Hanford Environmental Radiation Oversight Program

2012 Data Summary Report

May 2014

Washington State Department of Health

Office of Radiation Protection
Division of Environmental Health

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For more information or additional
copies of this report, contact:

Environmental Sciences Section
Office of Radiation Protection
Department of Health
309 Bradley Blvd., Suite 201
Richland WA 99357
509-946-0564
FAX: 509-946-0876

If you need this publication in an alternate format,
call 800-525-0127. For TTY/TDD call 800-833-6388

David Jansen, Director
Office of Radiation Protection

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Office of Radiation Protection

David Jansen, Office Director
Mike Priddy, Manager, Environmental Sciences Section

Lynn Albin
Mike Brennan
Kristin Felix
Eileen Kramer
Scott McDonald
Thomas Rogers
Bob Ruben
Scott Van Verst

Public Health Laboratory

Romesh Gautom, Director, Public Health Laboratories
Blaine Rhodes, Director, Public Health Laboratories Environmental Laboratory Sciences
Bud Taylor, Supervisor, Environmental and Radiation Sciences

Caitlin Bannan
Catherine Franklin
Richard Hinderer
Karin Kerr
Paul Marbourg
Steve Officer
Josephine Pompey
John Raney
David Robbins
Magdalena Skrzypkowski
Hung Tran

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Acronyms

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

Summary

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

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

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

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

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

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

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

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

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

1. Introduction

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

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

The primary objectives of the oversight program are:

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

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

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

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

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

2. The Hanford Environmental Radiation Oversight Program Description

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

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

2.1 Laboratory Qualifications

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

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

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

2.2 Interpretation of Results

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

2.2.1 Uncertainty in Radioactivity Measurements

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

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

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

2.2.2 Detection Limits

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

2.2.3 Laboratory Background and Negative Results

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

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

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

2.2.4 Techniques for Comparison of DOH and DOE Contractor Data

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

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

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

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

2.2.4.1 Qualitative Comparisons

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

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

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

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

2.2.4.2 Regression Analysis and Scatter Plots

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

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

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

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

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

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

2.2.5 Comparison of Current DOH Results to Historical Results

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

2.2.6 Gamma Analysis

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

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

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

3. Environmental Monitoring Results

This section presents the DOH and DOE contractor results for the Hanford Environmental Radiation Oversight Program. The types of samples collected are intended to encompass all of the potential public exposure pathways. These samples include air (Section 3.1); groundwater, riverbank seep water, surface water, drinking water, and discharge water (Section 3.2); dosimeters measuring external gamma radiation (Section 3.3); soil and sediment (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 air concentrations are in fair agreement for gross alpha and gross beta. The concentrations are similar and follow the same trends over time, but there is a small systematic discrepancy between the data sets.
- The DOH and DOE contractor monthly composite tritium (H-3) results are in poor agreement. The discrepancy is not understood at this time and is under investigation.
- The DOH and DOE contractor quarterly composite results are in good agreement for gamma emitting radionuclides and in fair agreement for isotopes of uranium. In all cases, the concentrations are very small.
- The DOH data analysis and QA/QC process for semiannual composite results are not complete, so these data will be discussed in a future report.
- Most DOH concentrations are consistent with historical results.

3.1.1 Purpose and General Discussion

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

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

3.1.2 Sample Types and Monitoring Locations

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

DOH collected air samples collocated with the Near Facilities and Operations program at six locations, five of which are near facilities that have the potential to emit radionuclides to the air. These locations include a tank farm (C Farm), the Environmental Restoration Disposal Facility (ERDF-SE), and the Plutonium Finishing Plant (PFP-N165), all in the 200 Area; the 100K East Area fuel storage basins (100K East Basin); and a burial ground in the 600 Area (618-10 BG N548). The sixth collocated site, which is not near any facility, is at the Wye Barricade.

DOH collected air samples collocated with the Site-Wide and Offsite program at six locations. These locations include the 300 Area Water Intake, Wye Barricade, Prosser Barricade, and Yakima Barricade, which are located throughout the Hanford Site; Station 8, which is located across the Columbia River from the Hanford perimeter; and Battelle Complex, which is located in the nearby community of Richland. The Yakima Barricade is in the prevailing upwind direction of potential sources of airborne radioactivity. The results at Wye Barricade are used for both the Near Facilities and Operations program and the Site-Wide and Offsite program.

DOH also collects biweekly air samples at the LIGO facility in the 600 Area. The air concentration data collected at this site in 2012 are similar to historical results. This sampling location is not collocated with DOE.

The DOH collocated air sampling sites are shown in Figure 3.1.1 (note that the 618-10 BG N548 site is not shown on the map).

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.

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 DOE 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 “definitively detected” above the detection limit. In this situation, the number of detected results is typically too small for a meaningful quantitative comparison by a statistical analysis.

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

The Site-Wide and Offsite program also collects monthly atmospheric water vapor for tritium (H-3) analysis by continuously drawing air through samplers containing adsorbent silica gel. Collocated samples are collected from only two locations for this analysis, the 300 Water Intake and Battelle Complex. The collected water is distilled from the silica gel and analyzed for its tritium content.

3.1.4 Comparison of DOH and DOE Contractor Data

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

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

Analyte	Collection Period	# Collocated Samples	Agreement	DOH Data Range (pCi/m^3)	Anomalous Data ?
Gross Alpha	biweekly[(a)]	246	**fair**	0.0001 to 0.01	**yes**
Gross Beta	biweekly[(a)]	246	**fair**	0.0008 to 0.05	no
H-3	monthly	25	**poor**	< 0.6 to 9	no
Co-60	quarterly	20	good	< 0.001	no
Cs-134	quarterly	12	good	< 0.001	no
Cs-137	quarterly	20	good	< 0.001	no
Eu-152	quarterly	12	good	< 0.001	no
Eu-154	quarterly	11	good	< 0.001	no
Eu-155	quarterly	12	good	< 0.001	no
Ru-106	quarterly	12	good	< 0.01	no
Sb-125	quarterly	12	good	< 0.003	no
U-234	quarterly	12	**fair**	< 0.000005 to 0.0001	no
U-235	quarterly	12	good	< 0.000004	no
U-238	quarterly	12	**fair**	< 0.00003 to 0.00009	no
Am-241[(b)]	semiannual	4			
Co-60[(b)]	semiannual	8			
Cs-134[(b)]	semiannual	8			
Cs-137[(b)]	semiannual	8			
Eu-152[(b)]	semiannual	8			
Eu-154[(b)]	semiannual	8			
Eu-155[(b)]	semiannual	8			
Pu-238[(b)]	semiannual	8			
Pu-239/240[(b)]	semiannual	8			
Pu-241[(b)]	semiannual	2			
Ru-106[(b)]	semiannual	8			
Sb-125[(b)]	semiannual	8			
Sr-90[(b)]	semiannual	7			
U-234[(b)]	semiannual	8			
U-235[(b)]	semiannual	8			
U-238[(b)]	semiannual	8			

(a) Biweekly at most sites, weekly at Station 8.
(b) DOH data analysis and QA/QC not complete. Results will be discussed in a future report.

Table 3.1.1 Summary of Samples Collocated with DOE

The DOH and DOE 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 (note that the uncertainty bars are not shown in the graph).

In this example, the concentrations reported by DOE are on average approximately one-half the value reported by DOH.

The scatter plot for DOH and DOE gross alpha data is shown in Figure 3.1.3. This plot shows the data from all sites that are collocated with the DOE contractor. There is significant scatter about the theoretical line in which the DOH and DOE results are identical, with differences up to a factor of two being common. In addition, there is a systematic bias between the DOH and DOE results. The preponderance of data points to the right of the theoretical line indicates that, on average, DOH reports higher concentrations than DOE. These data are similar to historical results.

One of the DOH gross alpha results was anomalous compared to typical concentrations. Specifically, one of the biweekly results at PFP-N165 (0.011 pCi/m^3) was approximately twice as high as the typical high concentration value. The corresponding DOE result of 0.004 pCi/m^3 did not confirm the slightly elevated concentration reported by DOH.

The DOH and DOE contractor gross beta concentrations are in fair agreement. The collocated concentrations are similar and follow the same temporal trend at each of the monitoring locations, but some of the uncertainty bars do not overlap. The collocated data at Battelle Complex are shown in Figure 3.1.4 (note that the uncertainty bars are not shown in the graph). In this example, some of the concentrations reported by DOE are slightly higher than those reported by DOH.

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

The gross beta concentrations at 100K East Basin were anomalously high in 2009 compared to historical results at this site. Smaller anomalies were seen in 2008 and 2010. However, in 2011 and 2012 the concentrations are similar to historical data. The last six years of data are shown in Figure 3.1.9. Radioactive material has been temporarily stored outside of the KE Basin facility since 2005. In addition, remediation has been ongoing in this area. It is possible that the increased air concentrations were a result of these activities.

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

The DOH and DOE U-234 and U-238 concentrations in quarterly composite air samples are in fair agreement. The U-238 data are shown in Figure 3.1.8 (the U-234 data are similar). Note that the U-235 concentrations are all below detection limits, and in good agreement.

The DOH and DOE concentrations are similar, but in most cases the error bars do not overlap. The concentrations are very small, only slightly above the detection limits. These data are similar to historical results.

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

The laboratory data analysis and QA/QC process for the DOH semiannual air samples are not complete at this time. The final results, and their comparison to DOE results, will be discussed in a future report.

3.1.5 Other Discussion

The gross beta results at all sites show a trend of higher concentration during the winter months, typically October through February. These higher gross beta activities are attributed to increased concentrations of radon decay products due to decreased atmospheric mixing during the winter months when there is decreased atmospheric heating. The annual cycle of increased gross beta activity in the winter months can easily be seen in Figure 3.1.10, which shows gross beta activity at Wye Barricade from 2001 through 2010.

DOH detected anomalously high concentrations of gross beta and Cs-137 in 2009 and 2010 at 100K East Basin. The gross beta data from 2007 through 2012 are shown in Figure 3.1.9. In addition, external radiation exposure rates, as discussed in Section 3.3, were 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 have been back to normal levels since 2011.

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.

