOH and PNNL Gross Beta Concentrations in Water Samples

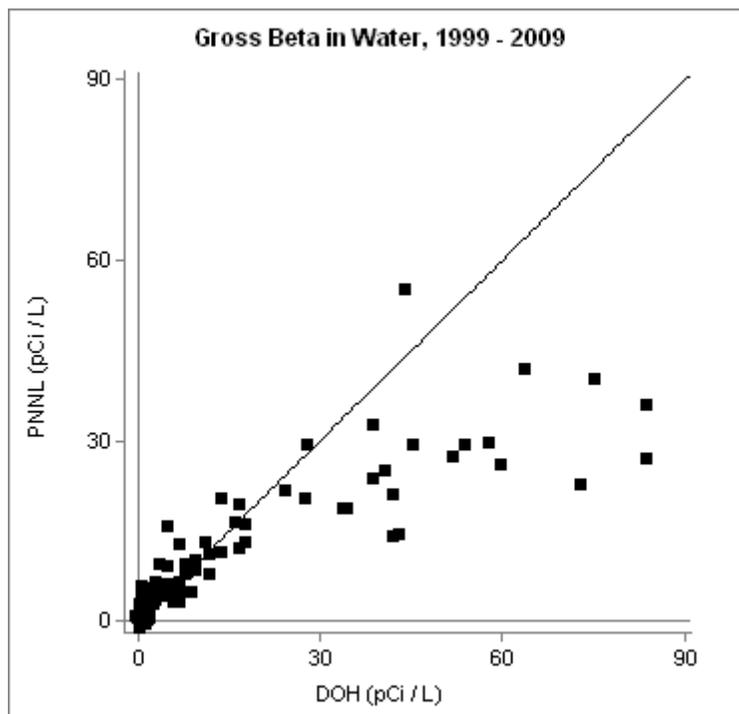


Figure 3.2.9 DOH and PNNL Scatter Plot for Historical Gross Beta Concentrations in Water Samples

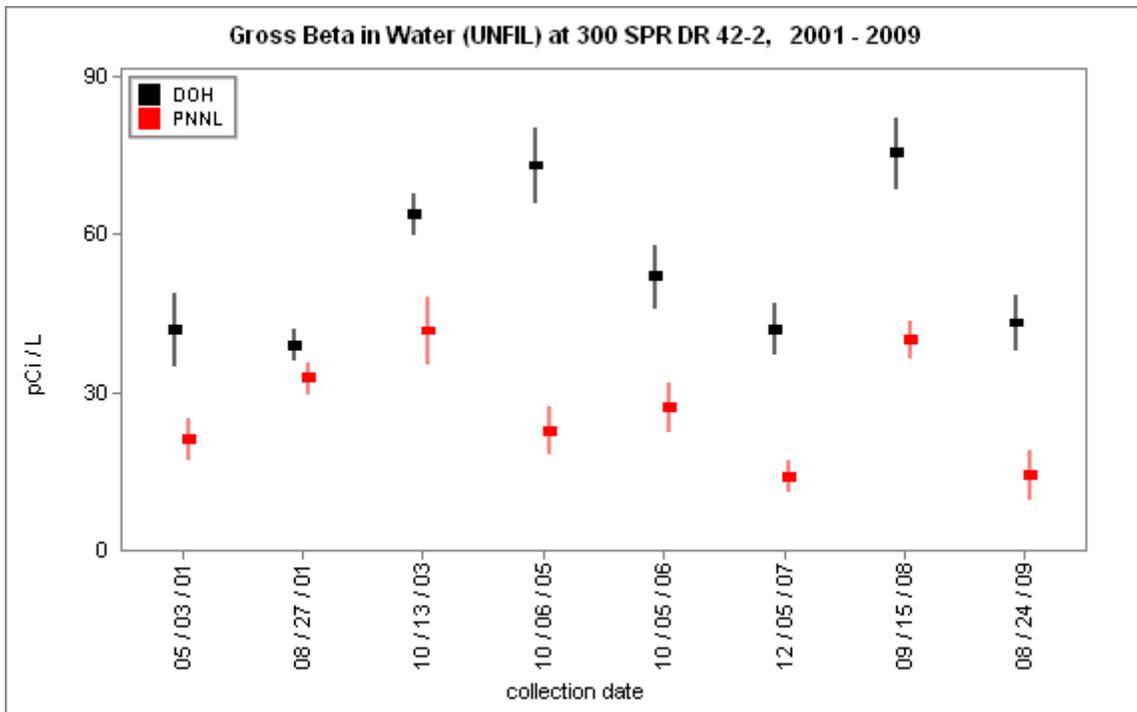


Figure 3.2.10 DOH and PNNL Historical Gross Beta Concentrations in 300 Area Seep Water

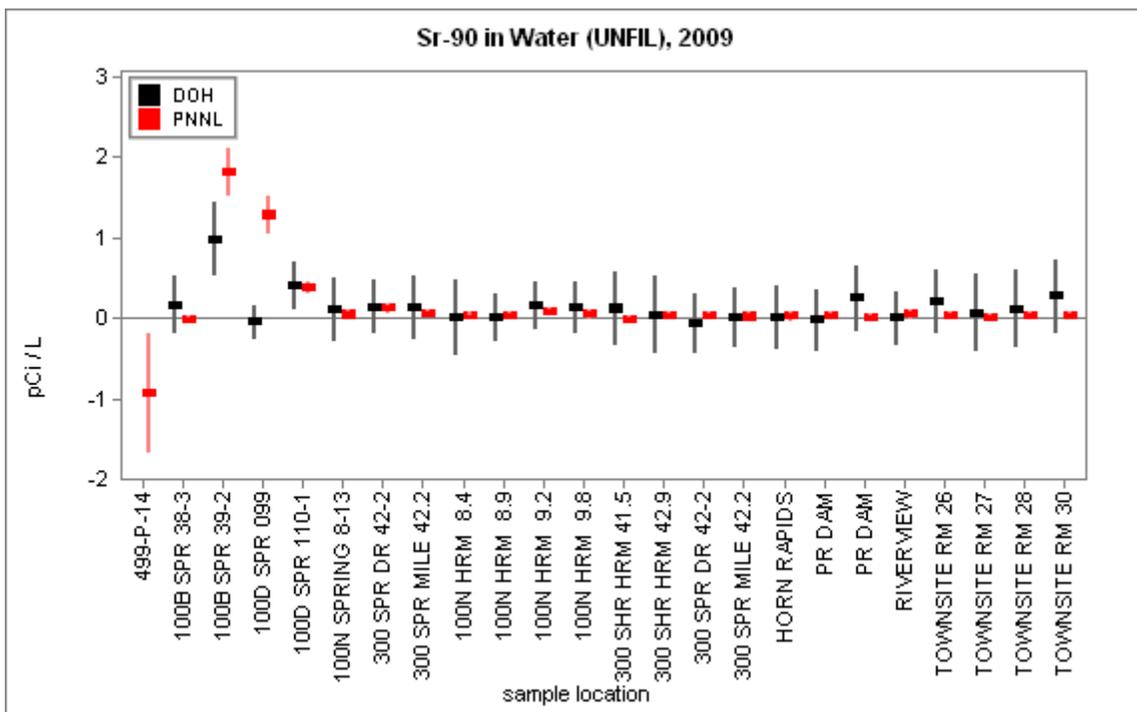


Figure 3.2.11 DOH and PNNL Sr-90 Concentrations Water Samples

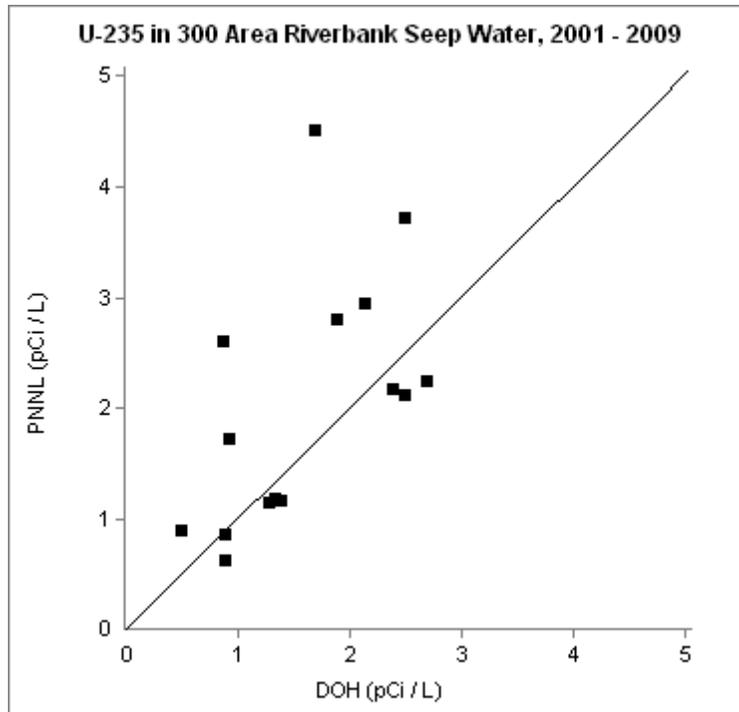


Figure 3.2.12 DOH and PNNL Historical U-235 Concentrations in 300 Area Seep Water

### 3.3 External Gamma Radiation Monitoring

#### Major Findings:

- The DOH and DOE contractor external radiation rates are in good 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 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 are anomalously high due to temporary outdoor storage of radioactive materials, and possibly due to cleanup activities.

#### 3.3.1 Purpose and General Discussion

The Department of Health and DOE contractors monitor external radiation levels 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 Near-Facilities and Operations monitoring program, historically run by Duratek; and the Site-Wide and Offsite monitoring program, historically run by PNNL. 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 PNNL. In addition, DOH will continue to maintain its original TLD sites that were collocated with PNNL. 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. The distant site at Toppenish was discontinued in 2006. Many of the TLD sites are collocated with air monitoring sites.

### 3.3.3 Monitoring Procedures

Collocated TLDs are deployed on a quarterly basis at each monitoring location, with the TLDs retrieved at the end of each calendar quarter. The DOH TLDs are sent to the State Public Health Laboratory where the time-integrated external radiation exposure is determined for the three-month 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

Comparisons of DOH and DOE Contractor data are summarized in [Table 3.3.1](#). A discussion of how the data are interpreted is presented in [Section 2.2](#). 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 agreement for collocated samples is good, and therefore there is no further discussion of the quality of agreement. Some exposure rates reported by DOH are outside the range of historical results and are considered anomalous, and these data are discussed in the text.

Analyte	Collection Period	# Collocated Samples	Agreement	DOH Data Range (mR/day)	Anomalous Data ?
TLD	quarterly	20	good	0.17 to 1.0	yes

Table 3.3.1 Summary of TLD Samples Collocated with MSA

Historically, the agreement between DOH and the DOE contractor (historically Duratek) TLD results has been fair, not good. The DOE contractor systematically reported slightly higher

exposure rates (approximately 10%) than DOH. The discrepancy was primarily observed for third quarter results, and was not understood. However, starting in 2009, a new contractor (MSA) took over this program, and the agreement appears good. Presently, there is not enough historical data with this contractor to ascertain if the same discrepancy exists.

Historically, DOH has measured elevated exposure rates at site 100N Spring, which is within Hanford’s 100N Area (see [Figure 3.3.2](#)). 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.

Elevated exposure rates have been seen at location 100K East Basin, within Hanford’s 100K East Area, since 2005. [Figure 3.3.3](#) 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 may have resulted in temporary increased dose rates. Measurements along the Columbia River at the 100K Area, 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	150	0.14 to 0.29	no

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 3.3.4](#). This graph includes data from these 44 sites plus the five sites collocated with MSA (all 49 DOH TLD sites). As can be seen, average dose rates are similar for all location categories. However, the maximum dose rate is highest for the sites that are onsite and near to contaminated or operational facilities.

The average exposure rate at sites distant from Hanford is slightly lower than that 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.