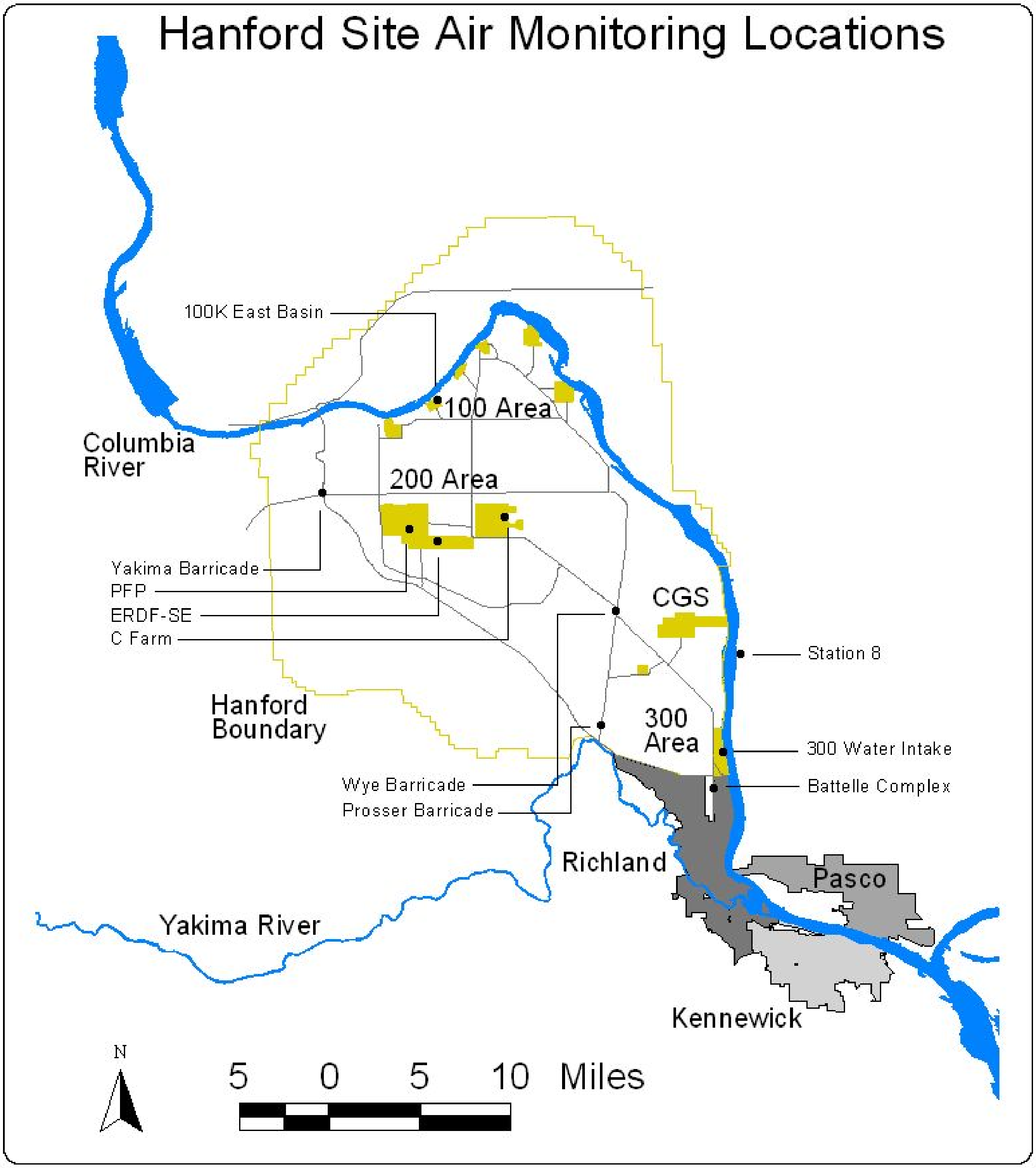

Figure 3.1.1 Hanford Area Air Monitoring Locations

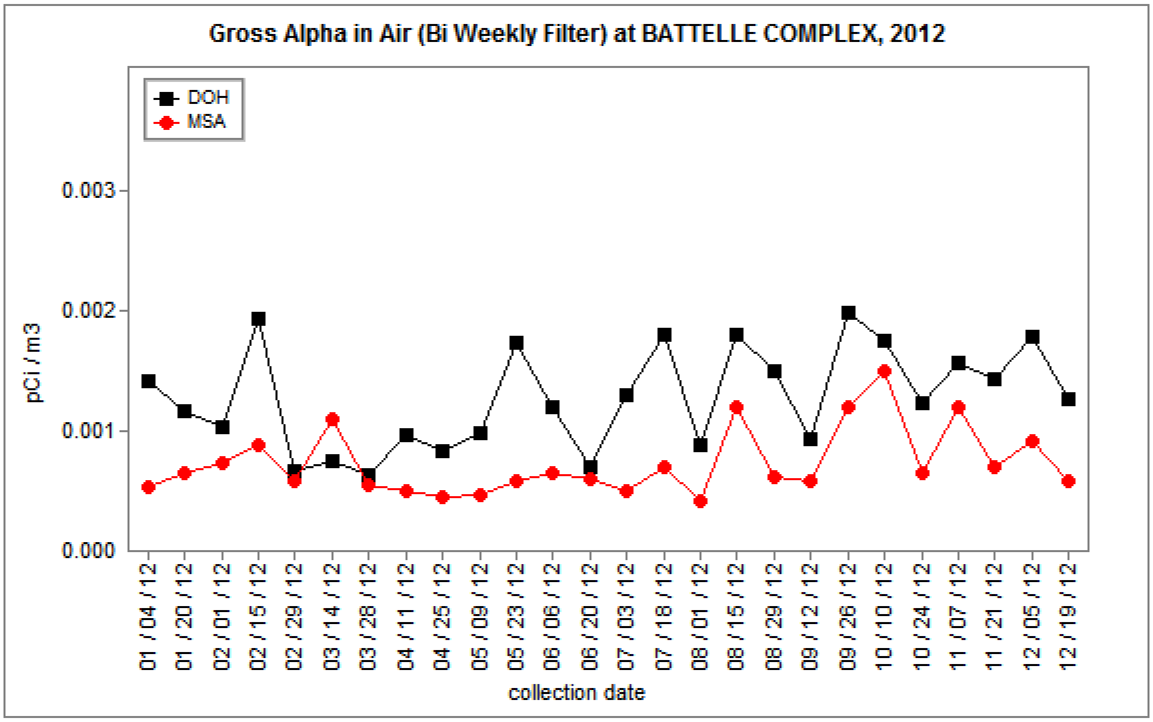

Figure 3.1.2 DOH and MSA Gross Alpha Concentrations in Air at Battelle Complex

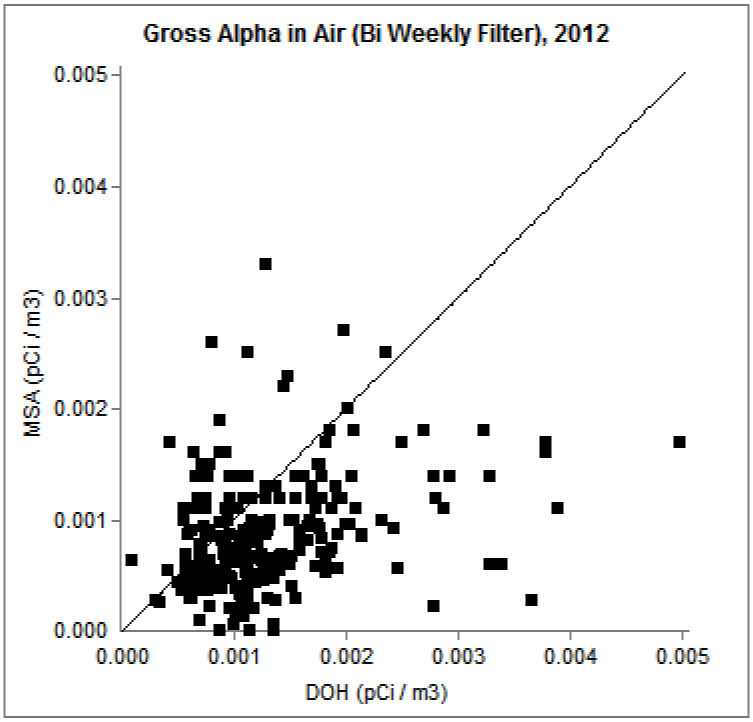

Figure 3.1.3 DOH and MSA Scatter Plot for Gross Alpha Concentrations in Air

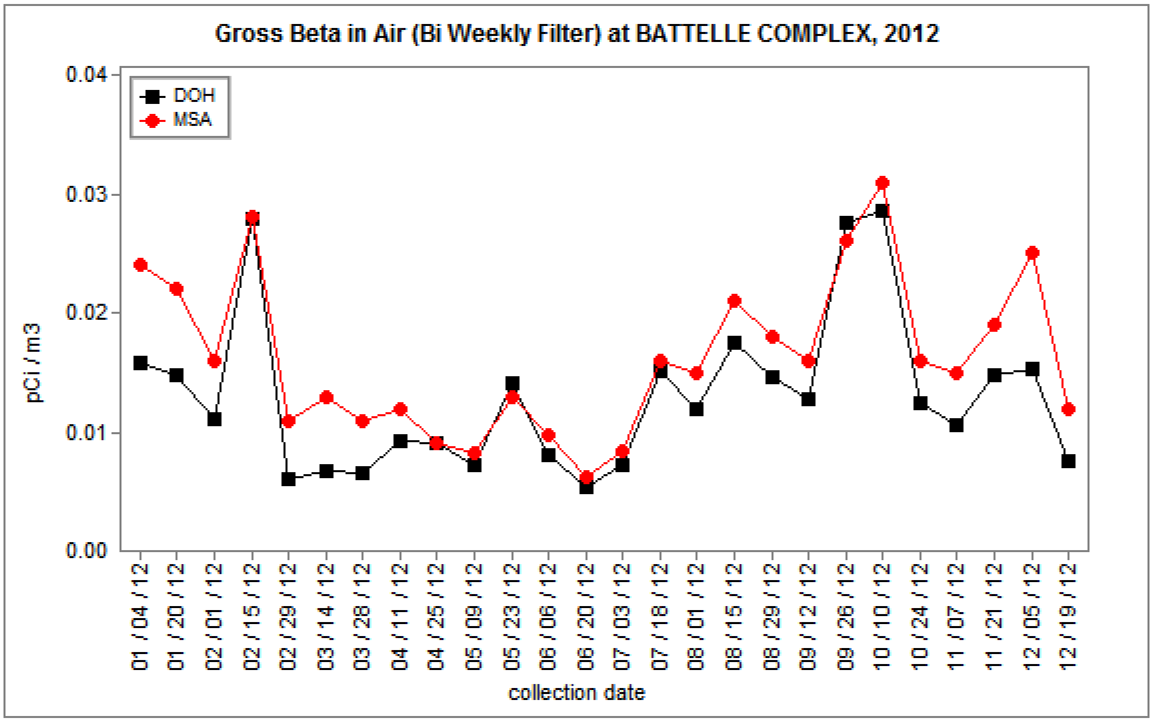

Figure 3.1.4 DOH and MSA Gross Beta Concentrations in Air at Prosser Barricade

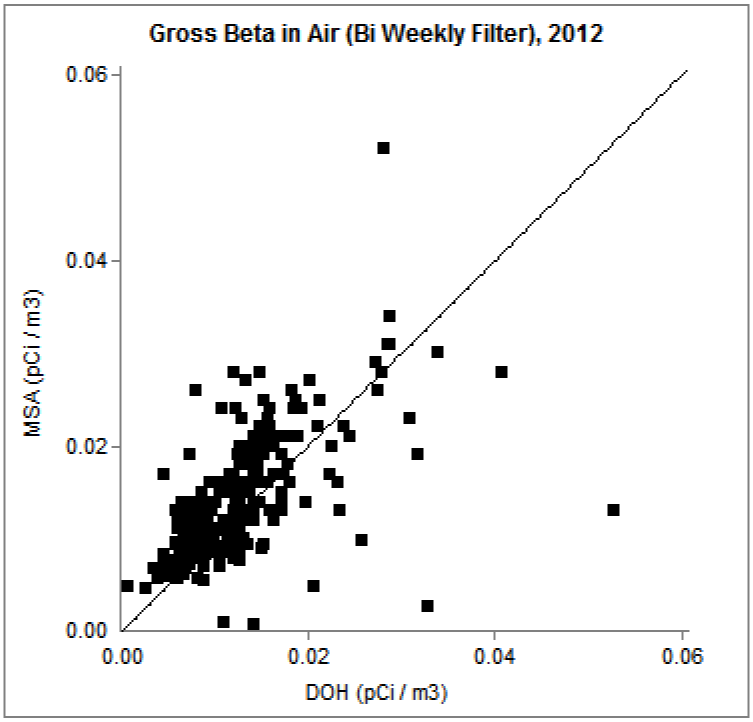

Figure 3.1.5 DOH and MSA Scatter Plot for Gross Beta Concentrations in Air

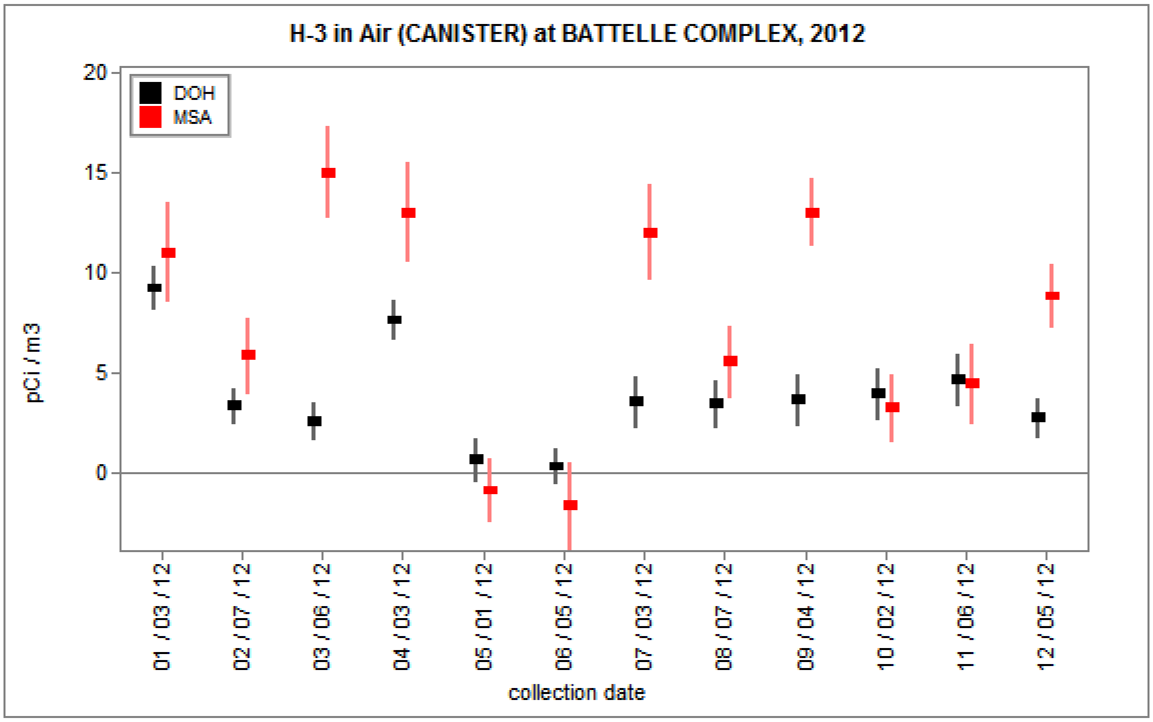

Figure 3.1.6 DOH and MSA H-3 Concentrations in Air at Battelle Complex

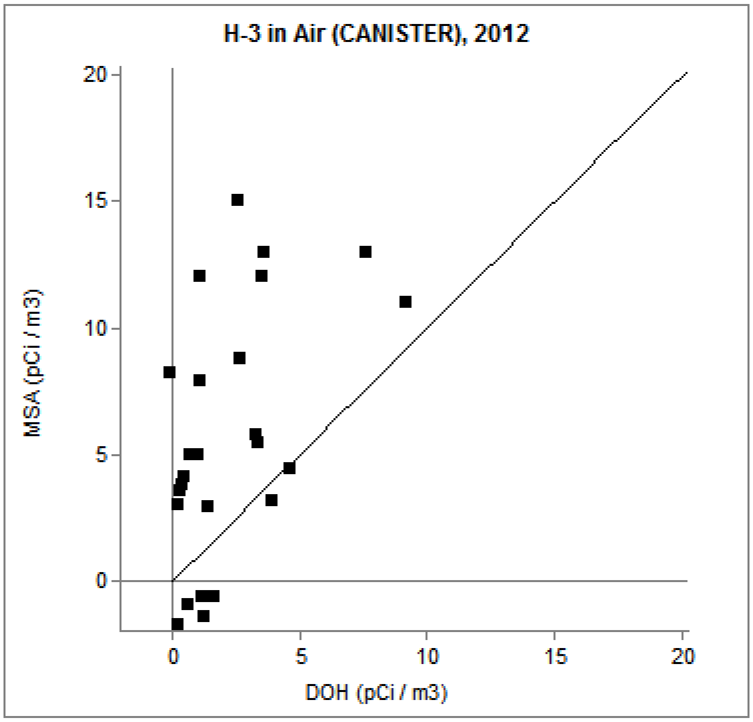

Figure 3.1.7 DOH and MSA Scatter Plot for H-3 Concentrations in Air

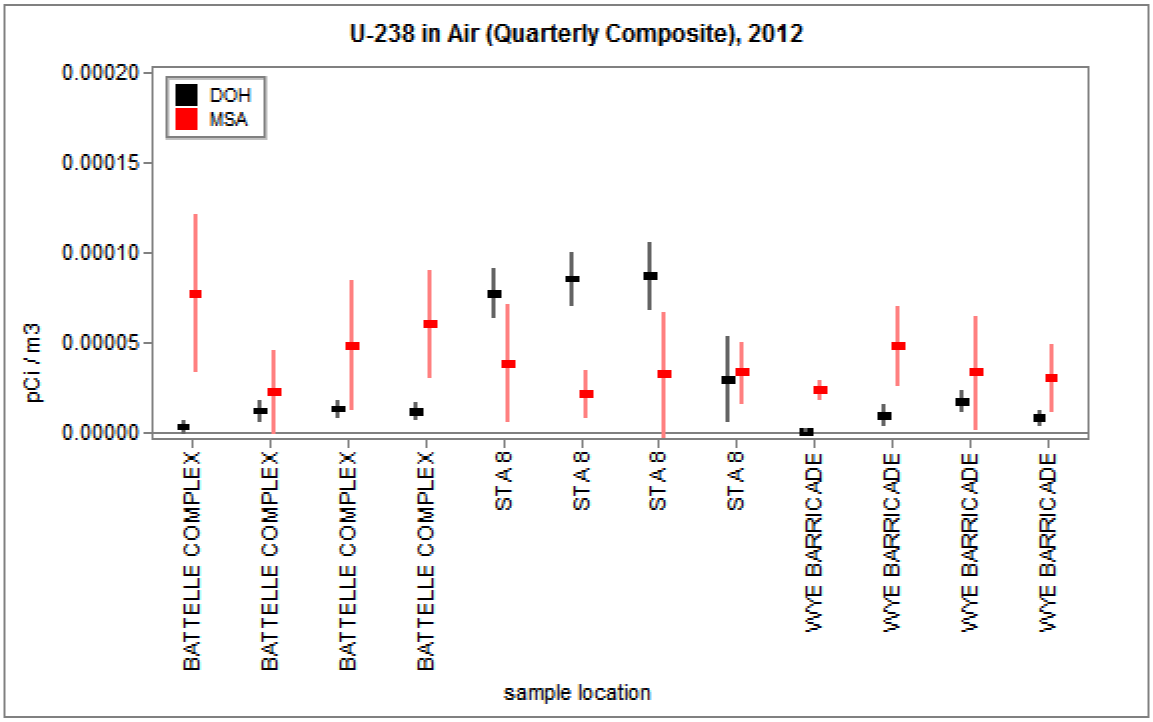

Figure 3.1.8 DOH and MSA Quarterly U-238 Concentrations in Air

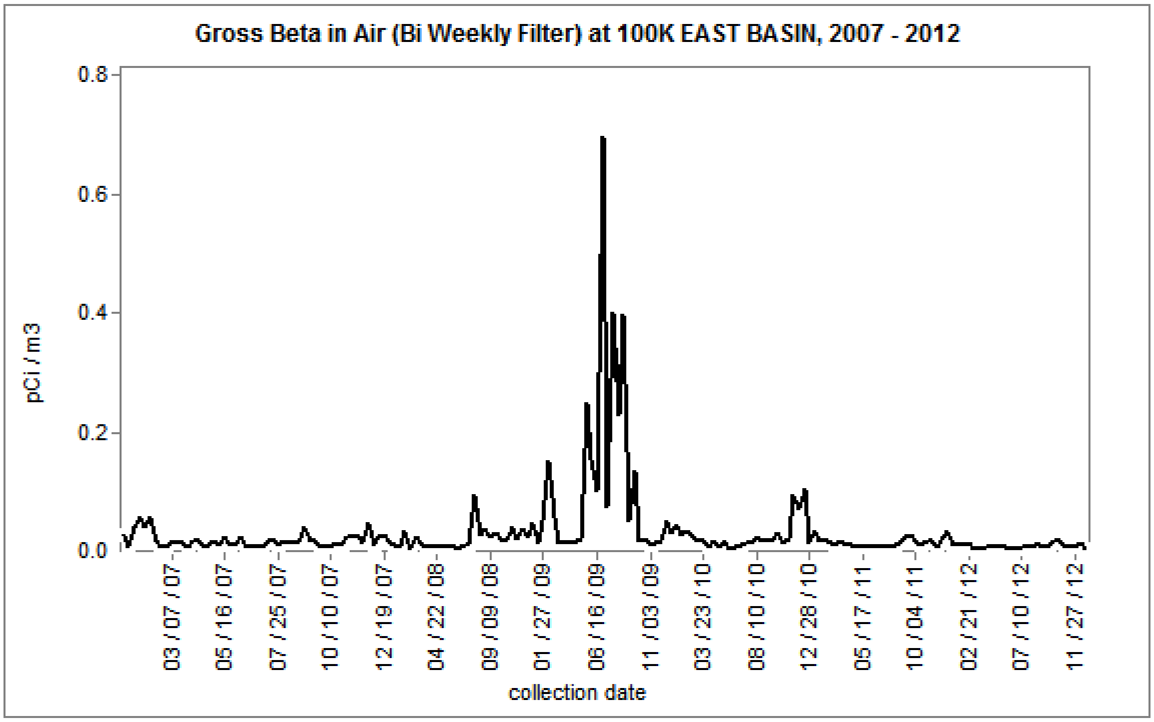

Figure 3.1.9 DOH Gross Beta Concentrations in Air at 100K East Basin

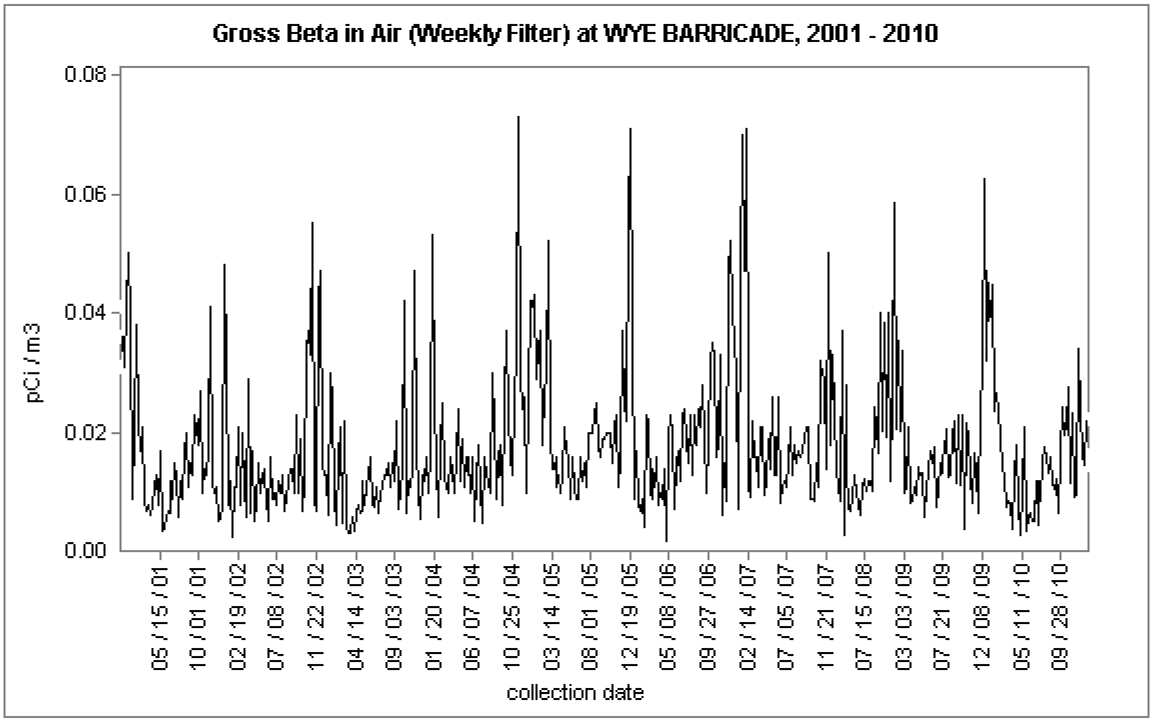

Figure 3.1.10 DOH Historical Gross Beta Concentrations in Air at Wye Barricade

3.2 Groundwater, Riverbank Seep, and Surface Water Monitoring

Major Findings:

- The DOH and DOE contractor split water concentrations are in poor agreement for C-14; fair agreement for I-129; and good agreement for all other radionuclides.
- Radionuclides were detected in groundwater in the vicinity of known groundwater plumes, and in riverbank seep water and Columbia River surface water in the vicinity of plumes known to be entering the Columbia River.
- DOH detected C-14, Cs-137, H-3, I-129, Pu-239/240, Sr-90, Tc-99, and isotopes of uranium in some Hanford groundwater, seep water, or surface water samples. Most concentrations are consistent with historical trends.
- Radionuclide concentrations in drinking water samples analyzed by DOH are all below federal standards.

3.2.1 Purpose and General Discussion

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

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

DOH splits groundwater, surface water, riverbank seep water, and drinking water samples with various DOE contractors. Monitoring is carried out to track contaminant plumes and to evaluate impacts to the public and environment.

3.2.2 Sample Types and Monitoring Locations

Typical DOH and DOE contractor split water sample locations are shown in Figure 3.2.1. Locations may vary from year to year.

Groundwater

DOH split 21 groundwater samples from 18 groundwater wells with the DOE contractor (CH2MHILL). Most well locations are on the Hanford Site, either within contaminated plumes, near waste sites, or along the Columbia River shoreline. A few of the co-sampled well locations are off the Hanford Site, located just south of Hanford in the northern part of Richland.

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

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

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

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

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

Riverbank Seeps

DOH and the DOE contractor (MSA) split six Columbia River riverbank seep samples. Groundwater enters the Columbia River through riverbank seeps. Split samples are collected from the historically predominant areas for discharge of riverbank seep water to the Columbia River, which include the 100 Area (three samples), the Old Hanford Town Site (one split sample), and the 300 Area (two split samples).

Surface Water

DOH and the DOE contractor (MSA) split four surface water samples from three different locations (one location had two samples). Two of the samples were collected from the Columbia River - both from near Priest Rapids Dam located upstream of Hanford. 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.

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. DOH split a sample at this site with CH2MHILL. One composite drinking water sample, from a drinking water storage tank in the 400 Area, was split with PNNL. In addition to the split 400 Area samples, DOH independently collected one drinking water sample from the Edwin Markham elementary school in Pasco.