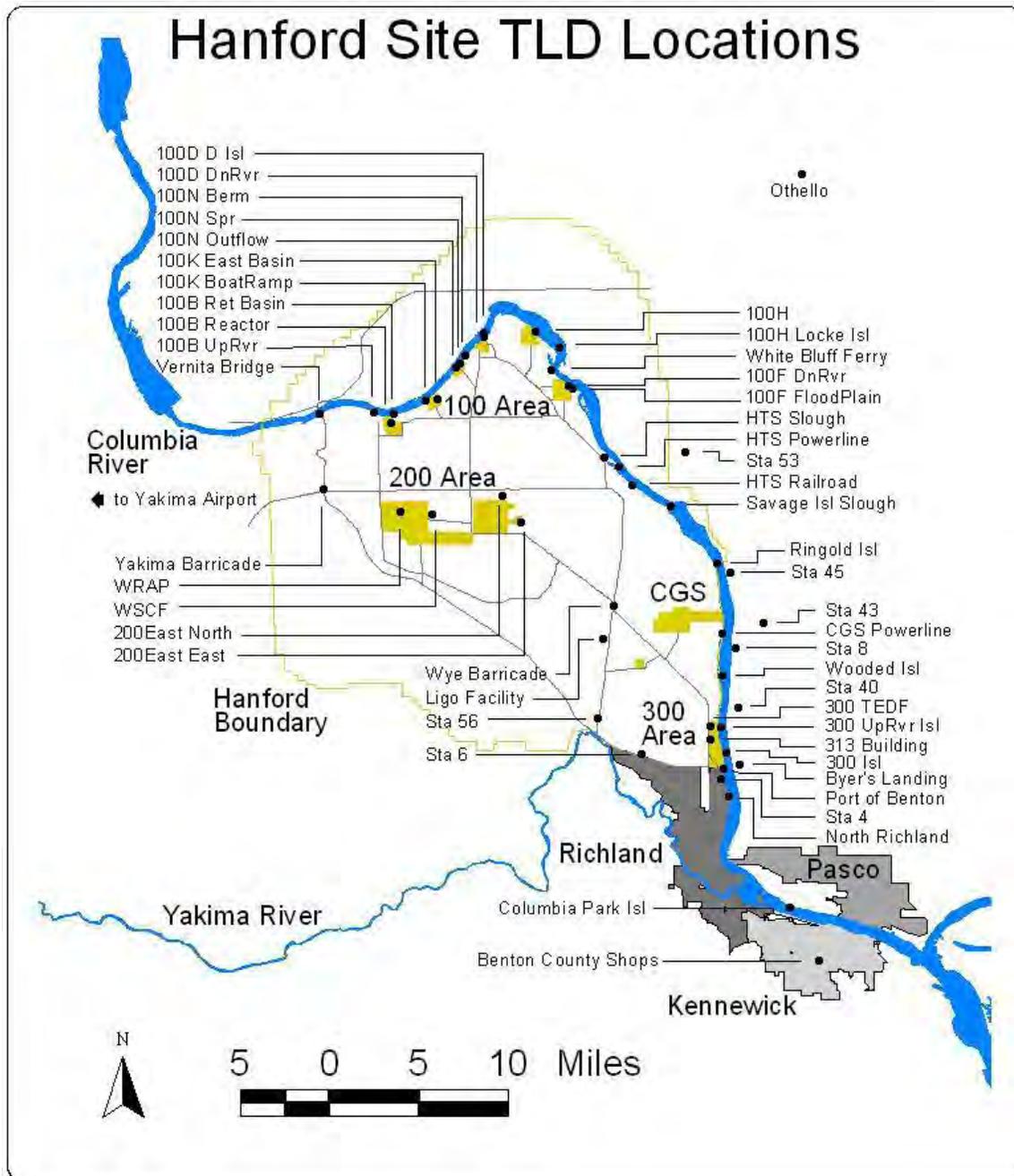


Figure 3.3.1 DOH External Radiation Monitoring (TLD) Locations

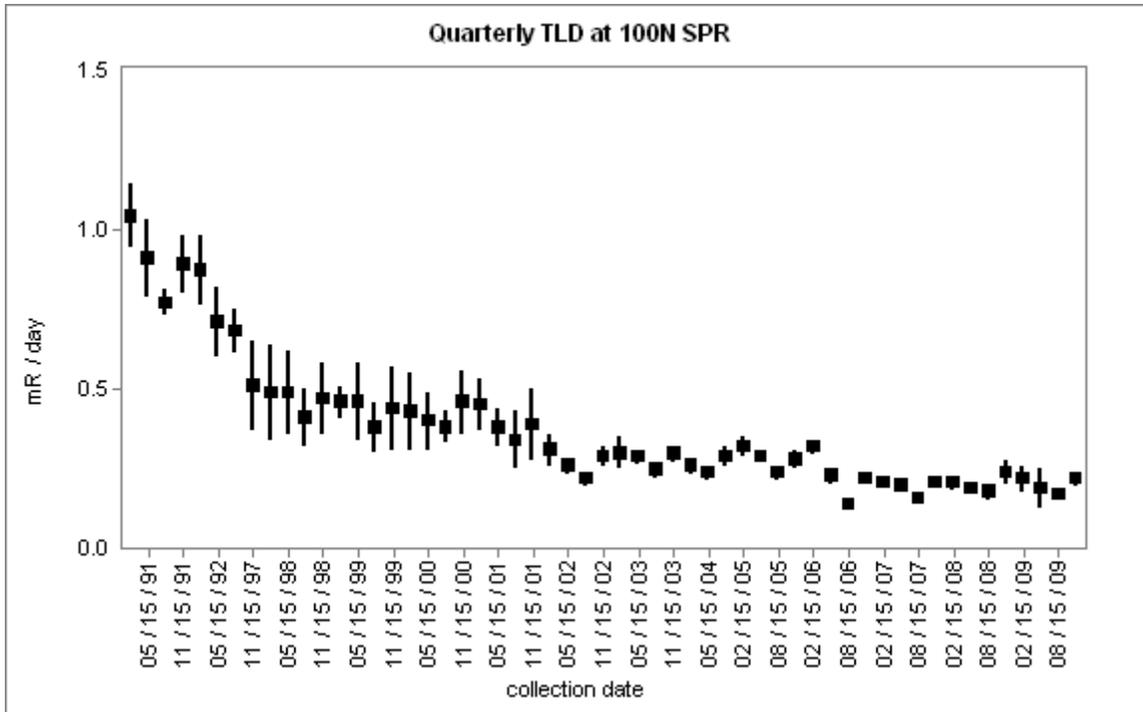


Figure 3.3.2 DOH Historical TLD Results at Location 100N SPR in the 100N Area

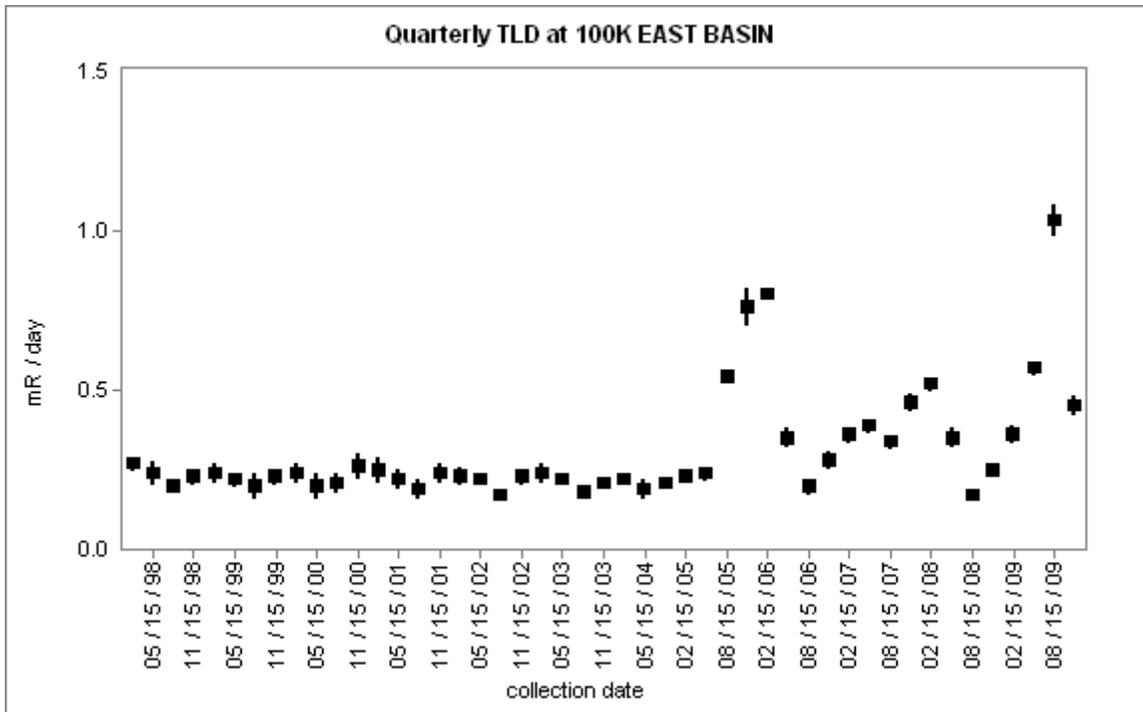


Figure 3.3.3 DOH Historical TLD Results at Location 100K East Basin in the 100K Area

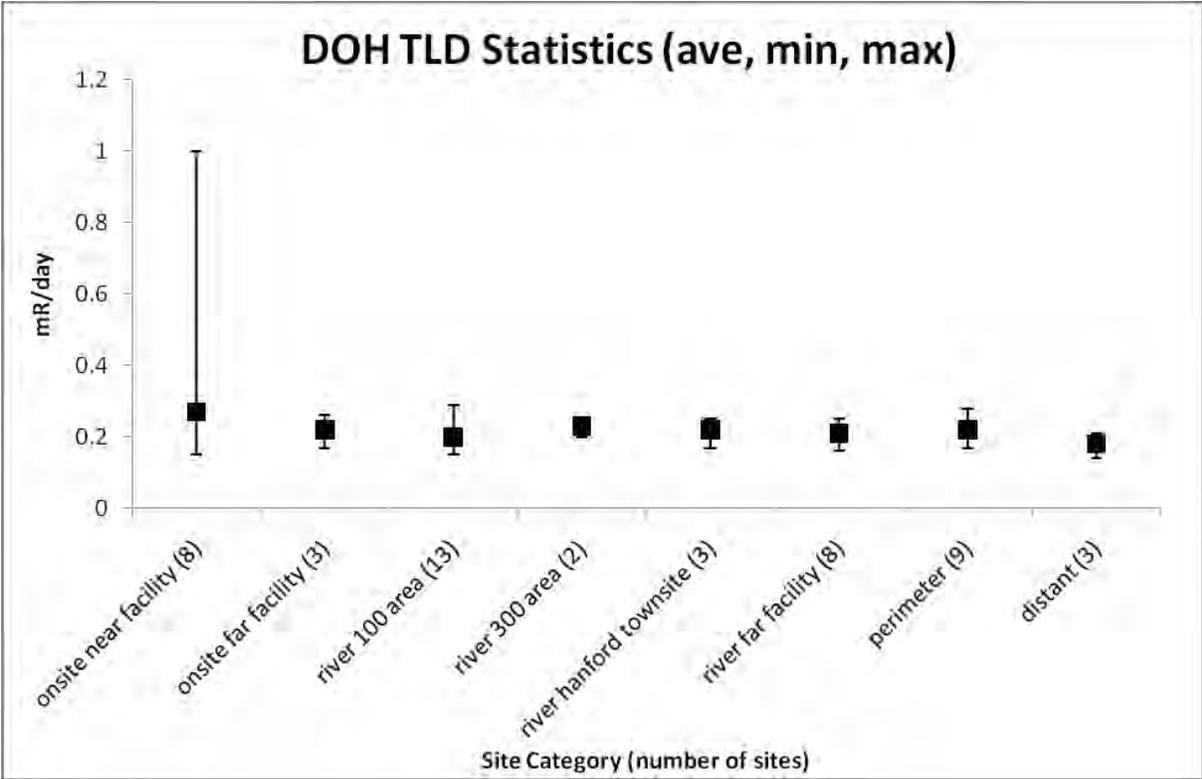


Figure 3.3.4 Statistical TLD Values for the Different DOH Site Location Types

### 3.4 Soil and Sediment Monitoring

#### Major Findings:

- DOH and DOE contractor radionuclide concentrations are in good agreement.
- Most DOH radionuclide concentrations are consistent with historical results. Cesium-137 and Eu-152 have been found at higher than average concentrations in the 300 Area for the last several years. Concentrations of most radionuclides in sediment samples from locations adjacent to or downriver from Hanford are consistent with those from locations upriver from Hanford.

#### 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, also consistently seen in soil and sediment, occurs naturally in the environment in addition to being present from Hanford operations.

#### 3.4.2 Sample Types and Monitoring Locations

Ten sediment samples from the Columbia River and one sediment sample from West Lake were split with PNNL. Soil samples were not included in this reporting period's oversight program. The Columbia River sediment samples were collected upriver from Hanford at Priest Rapids Dam, along the Hanford Site at the 100B Area, the Hanford Slough, the Old Hanford Townsite, and the 300 Area, and downriver from Hanford at McNary Dam. West Lake is located on the Hanford Site between the 100 and 200 Areas.

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 and 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. Sediment sample locations are shown in [Figure 3.4.1](#).

### 3.4.3 Monitoring Procedures

Soil samples 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

Comparisons of DOH and DOE Contractor data are summarized in [Table 3.4.1](#). A discussion of how the data are interpreted is presented in [Section 2.2](#). 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](#)).

Most of the sediment sampling sites are along the Columbia River, while the West Lake site is anomalous, as it is located inland on Hanford's central plateau at a known contaminated site. As such, the range of DOH data presented in [Table 3.4.1](#) first lists the range for the Columbia River sites, and then in parenthesis lists the West Lake result if a radionuclide was detected.

Cases in which the agreement is not good are discussed in the text. DOH data range concentrations prefaced by the "less than" symbol indicate that some or all results are less than the listed detection limit. Some concentrations reported by DOH are outside the range of historical results and are considered anomalous, and these data are discussed in the text.

Analyte	Collection Period	# Split Samples	Agreement	DOH Data Range (pCi/g)	Anomalous Data ?
Co-60	annual	11	good	< 0.01 to 0.013	no
Cs-137	annual	11	good	0.03 to 0.5, (1.5)	<b>yes</b>
Eu-152	annual	9	good	< 0.05 to 0.2	<b>yes</b>
Eu-154	annual	8	good	< 0.05	no
Eu-155	annual	8	good	< 0.06	<b>yes</b>
Gross Beta	annual	1	good	(23)	no
Pu-238	annual	5	good	< 0.005	no
Pu-239/240	annual	5	good	< 0.004 to 0.02	no
Sr-90	annual	11	good	< 0.002 to 0.01, (0.42)	no
Tc-99	annual	1	good	< 0.2	no
U-234	annual	11	good	0.7 to 3, (1.3)	no
U-235	annual	11	good	0.03 to 0.09, (0.07)	no
U-238	annual	11	good	0.6 to 3.1, (1.4)	no

Table 3.4.1 Summary of Columbia River Sediment Samples Split with PNNL

Cesium-137 and Eu-152 have been found at higher than average concentrations in the 300 Area (site 300 Spr DR 42-2) for the last several years. For both radionuclides, there is a trend of increasing concentration with time, as can be seen in [Figures 3.4.2 and 3.4.3](#).

One of the DOH Eu-155 results (100B Spr 38-3) has an anomalously large negative concentration (see [Section 2.2.3](#) for a discussion of negative results), as can be seen in [Figure 3.4.4](#). If all sources of uncertainty are accounted for, the uncertainty range (see [Section 2.2.1](#) for a discussion of measurement uncertainty) of the result should include zero. As can be seen in the figure, this is not the case. DOH does not account for all sources of uncertainty. In particular for this case, the uncertainty from subtraction of laboratory background, when no peak was present in the background energy spectrum, was not included since this uncertainty is not part of the software algorithm. This example is a case in point why a more complete uncertainty analysis is required for a rigorous quantitative comparison of data (see [Section 2.2.4](#)).