3.2.3 Monitoring Procedures

Groundwater

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

Riverbank Seeps

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

Surface Water

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

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

Drinking Water

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

3.2.4 Comparison of DOH and DOE Contractor Data

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

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

Analyte	Contractor[(a),(b),(c)]	# Split Samples	Agreement	DOH Data Range (pCi/l)	Anomalous Data ?
Groundwater					
C-14[(f)]	CH2MHILL	6	**poor**	140 to 360	no
Co-60	CH2MHILL	2	good	< 2	no
Cs-134	CH2MHILL	2	good	< 2	no
Cs-137	CH2MHILL	2	good	35 to 39	no
Eu-152	CH2MHILL	2	good	< 5	no
Eu-154	CH2MHILL	2	good	< 5	no
Eu-155	CH2MHILL	2	good	< 8	no
Gross Alpha[(f)]	CH2MHILL	14	good	<5 to 92	no
Gross Beta[(f)]	CH2MHILL	14	good	9 to 5,100	no
H-3[(d), (f)]	CH2MHILL	17	good	350 to 530,000	no
I-129[(d), (f)]	CH2MHILL	4	**fair**	< 0.5 to 14	no
Pu-238	CH2MHILL	3	good	< 0.04	no
Pu-239/240	CH2MHILL	3	good	< 0.05 to 0.6	no
Sr-90[(d)]	CH2MHILL	3	good	17 to 2,500	no
Tc-99[(d), (f)]	CH2MHILL	7	good	17 to 6,900	no
U-234[(f)]	CH2MHILL	3	good	4 to 36	no
U-235[(f)]	CH2MHILL	3	good	0.2 to 1.7	no
U-236[(d), (f)]	CH2MHILL	0		0.8 to 1.1	no
U-238[(f)]	CH2MHILL	3	good	4 to 33	no
Surface/Seep					
C-14[(e), (f)]	MSA	0			
Co-60[(e), (f)]	MSA	2	good	< 2	no
Cs-134	MSA	2	good	< 2	no
Cs-137[(e), (f)]	MSA	2	good	< 2	no
Eu-152[(e), (f)]	MSA	2	good	< 5	no
Eu-154[(e), (f)]	MSA	2	good	< 5	no
Eu-155[(e), (f)]	MSA	2	good	< 8	no
Gross Alpha[(e), (f)]	MSA	2	good	< 5	no
Gross Beta[(e), (f)]	MSA	2	good	2	no
H-3[(f)]	MSA	6	good	< 70 to 33,000	no
I-129[(e)]	MSA	0		< 0.5	no
Sr-90[(e), (f)]	MSA	2	good	< 1	no
Tc-99[(e), (f)]	MSA	0			
U-234[(f)]	MSA	4	good	0.2 to 24	no
U-235[(f)]	MSA	4	good	< 0.1 to 1.1	no
U-238[(f)]	MSA	4	good	0.1 to 23	no
Drinking water					
H-3	PNNL	1	good	2,000	no

(a) CH2MHILL samples include groundwater.
(b) MSA samples include riverbank seep water and surface water.
(c) PNNL samples include drinking water.
(d) CH2MHILL data for this analyte not provided for some or all of the scheduled split samples.
(e) MSA data for this analyte not provided for some of the scheduled split samples.
(f) DOH results that have not completed the QA/QC process are not included in the analysis.

Table 3.2.1 Summary of Water Samples Split with DOE Contractors.

The value for the number of split results in Table 3.2.1 represents only those in which both DOH and the DOE contractor report results that have gone through the complete QA/QC process. This number of split results in the table may be less than the number of scheduled split results, due to results not being reported or results not having completed the QA/QC process. The values in the DOH Data Range column represent all DOH results, even if there is no corresponding split result with the DOE contractor.

The DOH and DOE contractor C-14 concentrations in groundwater are in poor agreement, as can be seen in Figure 3.2.2. Some of the results are in agreement, while others differ significantly. Historically, the DOH and DOE C-14 data are in poor agreement. The discrepancy is not understood at this time and is under investigation.

The DOH and DOE contractor I-129 concentrations in groundwater are in fair agreement, as can be seen in Figure 3.2.3 where the DOE concentration at well 699-36-70A is three times greater than the value reported by DOH.

Historically, the DOH and DOE contractor isotopic uranium concentrations in groundwater are in good agreement. However, in June of 2011, DOH measured anomalously high concentrations at well 399-1-17A, while the initial DOE results at this well were consistent with historical values. DOE reanalyzed its sample and the results agreed with the anomalously high concentrations measured by DOH. For 2012, both DOH and DOE reported concentrations consistent with historical values.

All of the DOH and DOE contractor (MSA) results are in good agreement for the riverbank seep and surface water samples. The DOH and PNNL results are in good agreement for the drinking water sample. Note that the H-3 concentration in the drinking water sample (2,000 pCi/l) is significantly less than the U.S. EPA's drinking water standard (20,000 pCi/l).

3.2.5 Other Discussion

In addition to the split water samples discussed above, DOH collected and analyzed a drinking water sample from 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. Both DOH and DOE were scheduled to report U-236 concentrations for three split groundwater samples (DOE did not report their results to DOH), and DOH independently reported U-236 in two riverbank seep samples (no scheduled split sample with DOE, not listed in Table 3.2.1). DOH detected

U-236 in groundwater and riverbank seep samples from the 300 Area. Concentrations ranged from 0.2 pCi/l (300 Area riverbank seep) to 1.1 pCi/l (groundwater well 399-1-17A). Gross alpha and gross beta analyses are for the purpose of screening, and are generally indicative of the presence of uranium/plutonium isotopes and Sr-90/Tc-99, respectively. DOH checks samples to test if the gross concentrations are consistent with the sum of all the individual radionuclide contributions. No anomalous situations were found.

For the 2012 oversight program, groundwater well 299-E33-344 was targeted for split sampling because of the known historical high concentrations of several radionuclides. Both DOH and DOE reported results for this well; however, the DOH results have not completed the QA process, so these data are not included in the analysis of this report. These results will be discussed in a future report.

Radionuclides detected in drinking water samples include gross alpha (17 pCi/l at Edwin Markam), gross beta (17 pCi/l at Edwin Markam), H-3 (2,000 pCi/l at the 400 Area drinking water tank), and Total Uranium (13 pCi/l at Edwin Markham). The U.S. EPA drinking water standards are 15 pCi/l for gross alpha, 50 pCi/l for gross beta, 20,000 pCi/l for H-3, and 21 pCi/l total uranium). EPA rules require drinking water systems be tested for uranium if the gross alpha results exceed 15 pCi/l.

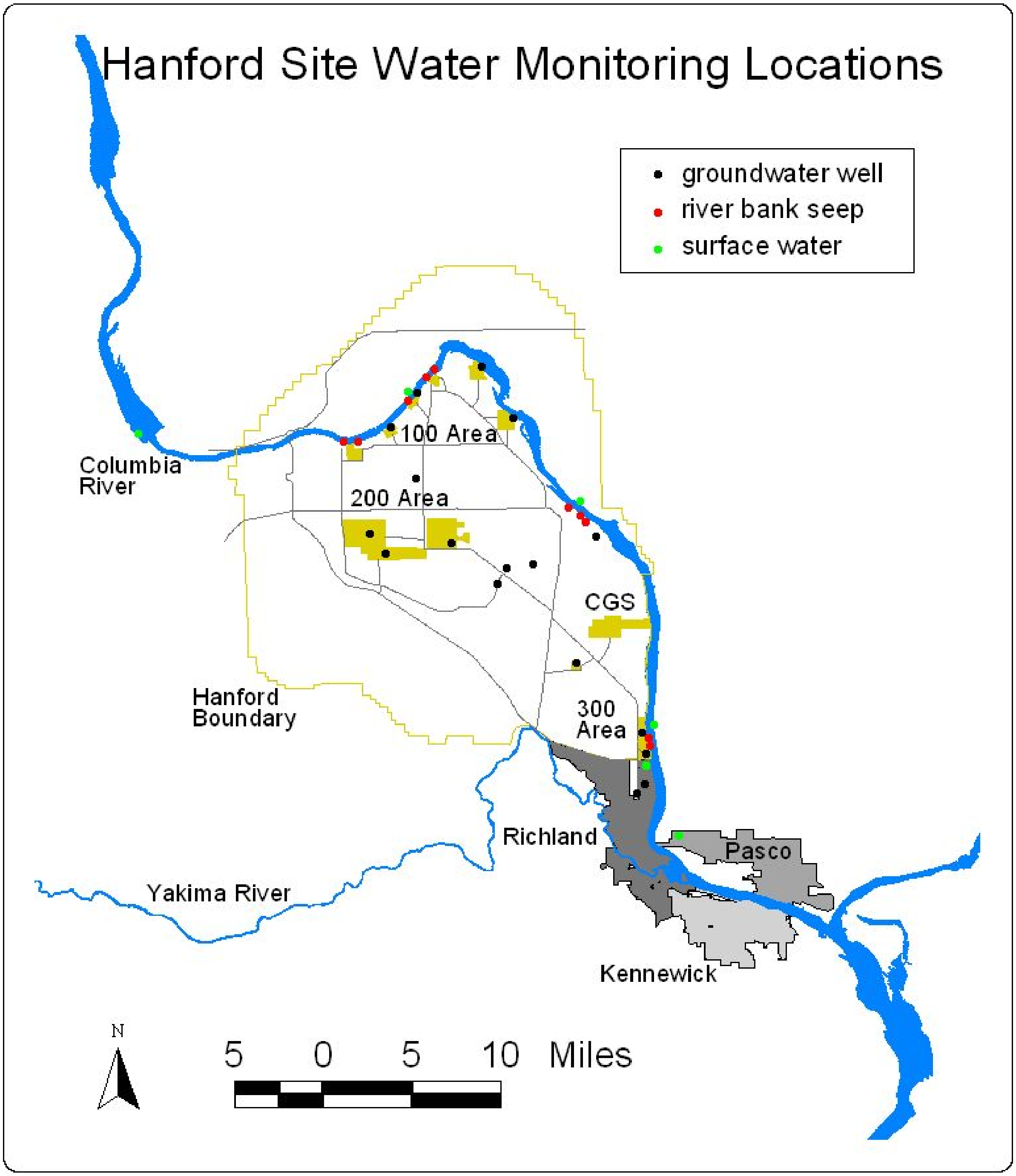

Figure 3.2.1 Typical Locations for Split Water Samples

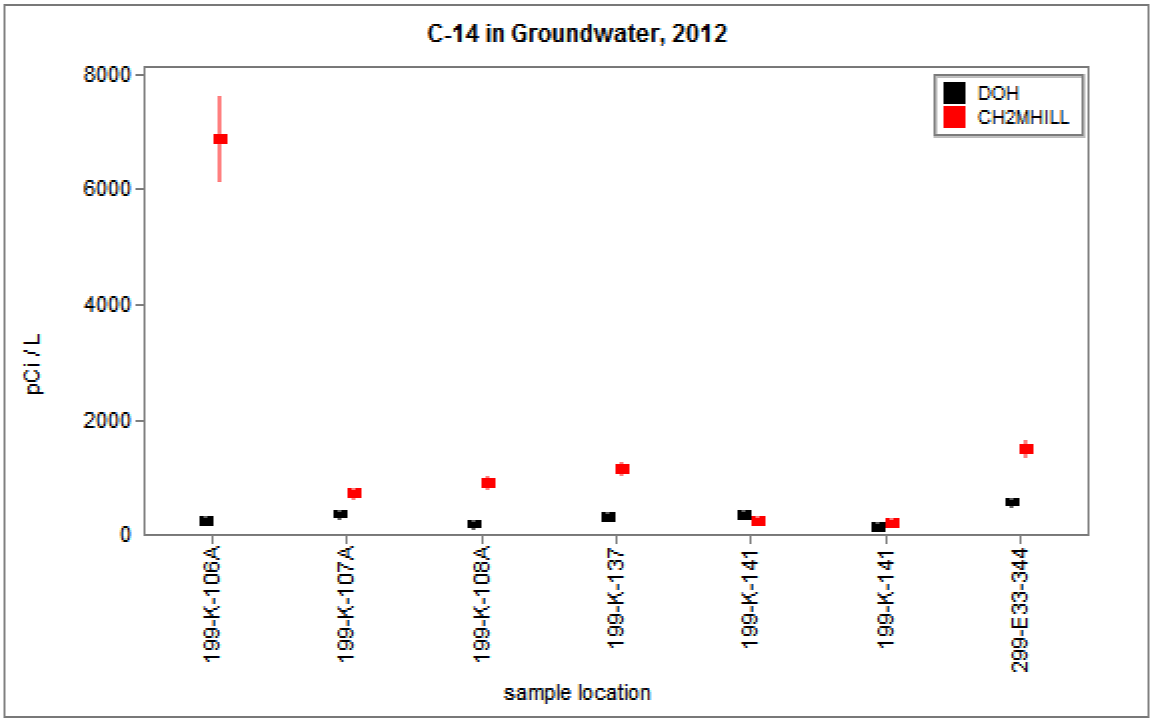

Figure 3.2.2 DOH and CH2MHILL C-14 Concentrations in Groundwater

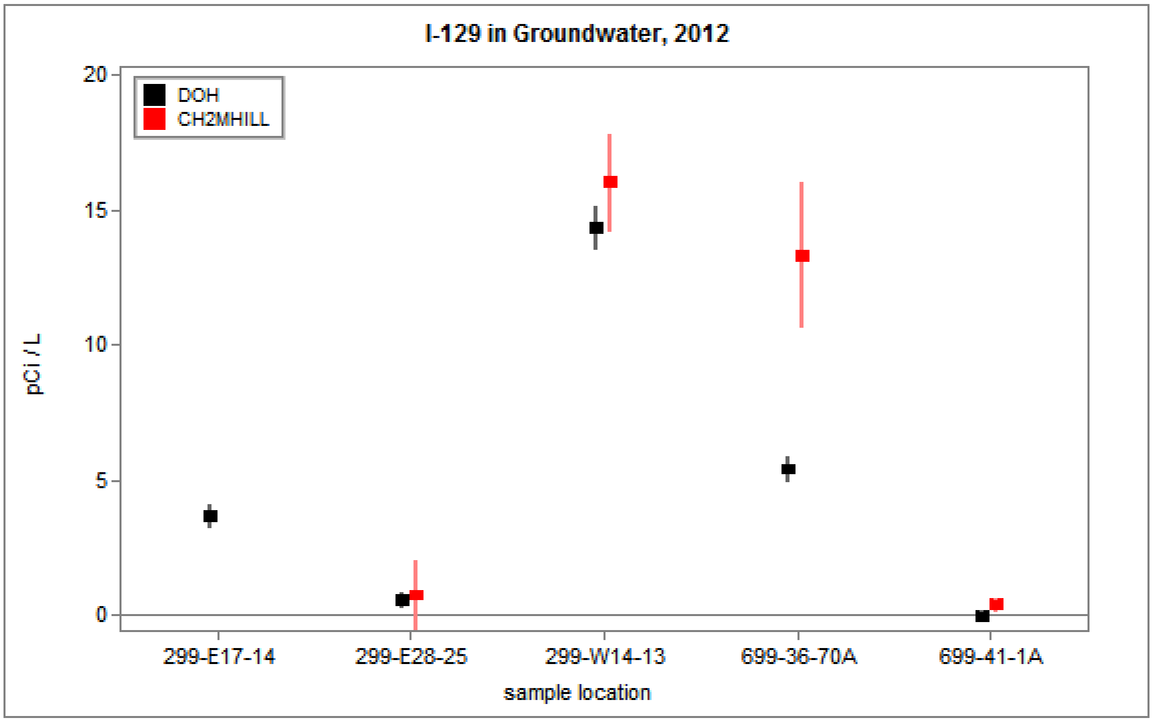

Figure 3.2.3 DOH and CH2MHILL I-129 Concentrations in Groundwater

3.3 External Radiation Monitoring

Major Findings:

- The DOH and DOE contractor external radiation exposure rates are in fair agreement.
- Exposure rates at most DOH locations on the Hanford Site are consistent with historical results, and are similar to rates at locations along the Hanford perimeter and offsite locations.
- Exposure rates along the Columbia River are consistent with background.

3.3.1 Purpose and General Discussion

People can be exposed to radiation by ingesting or inhaling radioactive materials, for example ingesting contaminated water or inhaling contaminated air. It is also possible to be exposed to radiation by a radioactive source outside the body at a distance. This is called external radiation, where radiation is emitted from an external source and travels through space to interact with the body.

DOH and DOE contractors monitor external radiation rates (also referred to as "exposure rates" in this report) on and around the Hanford Site. Historically, thermoluminescent dosimeters (TLDs) have been used to measure external radiation. Starting in 2012, DOH switched to using optically stimulated luminescence dosimeters (OSLs), while DOE continues to use TLDs. Both OSLs and TLDs, referred to as dosimeters, 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 exposure rates 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 external radiation monitoring sites collocated with the DOE Near-Facilities and Operations monitoring program, and the DOE Site-Wide and Offsite monitoring program. In 2006, the Site-Wide and Offsite external radiation monitoring program was terminated by DOE. In response, DOH added 26 new monitoring sites along the Columbia River to independently monitor locations that were previously monitored by DOE. In addition, DOH will continue to maintain its original monitoring sites that were collocated with DOE. Therefore, from 2006 forward, 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 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 external radiation monitoring locations are shown in Figure 3.3.1. Eight of the sites are near Hanford facilities with known, suspected, or potential radiation sources. Three sites (Yakima and Wye Barricades, and LIGO Facility) are located on the Hanford Site, but away from radiation sources. Twenty-six sites are along the Columbia River shoreline from the Vernita Bridge to downstream of Bateman Island at the mouth of the Yakima River. Nine sites are located around the Hanford Site perimeter. The remaining three sites (Othello, Yakima Airport, and Benton County Shops) are significantly distant from the Hanford Site. Many of the sites are collocated with air monitoring sites.

3.3.3 Monitoring Procedures

Most collocated dosimeters are deployed on a quarterly basis at each monitoring location, with the dosimeters retrieved at the end of each calendar quarter. Columbia River dosimeters are deployed semi-annually. The DOH dosimeters are sent to a contracted laboratory (Landauer), where the time-integrated external radiation exposure is determined for the deployment period. The results are then converted to an average daily radiation exposure rate and reported in units of milliroentgen per day (mR/day). At the same time the dosimeters are retrieved, new dosimeters are placed at each site.

3.3.4 Comparison of DOH and DOE Contractor Data

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

The text following the table discusses cases in which 1) the agreement between DOH and DOE data is not good (i.e. is fair or poor), and 2) some of the DOH data are anomalous compared to historical results

Analyte	Collection Period	# Collocated Samples	Agreement	DOH Data Range (mR/day)	Anomalous Data ?
External Rad	quarterly	20	**fair**	0.26 to 0.35	no

Table 3.3.1 Summary of External Radiation Dosimeters Collocated with MSA

Historically, the agreement between DOH and the DOE contractor exposure rate results has been fair, not good. The DOE contractor systematically reported slightly higher exposure rates (approximately 10% averaged over all data) than DOH. The discrepancy was primarily observed for third quarter results, and was not understood. Starting in 2009, a new DOE contractor (MSA) took over this program, and the third quarter discrepancy still appeared.

Starting in 2012 (this report), DOH started using OSL dosimeters instead of TLDs, and the dosimeters were sent to Landauer Laboratory for analysis, instead of the DOH Public Health Laboratory.

The DOH and DOE quarterly collocated external radiation rate data are shown in Figure 3.3.2. Note that this graph shows the first, then second, then third, and finally fourth quarter results at each monitoring location. The agreement is fair, as the DOH and DOE results follow the same trend. However, the DOH exposure rates are consistently greater than the DOE rates by approximately 20% to 25%, at least for the first, second, and third quarters. The DOH and DOE exposure rates are in good agreement for the fourth quarter data.

The Department of Health's use of OSL dosimeters and the use of an outside laboratory for dosimeter analysis is new for 2012, and DOH is investigating the difference between current OSL and historical TLD results at this time. Landauer , using OSL dosimeters, reports exposure rates approximately 25% greater than those historically reported by the DOH Public Health Laboratory using TLD dosimeters.

Historically, DOH has measured elevated exposure rates at site 100N Spring, which is within Hanford's 100N Area (see Figure 3.3.3). The exposure rate at this site has steadily been decreasing with time, due to the natural decay of Co-60 surface contamination. With the recent cleanup of contaminated surface soil, exposure rates over the past several years now are constant, and are consistent with exposure rates from locations away from contaminated areas. The slight increase in exposure rate in 2012 (far right data points in the graph) is most likely due to the use of OSL dosimeters starting in 2012, compared to TLD dosimeters for earlier data.

Elevated exposure rates have been observed since 2005 at location 100K East Basin, near a fuel storage basin within Hanford's 100K East Area. Figure 3.3.4 shows historical TLD data at this location. Radioactive material has been temporarily stored outside of the KE Basin facility since 2005, resulting in increased dose rates. The storage area was properly posted and access restricted. In addition, cleanup activities have resulted in temporary increased dose rates. The slight increase in exposure rate in 2012 (far right data points in the graph) is most likely due to the use of OSL dosimeters starting in 2012, compared to TLD dosimeters for earlier data. Measurements along the Columbia River at the 100K Area (site location 100K Boat Ramp), the closest public access point, do not indicate elevated exposure rates.

3.3.5 Other Discussion

In addition to the five sites collocated with the DOE contractor discussed above, DOH independently monitors 35 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 ?
External Rad	Quarterly / Semiannual	103	0.19 to 0.42	no

Table 3.3.2 Summary of Independent DOH External Radiation Dosimeters

The DOH external radiation sites are categorized by their location type, as described in Section 3.3.2. The average, minimum, and maximum dose rates for all of the sites in each location category are shown in the graph of Figure 3.3.5. This graph includes data from these 44 sites plus the five sites collocated with MSA discussed in Section 3.3.4 (all 49 DOH sites). As can be seen, average dose rates are similar for all location categories. The maximum dose rates are slightly higher for the sites that are onsite and near to contaminated or operational facilities, or along the Hanford perimeter.

The exposure rates along the Columbia River are slightly lower, most likely due to river water shielding natural radiation from the earth's crust. The exposure rates are also slightly lower at sites distant from Hanford, most likely because these sites are located in areas covered by concrete, which has a greater shielding factor than the soil cover for most other sites.