Historically, split Sr-90 concentrations are in good agreement, and this is the case for the 2009 data. In 2008, however (the previous year's report), the split Sr-90 concentrations were only in fair agreement, which now appears to be an anomaly for that particular year.

The split isotopic uranium concentrations are in good agreement for samples collected in 2009. However, this agreement is anomalous, as historically the results are only in fair agreement due to a systematic bias in which the PNNL concentrations are approximately 80% of those reported by DOH. As an example, the U-238 concentrations for 2009 are shown in [Figure 3.4.5](#), while a scatter plot of historical results from 1999 to 2008 is shown in [Figure 3.4.6](#). The scatter plot clearly shows the historical systematic bias, which is not seen in a scatter plot of the 2009 data.

The historical discrepancy in uranium results for soil and sediment originates from different laboratory procedures. DOH completely dissolves soil and sediment samples prior to analysis and reports uranium present in the entire sample, whereas the contractor laboratory reports only the uranium that can be leached from the surface of the soil or sediment granules. Laboratory procedures have not been changed, so the anomalous agreement of the 2009 data is not currently understood.

DOH started sampling sediment at West Lake in 2007. The West Lake concentrations are higher than those typically found in Columbia River sediment; however, the area is known to be contaminated. The concentrations for this reporting period are consistent with those found since 2007.

In 2008 (the previous reporting period), 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. For this reporting period (2009), the measured concentrations are consistent with average 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 1.4 to 4.3 pCi/g. While these concentrations are elevated compared to typical Columbia River sediment, they are consistent with historical results at that location. Uranium contamination is well known in the 300 Area.