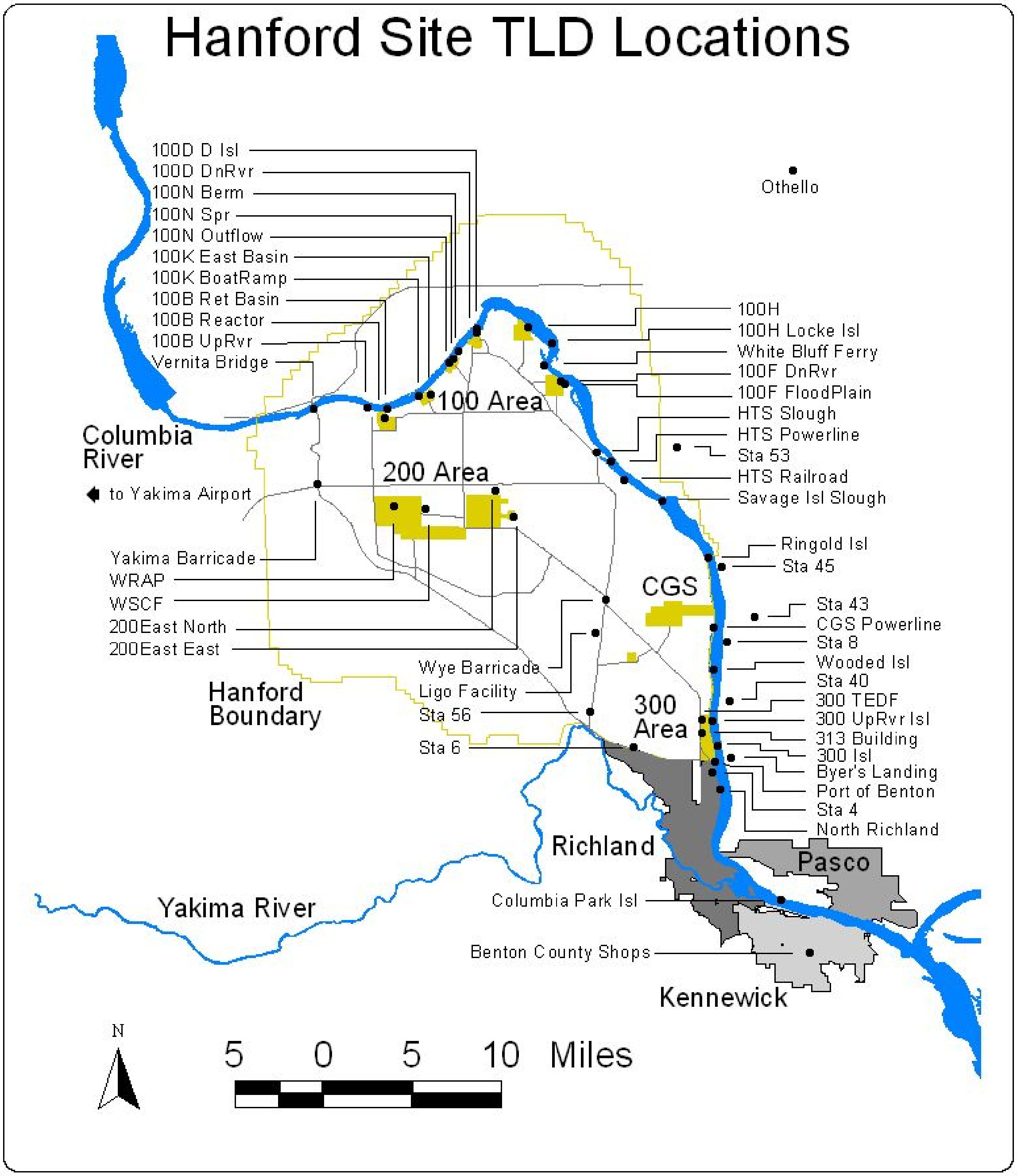

Figure 3.3.1 DOH External Radiation Monitoring (TLD) Locations

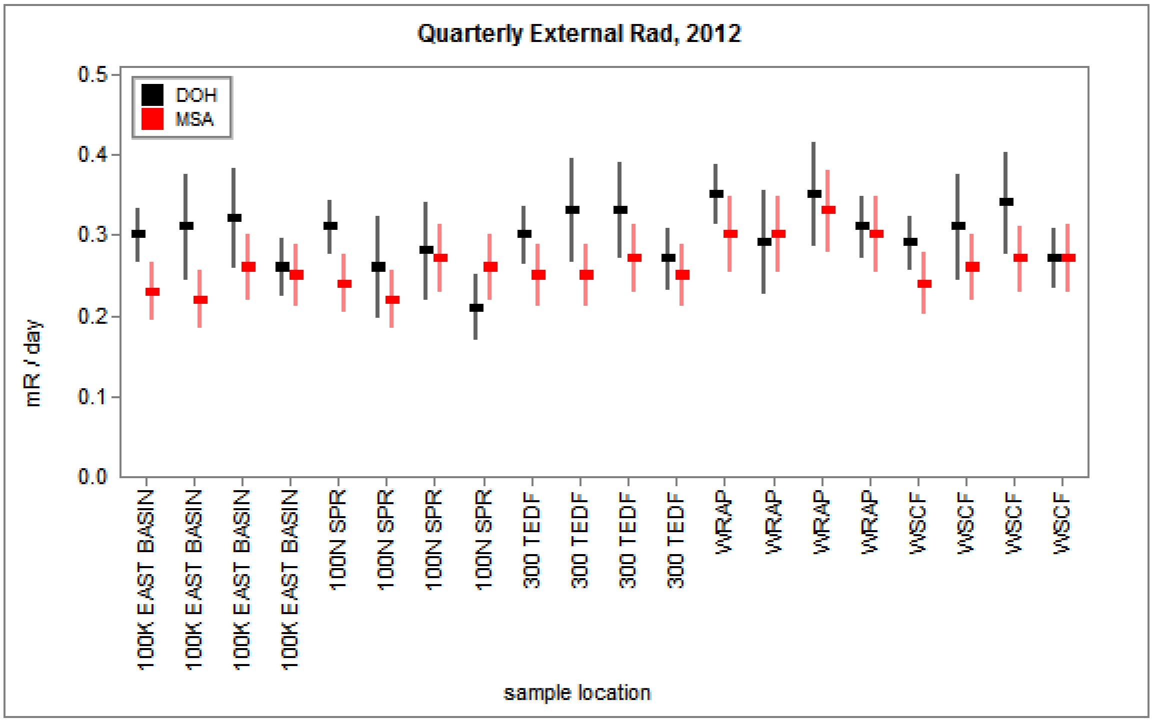

Figure 3.3.2 DOH and MSA Quarterly TLD Results

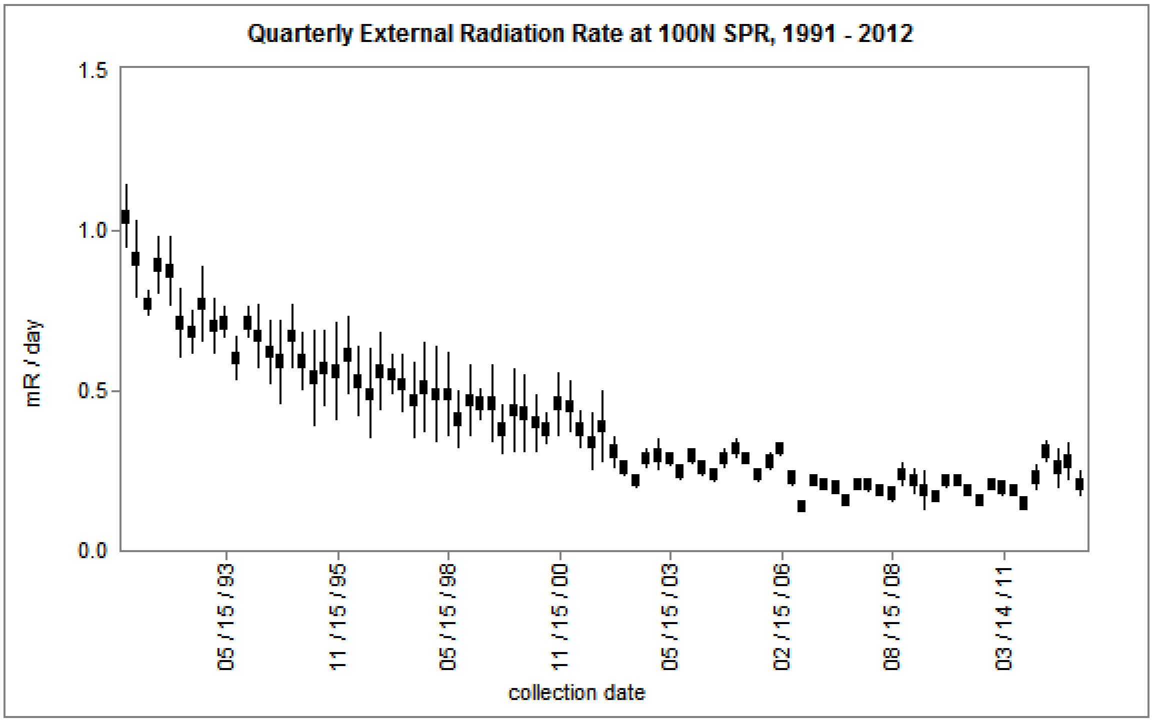

Figure 3.3.3 DOH Historical TLD Results at Location 100N SPR in the 100N Area

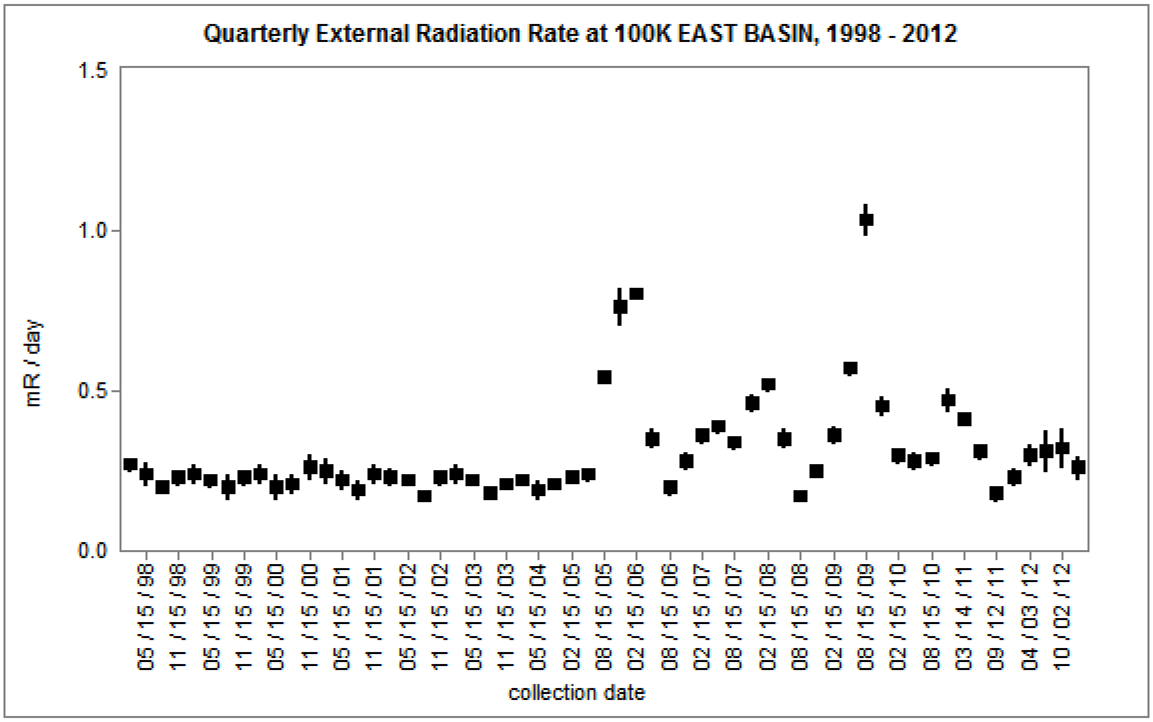

Figure 3.3.4 DOH Historical TLD Results at Location 100K East Basin in the 100K Area

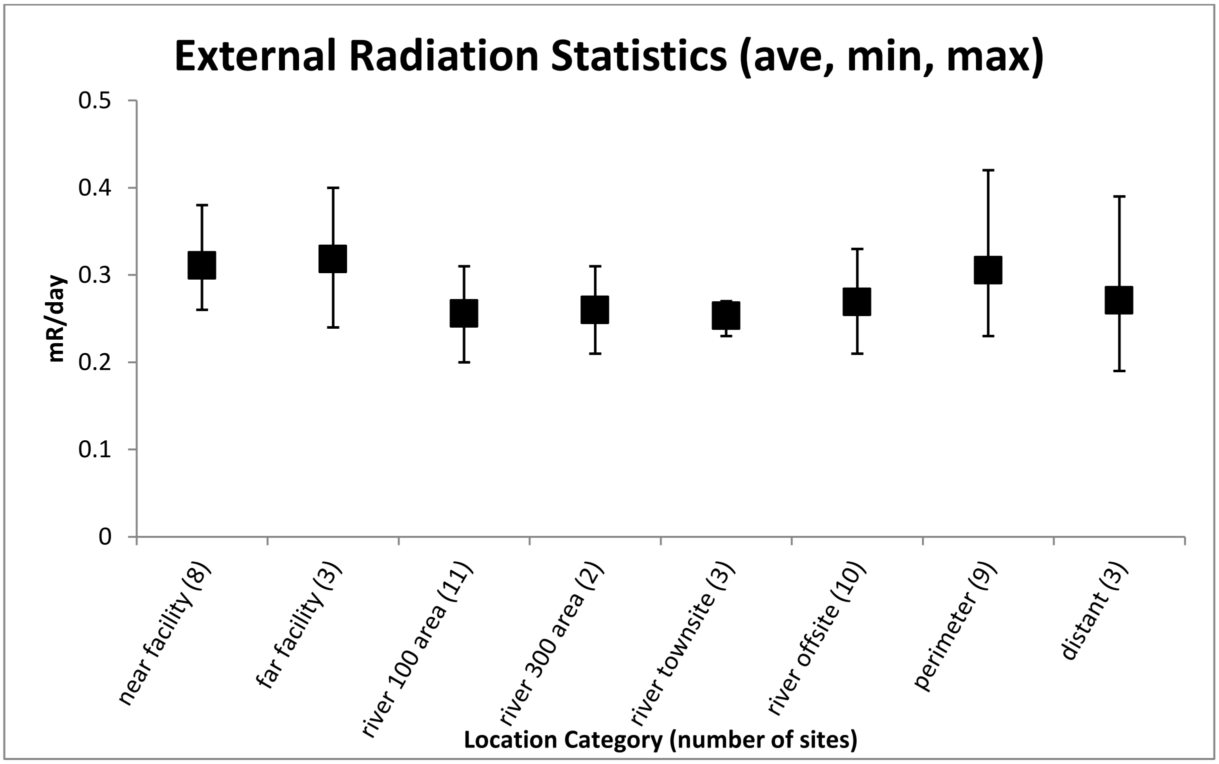

Figure 3.3.5 External Radiation Rate Statistics by Location Type, 2012

3.4 Soil and Sediment Monitoring

Major Findings:

- The DOH data analysis and QA/QC process for these samples are not complete. The 2012 sediment data will be discussed in a future report.

3.4.1 Purpose and General Discussion

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

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

3.4.2 Sample Types and Monitoring Locations

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

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

3.4.3 Monitoring Procedures

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

Sediment samples represent surface sediments and are collected with either a clam-shell style sediment dredge or, in the case of shoreline sediments, a plastic spoon. Sediment samples are collected by the DOE contractor 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

The 2012 DOH data are not available for this report. The final results, and their comparison to DOE results, will be discussed in a future report. Five split sediment samples were scheduled for 2012. Historically, DOH and DOE soil and sediment concentrations are in good agreement.

3.4.5 Other Discussion

The 2012 DOH data are not available for this report. The final DOH results will be discussed in a future report. However, general information on radionuclides in soil and sediment are discussed below.

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

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

Typically, radionuclide concentrations in sediment at most sites adjacent to and downriver from Hanford are not significantly different from those at the upstream background location at Priest Rapids Dam. Exceptions are elevated uranium concentrations from sediment adjacent to the 300 Area, and low-level Eu-152 concentrations downstream of Hanford at McNary Dam.

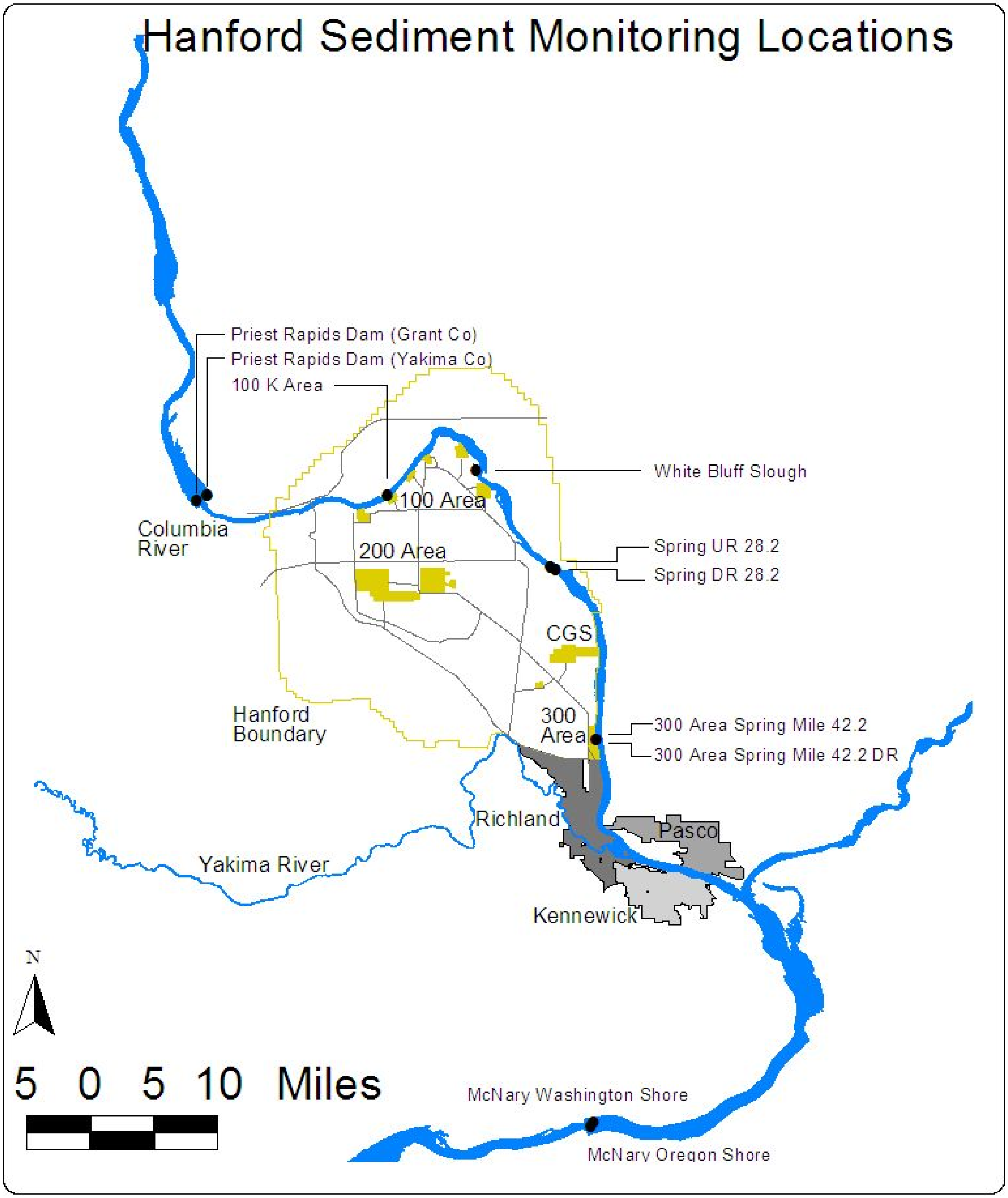

Figure 3.4.1 Historical Sediment Monitoring Locations

3.5 Farm Products Monitoring

Major Findings:

- The DOH and DOE contractor concentrations for gamma emitting radionuclides are in good agreement, while the agreement for Sr-90 is only fair.
- Most DOH concentrations are below detection limits. The single detected Sr-90 result is consistent with the range of concentrations detected historically.

3.5.1 Purpose and General Discussion

The Department of Health and DOE contractors monitor farm products grown in Washington State; i.e., food, milk, and wine, to determine if contamination has migrated to farms near the Hanford Reservation.

Strontium-90 is occasionally detected in farm product samples. In addition to the possibility that this radionuclide originates from Hanford-related contamination, Sr-90 is a product of fallout from atmospheric weapons testing.

3.5.2 Sample Types and Monitoring Locations

Farm product monitoring for this year's oversight program included three apple samples, two leafy vegetable samples, and two potato samples. Wine samples are occasionally collected, but not in 2012.

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

3.5.3 Monitoring Procedures

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

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

Wine, in years when it is collected, 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

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

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

Analyte	Collection Period	# Split Samples	Agreement	DOH Data Range (pCi/g)	Anomalous Data ?
Co-60	annual	7	good	< 0.02	no
Cs-134	annual	7	good	< 0.02	no
Cs-137	annual	7	good	< 0.02	no
Eu-152	annual	7	good	<0.04	no
Eu-154	annual	7	good	< 0.04	no
Eu-155	annual	7	good	< 0.04	no
Sr-90	annual	7	**fair**	< 0.005 to 0.01	no

Table 3.5.1 Summary of Split Solid Farm Product Samples

Most of the DOH and DOE split farm product concentrations are in good agreement. A single leafy vegetable sample was in disagreement for Sr-90 analysis, in which DOH reported a concentration of 0.01 pCi/g while DOE reported a concentration of 0.0 pCi/g (see Figure 3.5.1).

All of the DOH concentrations are below the DOH detection limit, except for the leafy vegetable Sr-90 concentration discussed above.

3.5.5 Other Discussion

DOH occasionally detects small concentrations of Sr-90 in farm products, with historical concentrations ranging from 0 to 0.1 pCi/g. For this reporting period, all Sr-90 concentrations were below detection limits; except for one of the leafy vegetable samples which had a concentration of 0.01 pCi/g, well within the range of typical results.

These Sr-90 concentrations are most likely due to fallout from historical atmospheric testing of nuclear weapons.

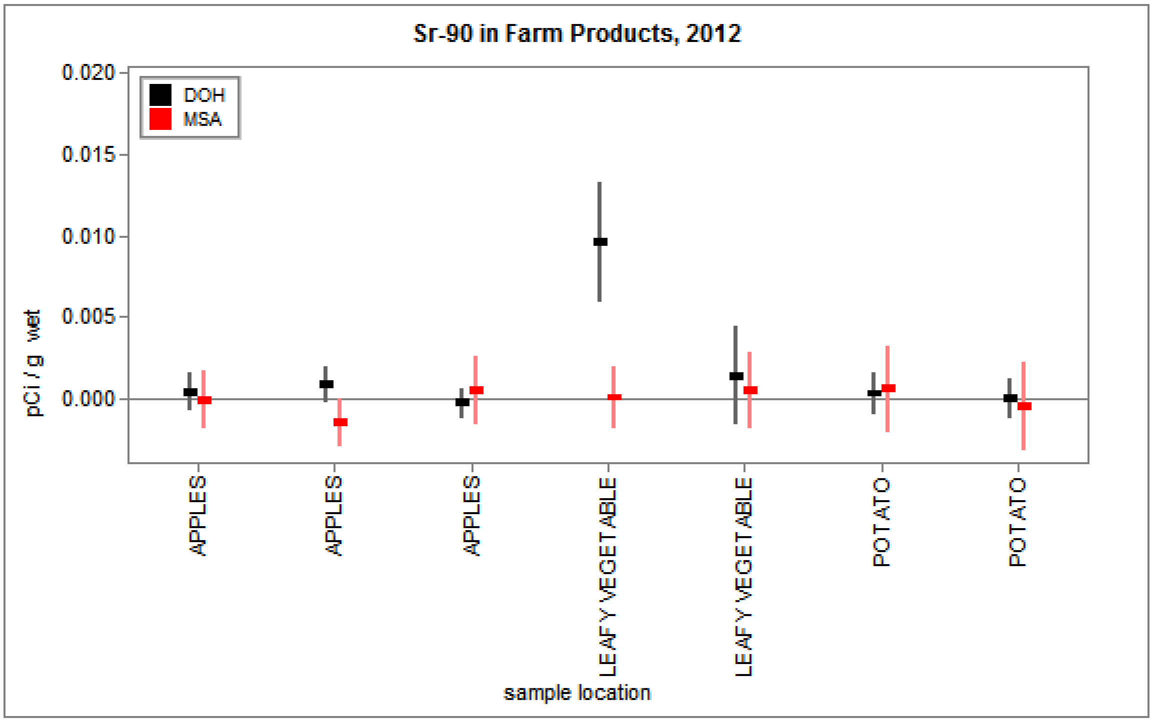

Figure 3.5.1 DOH and MSA Sr-90 Concentrations in Farm Products

3.6 Fish and Wildlife Monitoring

Major Findings:

- DOH and DOE contractor concentrations for all radionuclides are in good agreement.
- Concentrations of most gamma emitting radionuclides are below detection limits, and concentrations of Cs-137 and Sr-90 are consistent with historical results and those from background locations.

3.6.1 Purpose and General Discussion

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

3.6.2 Sample Types and Monitoring Locations

One collocated fish (bass) sample was collected from the Columbia River adjacent to Hanford's 300 Area.

Two wildlife (elk) samples were collected from near North Bend, WA, which is a background location relative to the Hanford Site. One of the elk samples was split with DOE, and the other independently analyzed by DOH.

Two game bird (quail) samples were collected from Hanford's 100 Area, and both were split with DOE.

Two wildlife (rabbit) samples were collected from Hanford's 200 Area, and both were split with DOE.

3.6.3 Monitoring Procedures

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

Most wildlife samples are collected by the DOE contractor, and then split with DOH. Elk samples from western Washington State were collected by DOH and split with the DOE contractor.

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

3.6.4 Comparison of DOH and DOE Contractor Data

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

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

Analyte	Collection Period	# Collocated/Split Samples	Agreement	DOH Data Range (pCi/g)	Anomalous Data ?
Co-60	annual	6	good	< 0.04	no
Cs-134	annual	4	good	< 0.03	no
Cs-137	annual	6	good	< 0.03	no
Eu-152	annual	4	good	< 0.05	no
Eu-154	annual	4	good	< 0.04	no
Eu-155	annual	4	good	< 0.06	no
Pu-238	annual	1	good	< 0.0007	no
Pu-239/240	annual	1	good	< 0.0005	no
Sr-90	annual	3[a]	**poor**	0.05 to 0.35	no

(a) Three split samples were scheduled, one elk sample and two rabbits samples. The DOH elk sample has not yet been reported, so only the two rabbits samples are included in the collocated analysis.

Table 3.6.1 Summary of Collocated Fish and Wildlife Samples

All of the DOH and DOE contractor split/collocated results are in good agreement, except for Sr-90. All concentrations are below the detection limits, except for Sr-90 in the two split rabbit samples. The poor agreement of the Sr-90 results can be seen in Figure 3.6.1 (DOH has not yet reported the Sr-90 for the elk sample). Historically, there is often disagreement for Sr-90 results in fish and wildlife.

3.6.5 Other Discussion

Two elk samples were collected from North Bend, WA. One of the samples was split with DOE, and the other analyzed independently by DOH. For the independent DOH sample, all reported radionuclide concentrations were below detection limits; and the Sr-90 result has not yet been reported.

DOH detected Sr-90 in the two rabbit samples from the 200 Area (0.05 and 0.35 pCi/g). These concentrations are within the range historically detected in fish and wildlife samples (< 0.02 to 2.8 pCi/g).