### **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 than 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.

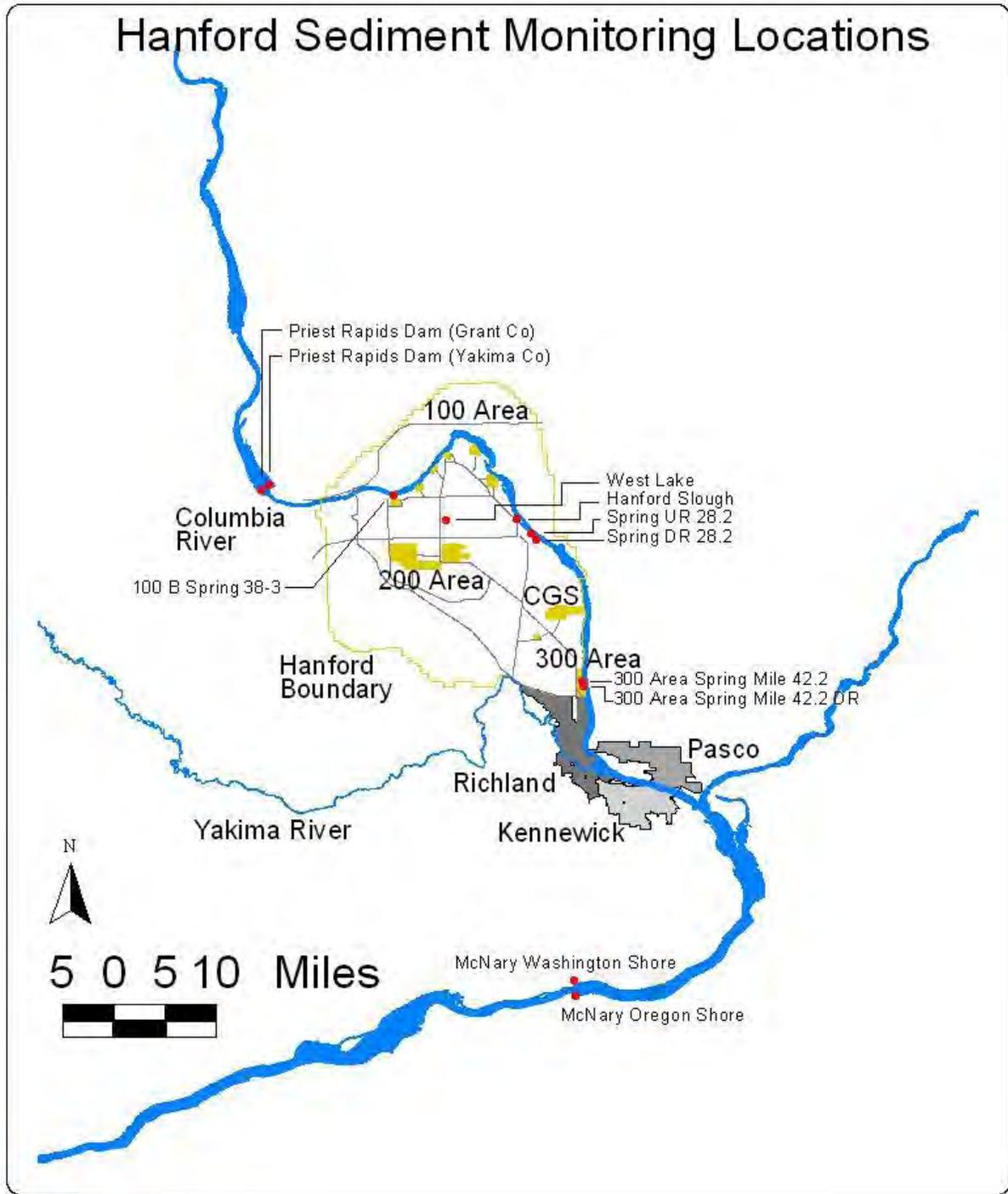


Figure 3.4.1 Split Sediment Monitoring Locations

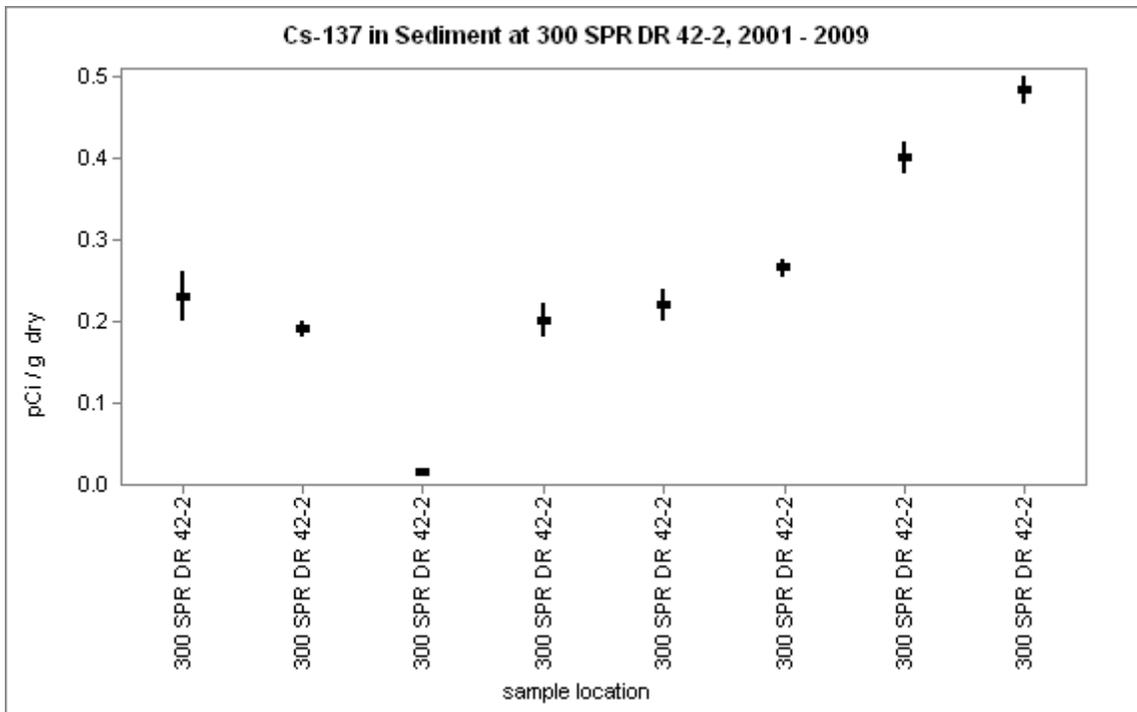


Figure 3.4.2 DOH Historical Cs-137 Concentrations in Sediment in the 300 Area

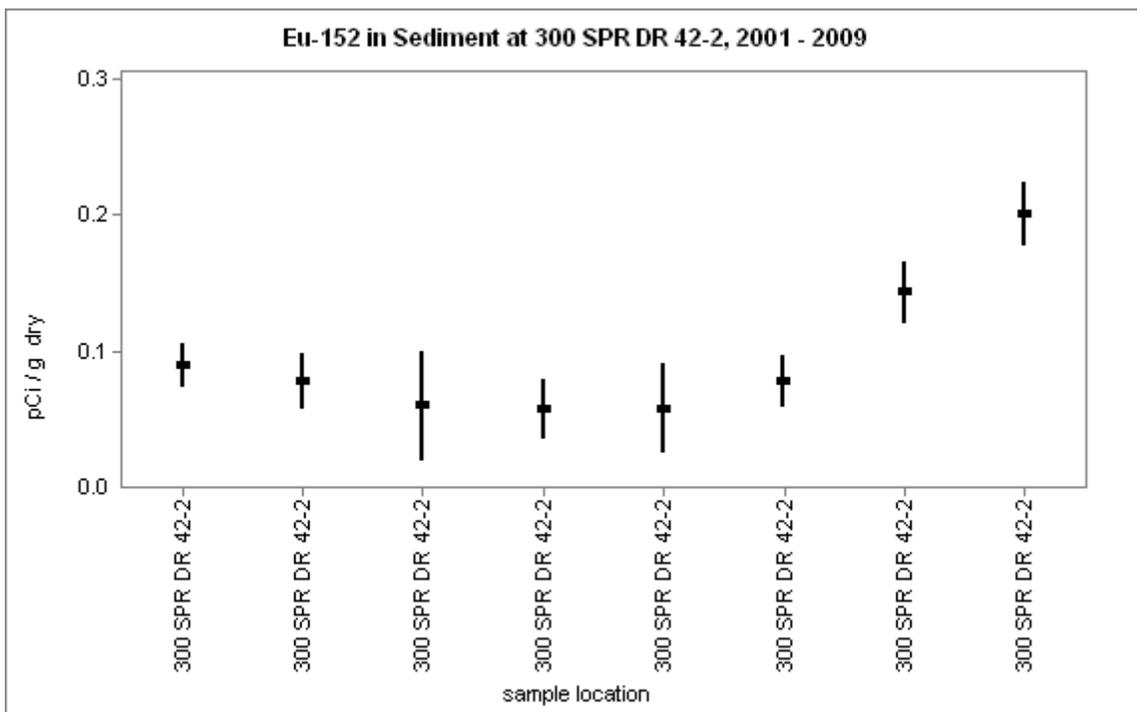


Figure 3.4.3 DOH Historical Eu-152 Concentrations in Sediment in the 300 Area

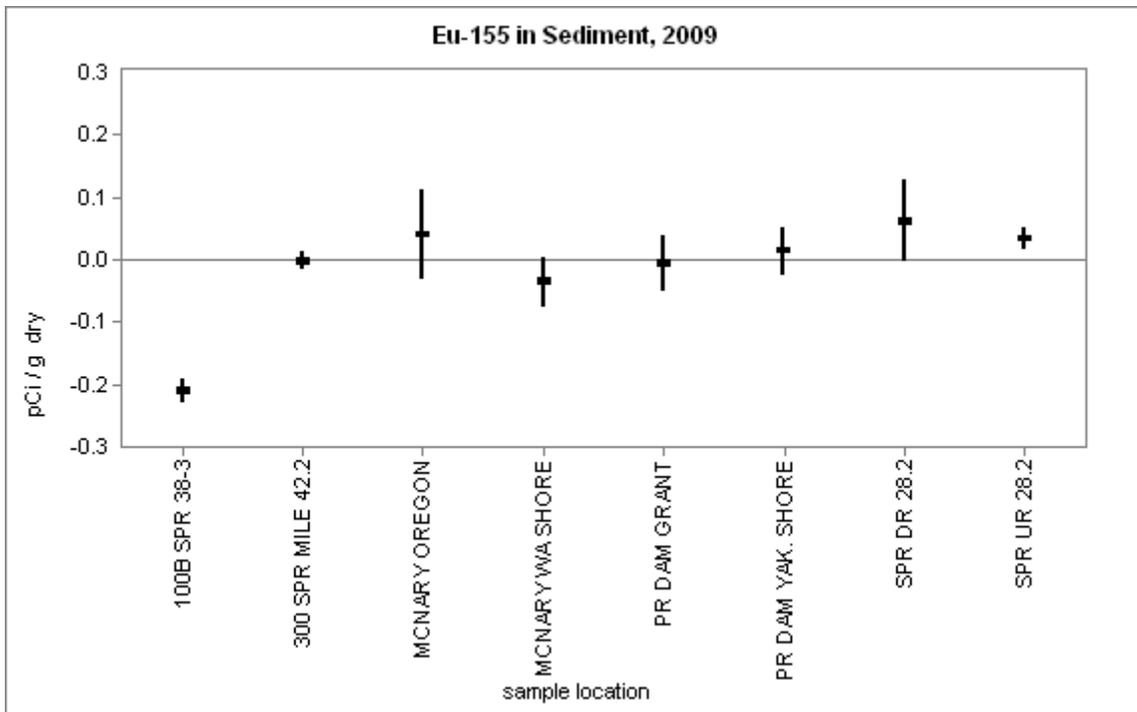


Figure 3.4.4 DOH Eu-155 Concentrations in Sediment

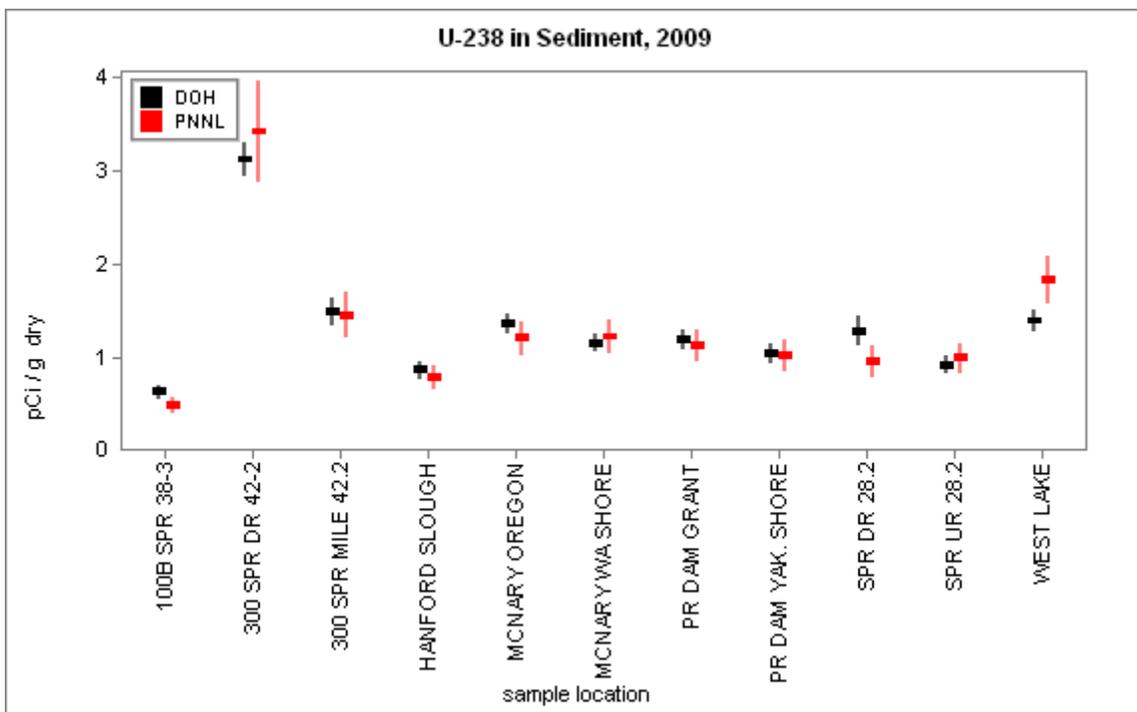


Figure 3.4.5 DOH and PNNL U-238 Concentrations in Sediment

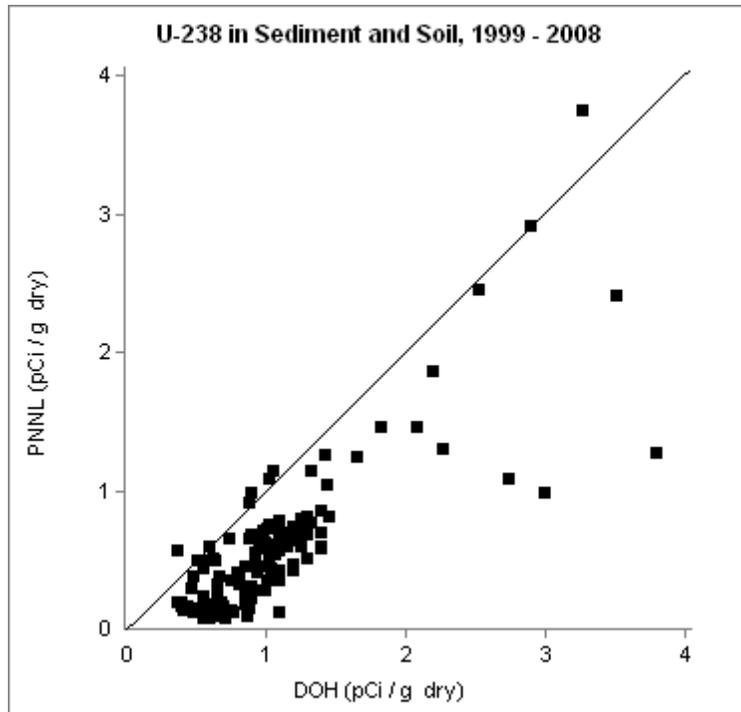


Figure 3.4.6 DOH and PNNL Scatter Plot for Historical U-238 Concentrations in Soil and Sediment

## **3.5 Farm Products Monitoring**

### Major Findings:

- The DOH and DOE contractor concentrations of gamma emitting radionuclides, Sr-90, and tritium (H-3) are all in good agreement.
- All DOH concentrations are below detection limits and consistent with historical results.

### **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 airborne contamination has deposited on plants that may be consumed by people.

### **3.5.2 Sample Types and Monitoring Locations**

Farm product monitoring for the oversight program included four apple samples, one leafy vegetable sample, four 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 PNNL and then split with DOH. Samples are generally collected once a year, at a time when the products are being harvested. DOH and PNNL independently analyze the samples and then compare results.

Solid 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

Comparisons of DOH and DOE Contractor data are summarized in [Tables 3.5.1](#) and [3.5.2](#). A discussion of how the data are interpreted is presented in [Section 2.2](#). 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](#)).

Cases in which the agreement is not good are discussed in the text (for this reporting period, all results are in good agreement). DOH data range concentrations prefaced by the “less than” symbol indicate that some or all results are less than the listed detection limit. The concentrations reported by DOH are consistent with historical results, and no anomalous data were encountered.

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	< 0.02	no
Sr-90	annual	9	good	< 0.06	no

Table 3.5.1 Summary of Solid Farm Product Samples Split with PNNL

Analyte	Collection Period	# Split Samples	Agreement	DOH Data Range (pCi/L)	Anomalous Data ?
Cs-137	annual	6	good	< 7	no
H-3	annual	6	good	< 50	no

Table 3.5.2 Summary of Wine Samples Split with PNNL

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

PNNL has a much lower detection limit for H-3 in wine (10 pCi/L) than DOH (50 pCi/L). PNNL detected very small concentrations of H-3 in all six wine samples, with values ranging from 13 to 23 pCi/L. These concentrations detected by PNNL are well below the DOH detection limit.

PNNL detected Sr-90 (0.006 pCi/g) in the one leafy vegetable sample. The DOH concentration for that sample was also 0.006 pCi/g; however, the DOH detection limit was 0.02 pCi/g, and therefore the DOH result is considered not detected. The Sr-90 concentrations are shown in [Figure 3.5.1](#). Historically, the agreement for Sr-90 ranges from

good to fair, as occasionally the split concentrations are similar but the uncertainty bars do not overlap.

### **3.5.5 Other Discussion**

DOH occasionally detects small concentrations of Sr-90 in farm products, but all results were below the DOH detection limit for this reporting period.

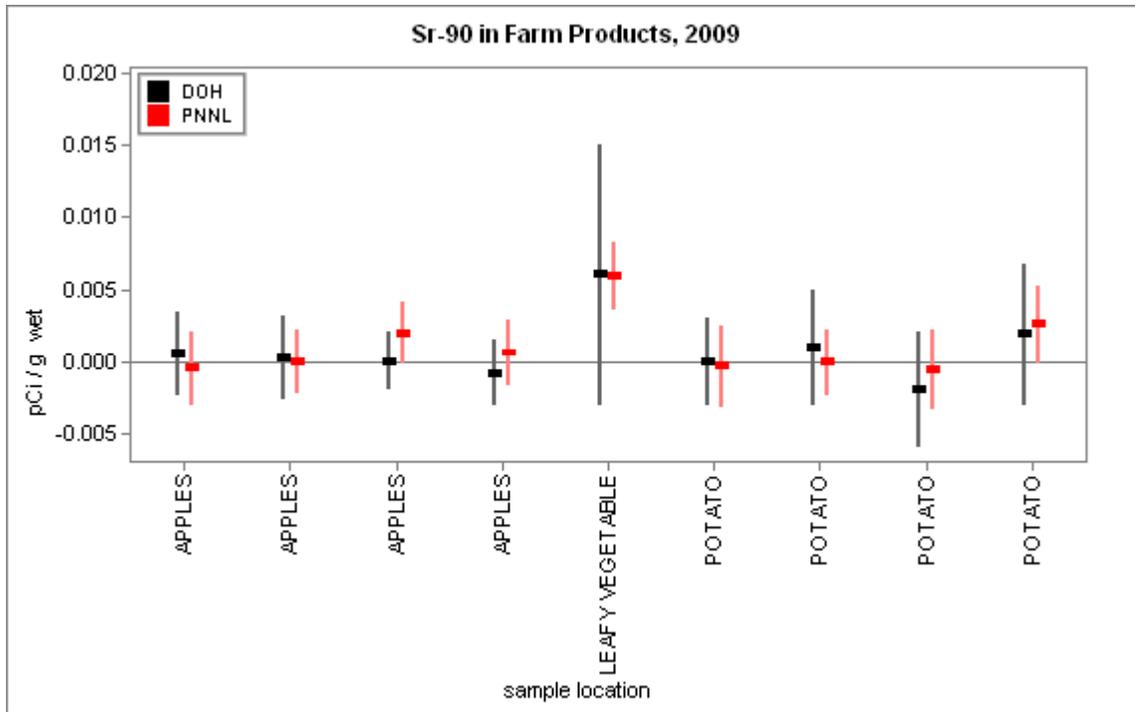


Figure 3.5.1 DOH and PNNL Sr-90 Concentrations in Farm Products

## **3.6 Fish and Wildlife Monitoring**

### Major Findings:

- DOH and DOE contractor concentrations of gamma emitting radionuclides are in good agreement, with all results below the detection limit. Concentrations of Sr-90 are in fair agreement, with results near the detection limit.
- All DOH concentrations are within the range of historical results.

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

The Department of Health 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**

A single collocated whitefish sample was collected from the Columbia River adjacent to Hanford's 100 Area.

No split or collocated wildlife samples were collected for this reporting period.

### **3.6.3 Monitoring Procedures**

Fish samples are collected by PNNL. At each location, PNNL collects multiple samples, one or more of which are analyzed by PNNL, 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 not unexpected. Wildlife samples are collected by PNNL and then split with DOH. DOH and PNNL independently analyze the fish and wildlife samples, and then compare results.

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

Comparisons of DOH and DOE Contractor data are summarized in [Table 3.6.1](#). For this reporting period, the data consists of a single collocated whitefish sample. A discussion of how the data are interpreted is presented in [Section 2.2](#). 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](#)).

Cases in which the agreement is not good are discussed in the text. DOH data range concentrations prefaced by the “less than” symbol indicate that some or all results are less than the listed detection limit. The concentrations reported by DOH are consistent with historical results, and no anomalous data were encountered.

Analyte	Collection Period	# Collocated Samples	Agreement	DOH Data Range (pCi/g)	Anomalous Data ?
Co-60	annual	1	good	< 0.008	no
Cs-137	annual	1	good	< 0.006	no
Sr-90	annual	1	<b>fair</b>	0.08	no

Table 3.6.1 Summary of Fish and Wildlife Samples Collocated and Split with PNNL

No gamma emitting radionuclides were detected by either DOH or PNNL in the fish sample.

The DOH and PNNL Sr-90 concentrations in the collocated fish sample, shown in [Figure 3.6.1](#), are in fair agreement. The two results are both near the sample specific detection limit for each laboratory (approximately 0.04 pCi/g), but the uncertainty bars do not overlap. Historically, the agreement ranges from good to fair, as it is common that the collocated concentrations are similar but the uncertainty bars do not overlap (see [Figure 3.6.2](#)).

### 3.6.5 Other Discussion

Only a single sample was collected for this period’s oversight program. For the 2010 oversight program, a deer sample and three fish samples will be reported.

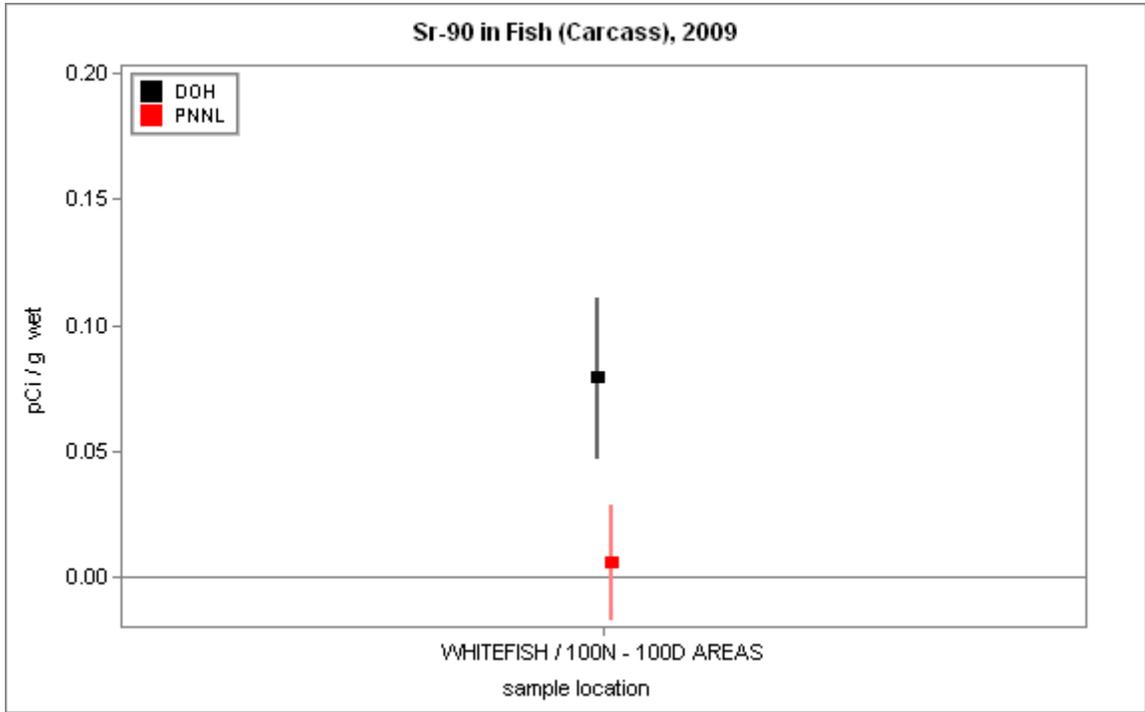


Figure 3.6.1 DOH and PNNL Sr-90 Concentrations in Fish

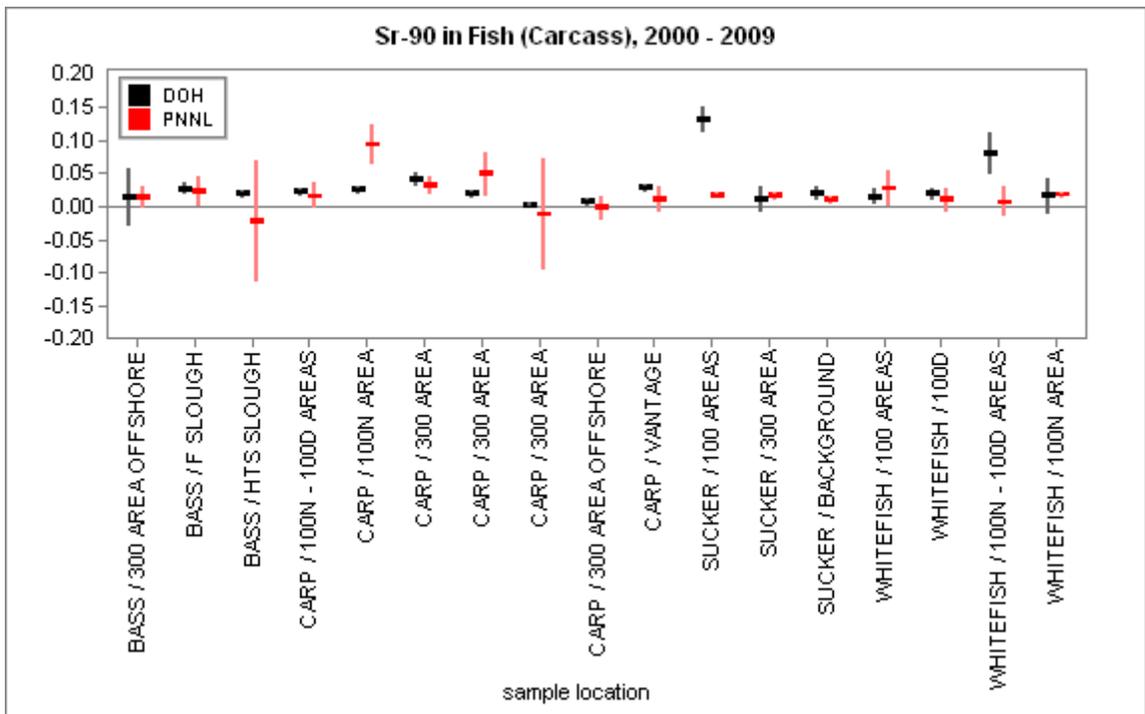


Figure 3.6.2 DOH and PNNL Historical Sr-90 Concentrations in Fish

## 3.7 Vegetation Monitoring

### Major Findings:

- DOH and DOE contractor concentrations of gamma emitting radionuclides are in good agreement, while concentrations of Sr-90 are in fair agreement.
- All DOH concentrations are within the range of historical results.

### 3.7.1 Purpose and General Discussion

The Department of Health 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

Alfalfa was the sole vegetation type collected for this sampling period.

Vegetation is typically collected from locations that could potentially be affected by contaminants from Hanford Site operations, as well as from background locations.

Split samples were collected from two offsite locations (Horn Rapids and Riverview). The sample locations are shown in [Figure 3.7.1](#).

### 3.7.3 Monitoring Procedures

The vegetation samples were collected in late spring, and then split with PNNL. DOH and PNNL independently analyzed the samples. Samples were 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). The samples were not analyzed for isotopes of uranium this period.

### 3.7.4 Comparison of DOH and DOE Contractor Data

Comparisons of DOH and DOE contractor data are summarized in [Table 3.7.1](#). A discussion of how the data are compared is presented in [Section 2.2](#). 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](#)).

Cases in which the agreement is not good are discussed in the text. DOH data range concentrations prefaced by the “less than” symbol indicate that some or all results are less than the listed detection limit. The concentrations reported by DOH are consistent with historical results, and no anomalous data were encountered.

Analyte	Collection Period	# Split Samples	Agreement	DOH Data Range (pCi/g)	Anomalous Data ?
Co-60	annual	2	good	< 0.04	no
Cs-137	annual	2	good	< 0.04	no
Sr-90	annual	2	<b>fair</b>	0.05 to 0.08	no

Table 3.7.1 Summary of Vegetation Samples Split with PNNL

The DOH and DOE contractor results are in fair agreement for Sr-90 (see [Figure 3.7.2](#)). Both report very low concentrations, but the results do not agree. DOH detected concentrations in the range from 0.05 to 0.08 pCi/g, while the DOE results are considered not detected with a detection limit of approximately 0.03 pCi/g. Historically, the agreement for Sr-90 in vegetation ranges from good to fair to poor.

### 3.7.5 Other Discussion

Vegetation samples are typically analyzed for isotopes of uranium, but this was not the case for this reporting period.

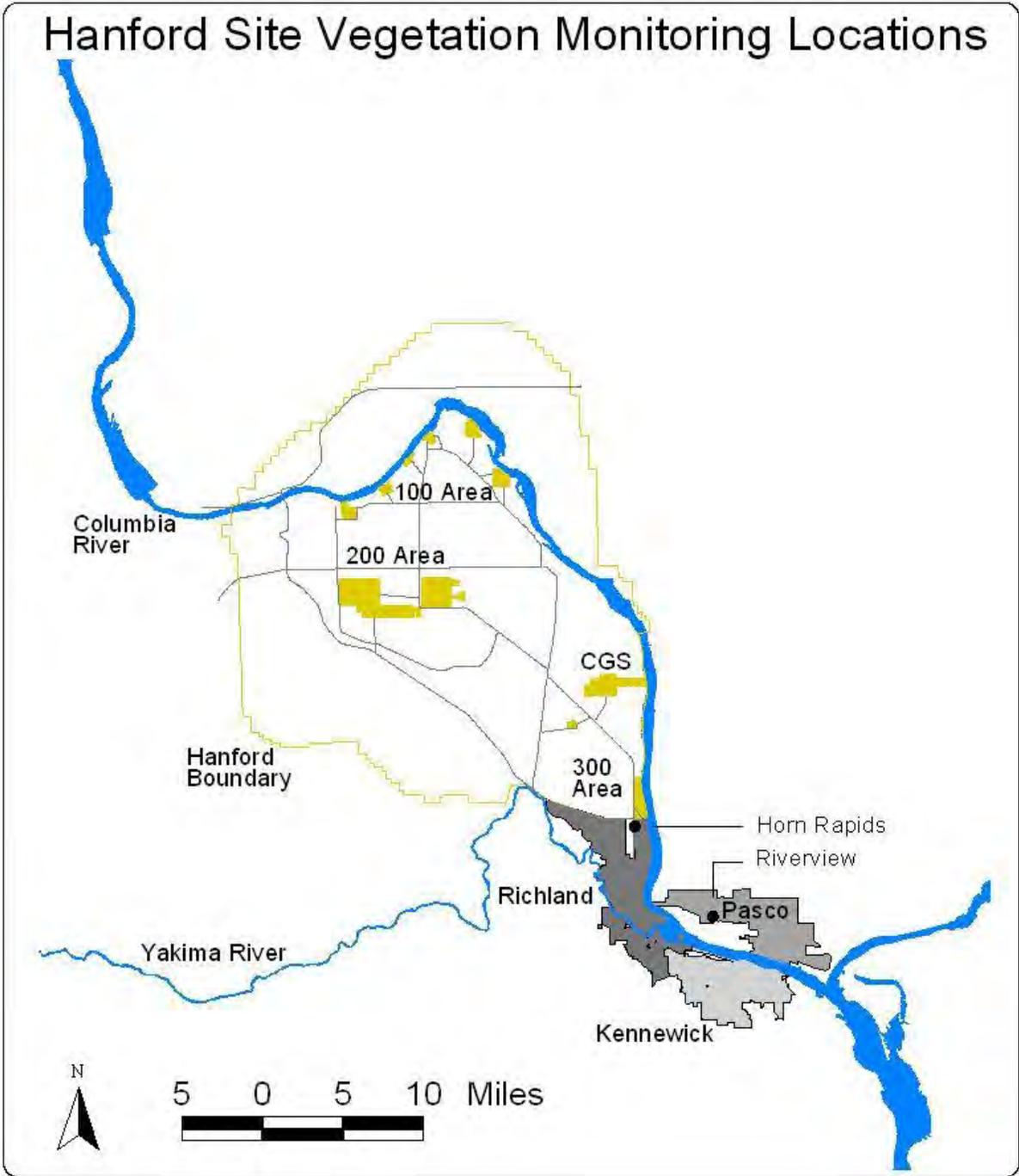


Figure 3.7.1 Vegetation Monitoring Location

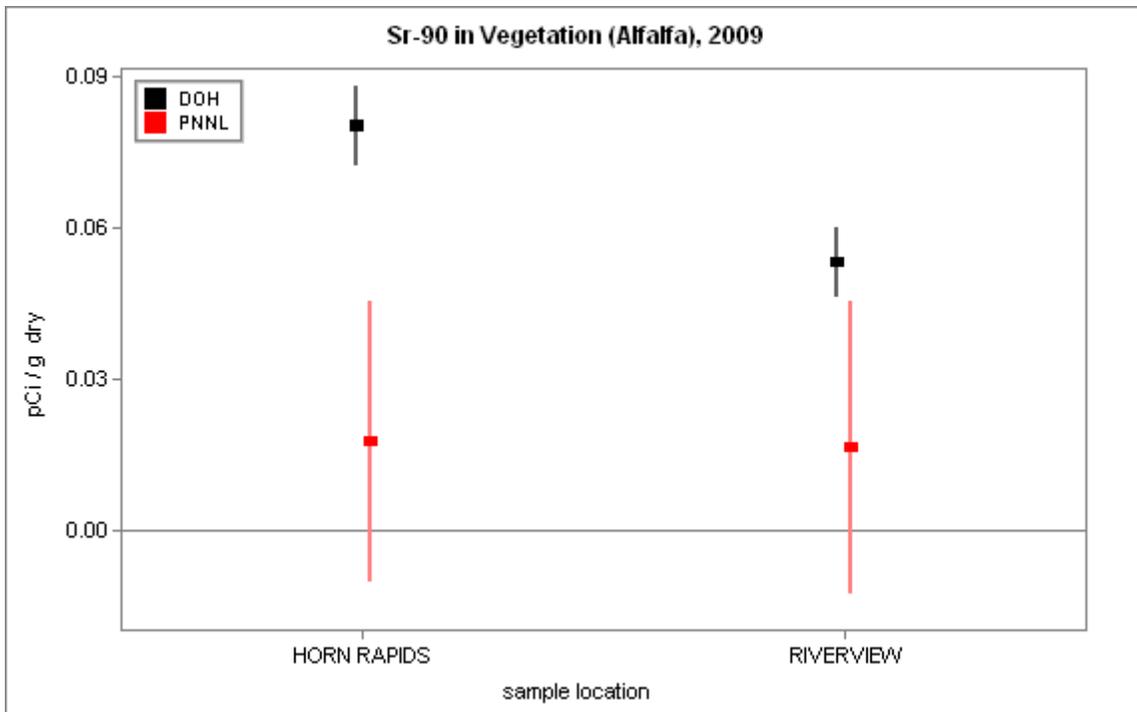


Figure 3.7.2 DOH and PNNL Sr-90 Concentrations in Vegetation

#### 4. Summary of Discrepancies Between DOH and DOE Contractor Results

Categories of *good*, *fair*, and *poor* are used to qualitatively describe the agreement between DOH and DOE contractor results. This section summarizes all data described as fair or poor.

The DOH and DOE contractor gross alpha concentrations in 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.

The DOH and DOE contractor gross beta concentrations in 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. At the lower range of reported concentrations, DOE consistently reports higher values than DOH. At the mid and upper range of concentrations, DOH consistently reports higher values than DOE. In most cases, the discrepancy is less than a factor of two. This discrepancy is observed in historical DOH and DOE results.

The DOH and DOE contractor H-3 concentrations in monthly air samples are in fair 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.

Historically, the DOH and DOE contractor uranium concentrations in quarterly composite air samples are in fair agreement. The data generally follow the same trends; however, the DOE contractor concentrations are significantly lower than the concentrations reported by DOH for cases in which the DOH result is above the detection limit. In this reporting period, however, the concentrations are in good agreement.

The DOH and DOE contractor Cs-137, and isotopic uranium and plutonium 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. For Cs-137, a systematic bias is historically observed in which DOE on average reports concentrations approximately 60% of those reported by DOH.

The DOH and DOE contractor C-14 concentrations in water samples, all of which are groundwater, are in fair agreement. The DOH detection limit is much higher than that of the DOE contractor, and because most of the historical results are near the DOH detection limit, it is difficult to compare the DOH and Fluor results. DOH will target groundwater wells with higher C-14 concentrations for future split sampling.

Historically, the DOH and DOE contractor split I-129 results in water samples, most of which are groundwater, are in poor agreement. The agreement continues to be poor for this reporting period. Three problems have been previously identified. First, for samples in which I-129 is detected, DOH typically reports concentrations significantly lower than those reported by DOE. Second 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 laboratory analysis

method. Third, 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 is currently working on steps to resolve these I-129 issues. The steps were initiated in 2006 and will continue until the issue is resolved. DOH will continue to document the progress of the ongoing investigation in this report.

The first step, which has been completed, was to review the DOH laboratory procedures. DOH identified potential sources of error with sample preparation, sample holding times, and detector calibration. The detector calibration has been investigated and while some bias cannot be ruled out, it would not be sufficient to account for the discrepancies observed in the split sample results. It is suspected that collectively, the laboratory sample preparation and processing protocols caused most of the DOH under-reported I-129 concentrations. To address these issues, new procedures which call for timely sample preparation and shorter holding times between sample collection and analysis have been implemented, starting with samples collected in 2008. These steps are expected to provide a more quantitative assessment of I-129 in the water samples.

For the second step, DOH reviewed sample collection practices and implemented 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 holding. Converting the iodine to a more stable form and then trapping the iodine on resin as soon as the sample is collected eliminates these loss problems.

In 2010, DOH will conduct a set of experiments to evaluate the extent to which sample collection procedures and holding times contribute to reported result bias in historic samples. 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 will provide results over a wider range of activity with which to evaluate the changes in collection practices and laboratory procedures

Fourth, DOH will review PNNL's laboratory procedures for I-129 analysis. Findings will be discussed in future reports.

The DOH and DOE contractor Tc-99 concentrations in water are in fair agreement. DOH will monitor to determine if this discrepancy continues in the future.

The DOH and DOE contractor gross beta concentrations in riverbank seep and surface water samples are in fair agreement. The results are similar, but the uncertainty bars do not overlap for several of the samples. A scatter plot of historical results shows that when concentrations are in the lower range, the DOH and PNNL results are in good agreement. However, for higher concentrations, there is a systematic bias in which DOH consistently reports higher values than PNNL. The laboratory is investigating this bias and results will be presented in a future report.

Historically, most DOH and DOE contractor Sr-90 and U-235 concentrations in riverbank seep and surface water are in good agreement. For this reporting period, most of the results are below the detection limit. However, for cases where the radionuclide was detected, the results often do not agree.

Historically, 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 has been observed for third quarter results, in which DOH reports concentrations slightly lower than those reported by DOE. The bias has also been 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 bias was not observed to a significant degree in this reporting period, and the results are in good agreement.

The DOH and DOE contractor Sr-90 concentrations in soil and sediment samples are in fair agreement for this reporting period, while historically the agreement is good. A scatter plot reveals that DOH consistently reports higher concentrations than PNNL. The linear regression fit to the data indicates that the PNNL concentrations are on average 72% of those reported by DOH. DOH will monitor to determine if this discrepancy continues in the future.

The DOH and DOE contractor uranium concentrations in sediment are in good agreement for samples collected in 2009. However, this agreement is anomalous, as historically the results are only in fair agreement due to a systematic bias

The historical discrepancy in uranium results for soil and sediment originates from different laboratory procedures. DOH completely dissolves soil and sediment samples prior to analysis and reports uranium present in the entire sample, whereas the contractor laboratory reports only the uranium that can be leached from the surface of the soil or sediment granules. Thus, the DOE contractor is less efficient in measuring the natural background component which is distributed throughout the volume of a sample. Laboratory procedures have not been changed, so the anomalous agreement of the 2009 data is not currently understood.

Historically, DOH and DOE contractor Sr-90 concentrations in farm products, fish and wildlife, and vegetation samples range from good to fair to poor agreement. This trend continued for the current reporting period. Strontium-90 concentrations did not agree for the fish and vegetation samples.

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

## 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 sieverts. Since radiation doses are often small, units of millirem (mrem) or millisievert (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<sup>3</sup>)

	Nuclide	Volume (m <sup>3</sup> )	Method*	Standard LLD (100 min.)
Gamma	I-131*	450	INGe	2.00E-02

### Air Filter (pCi/m<sup>3</sup>)

	Nuclide	Volume (m <sup>3</sup> )	Method	Standard LLD (100 min.)
Beta	Gross	450	αβ Cntr	1.00E-03

### Quarterly Composite Air Filter (pCi/m<sup>3</sup>)

	Nuclide	Volume (m <sup>3</sup> )	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
				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<sup>3</sup>)

	Nuclide	Volume (m <sup>3</sup> )	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<sup>3</sup>) Continued

	Nuclide	Volume (m <sup>3</sup> )	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	αβ 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/ αβ 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
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
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
				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 (1000 min.)	Standard LLD (100 min.)
	Nuclide	Volume (L)	Method		
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	$\alpha\beta$ 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. Random Uncertainty

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

B. Uncertainty (standard error) of the sample mean (U)

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

C. Lower Limit of Detection (LLD)

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

D. Definitions

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 $(\text{BKG}/T_2)^{1/2}$ )
sample cpm	=	counts per minute of sample
t	=	elapsed time between sample collection and counting
T <sub>1</sub>	=	sample count time
T <sub>2</sub>	=	background count time
T <sub>1/2</sub>	=	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.
CFR	Code of Federal Regulations

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.
DWS	Drinking Water Standard
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 $0.01 \text{ J kg}^{-1}$ ( $1 \text{ rad} = 0.01 \text{ gray}$ ).
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 ( $1 \text{ rem} = 0.01 \text{ sievert}$ ).
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
NO <sub>2</sub> +NO <sub>3</sub>	Nitrite + Nitrate
Pu-238	Plutonium-238
Pu-239/240	Plutonium-239/240
Ru-106	Ruthenium
Sb-125	Antimony
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