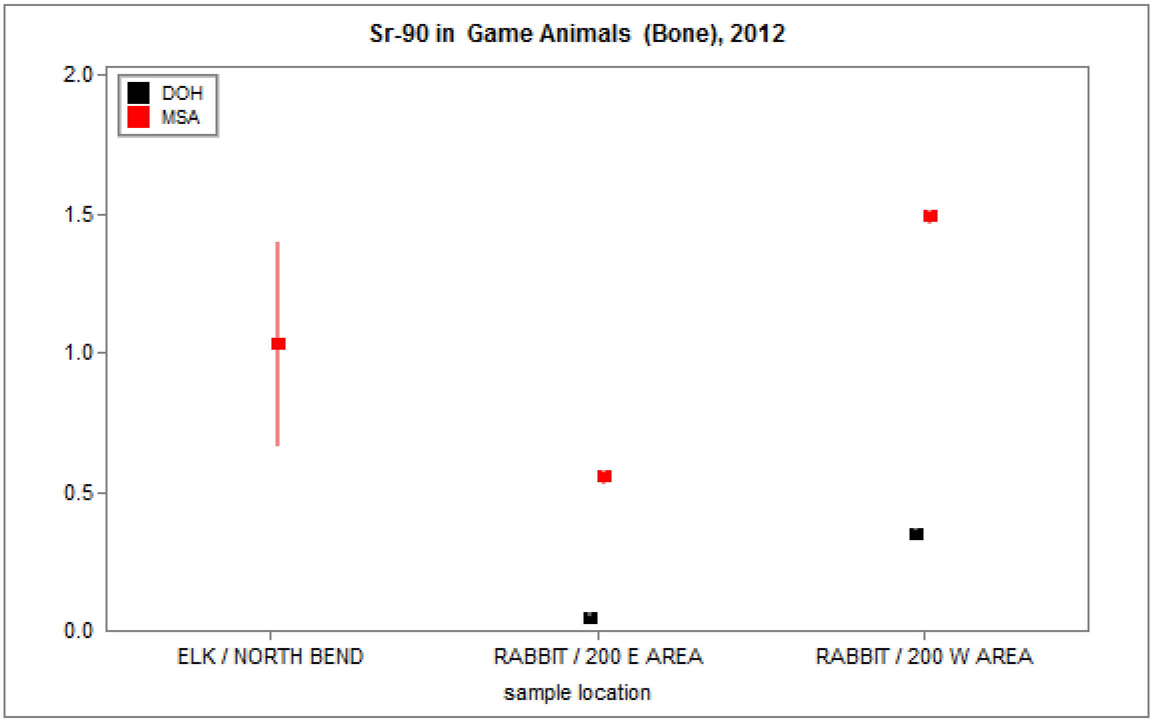

Figure 3.6.1 DOH and MSA Sr-90 Concentrations in Game Animals.

3.7 Vegetation Monitoring

Major Findings:

- DOH and DOE did not split vegetation samples for this reporting period.
- General information regarding vegetation monitoring is discussed in this chapter.

3.7.1 Purpose and General Discussion

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

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

3.7.2 Sample Types and Monitoring Locations

Vegetation is typically collected from locations that could potentially be affected by contaminants from Hanford Site operations, as well as from background locations. The map in Figure 3.7.1 shows the locations where vegetation samples are typically collected, which include farms in the Horn Rapids and Riverview areas. No vegetation samples were collected for this reporting period.

3.7.3 Monitoring Procedures

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

3.7.4 Comparison of DOH and DOE Contractor Data

DOH and DOE did not split vegetation samples for this reporting period. Historically, DOH and DOE split vegetation concentrations are in good agreement.

3.7.5 Other Discussion

DOH and DOE did not split vegetation samples for this reporting period. However, general information on radionuclides vegetation are discussed below.

Historically, gamma emitting radionuclides are not detected in vegetation samples, and Sr-90 concentrations are found in the range from <0.02 pCi/g to 0.2 pCi/g. Based on analysis of historical vegetation samples collected at background locations not influenced by the Hanford Site, Sr-90 concentrations detected in vegetation samples at Horn Rapids and Riverview are most likely due to fallout from atmospheric weapons testing.

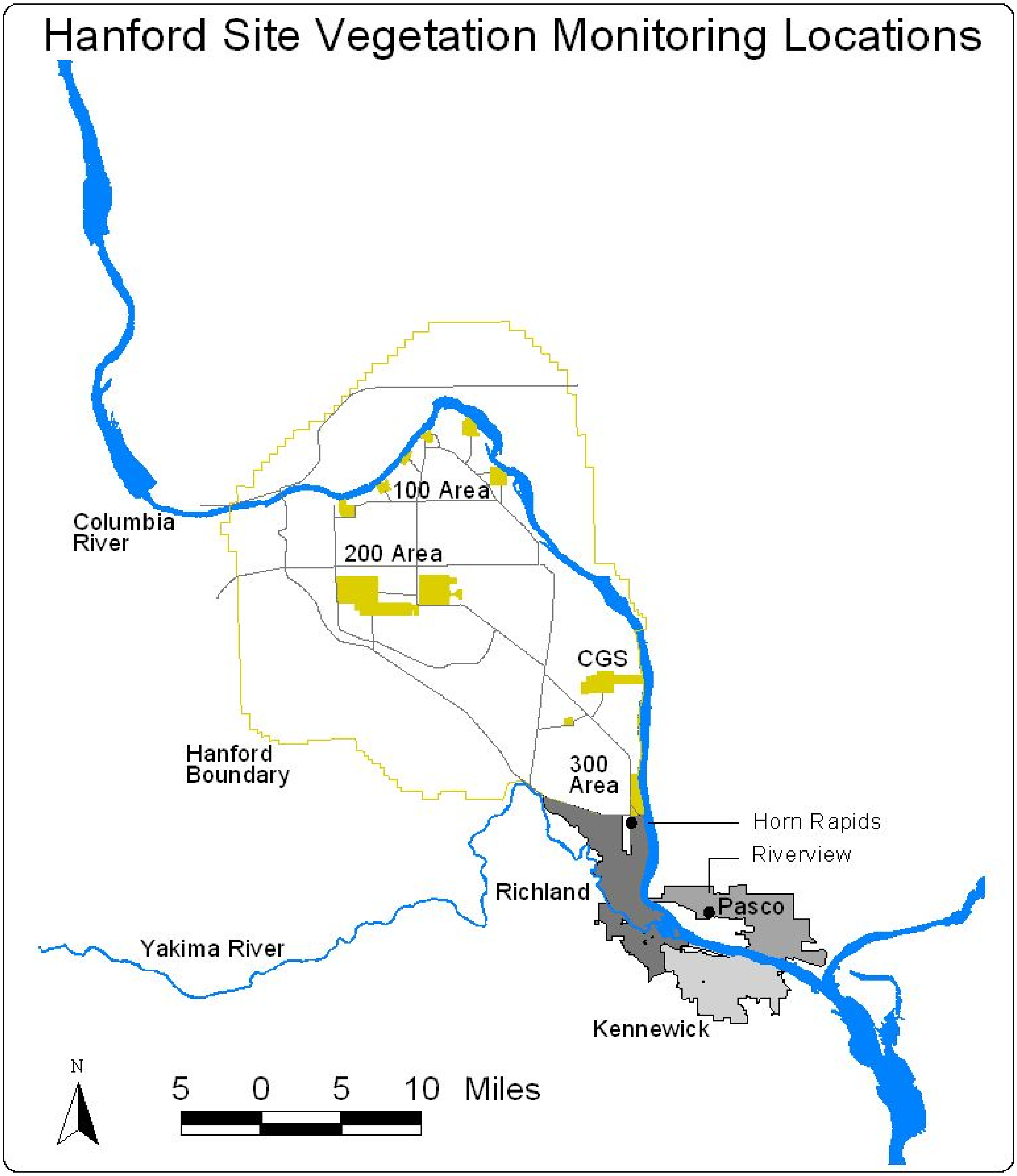

Figure 3.7.1 Typical Vegetation Monitoring Locations

4. Summary of Evaluation of DOH and DOE Contractor Results

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

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

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

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

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

Historically, the DOH and DOE Cs-137 concentrations in semiannual composite air samples are in fair agreement. Semiannual air results for 2012 are not complete, and are not discussed in this report; however, the historical discrepancy is discussed here. The two data sets are similar, with most results below or only slightly above the detection limits. However, in cases where the isotope is detected, the uncertainty bars do not overlap. A systematic bias has been historically observed in which DOE on average reports concentrations approximately 60% lower than those reported by DOH.

The DOH and DOE contractor C-14 concentrations in water samples, all of which are groundwater, are in poor agreement. This discrepancy is seen throughout historical data.

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

Three problems have been previously identified with regard to the I-129 comparison. First, for samples in which I-129 is detected, DOH typically reports concentrations significantly lower than those reported by DOE. Secondly and perhaps related to the first problem, for samples in which I-129 is not detected, DOH reports a disproportionate number of negative results, more so than statistically expected. This suggests a negative bias in the DOH measurement process.

Thirdly, some DOE results are reported at concentrations greater than the sample's minimum detectable activity (MDA), although the results are tagged as not detectable.

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

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

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

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

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

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

The DOH and DOE external radiation dose rates are in fair agreement. The results follow the same trend; however, the DOH exposure rates are consistently greater than the DOE rates by approximately 20% to 25%, at least for the first, second, and third quarters. The DOH and DOE exposure rates are in good agreement for the fourth quarter data.

The DOH and DOE Sr-90 concentrations in farm products, fish, and wildlife are in fair to poor agreement. This disagreement is seen throughout historical farm product, fish, wildlife, 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 seiverts. Since radiation doses are often small, units of millirem (mrem) or milliseivert (mSv) are commonly used. A mrem is one-thousandth of a rem. Table A.1 shows the average annual dose for the United States from both natural and artificial sources. Natural sources account for 82% of the annual dose to the U.S. population, with radon being the dominant natural dose contributor at 55%.

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

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

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

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

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

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

Appendix B - Laboratory a priori Lower Limits of Detection

Air Cartridge (pCi/m^3)

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

Air Filter (pCi/m^3)

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

Quarterly Composite Air Filter (pCi/m^3)

	Nuclide	Volume (m^3)	Method	Standard LLD (400 min.)
Gamma	Be-7	5200	INGe	8.00E-02
	Co-60	5200	INGe	1.00E-03
	Cs-134	5200	INGe	2.00E-03
	Cs-137	5200	INGe	1.00E-03
				Standard LLD (1000 min.)
Alpha	Nat U	5200	Alpha Spec	2.50E-05
	U-234	5200	Alpha Spec	2.50E-05
	U-235	5200	Alpha Spec	1.00E-05
	U-238	5200	Alpha Spec	2.50E-05

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

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

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

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

Food (pCi/g)

	Nuclide	Mass (g)	Method	Standard LLD (1000 min.)
Alpha	Nat U	20	Alpha Spec	2.00E-03
	U-234	20	Alpha Spec	1.50E-02
	U-235	20	Alpha Spec	1.00E-03
	U-238	20	Alpha Spec	2.00E-03
	Pu-238	20	Alpha Spec	3.00E-03
	Pu-239	20	Alpha Spec	2.00E-03
	Th-230	20	Alpha Spec	5.00E-03
	Th 232	20	Alpha Spec	2.00E-03
	Am-241	20	Alpha Spec	2.00E-03
	Ra – 226	20	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/ αβ 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	αβ Cntr	1.00E-01
	Ra-226(DA)	600	INGe	2.00E-02
				Standard (100 min.)
Alpha	Gross	0.1	αβ Cntr	4.00E+01
				Standard LLD (1000 min.)
Gamma	K-40	600	INGe	1.50E-01
	Mn-54	600	INGe	1.00E-02
	Co-60	600	INGe	1.00E-02
	Zn-65	600	INGe	2.00E-02
	Zr-95	600	INGe	1.00E-02
	Ru-103	600	INGe	1.50E-02
	Ru-106	600	INGe	1.00E-02
	Sb-125	600	INGe	2.00E-02
	Cs-134	600	INGe	1.20E-02
	Cs-137	600	INGe	1.50E-02
	Ce-144	600	INGe	5.00E-02
	Eu-152	600	INGe	1.50E-02
	Eu-154	600	INGe	1.50E-02
	Eu-155	600	INGe	2.00E-02
	Ra-226(DA)	600	INGe	1.00E-01
	Am-241(GA)	600	INGe	2.00E-02
	Tot U(GA)	600	INGe	2.00E-01
				Standard (100 min.)
Beta	Sr-90	150	Nitric Acid/	1.80E-03
	Tc-99	10	3M/LS	2.00E-01
	Gross beta	0.4	αβ 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	αβ Cntr	1.50E+00
	Sr-90	20	Nitric Acid/ αβ 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)	Nuclide	Volume (L)	Method	Standard LLD (1000 min.)	Standard LLD (100 min.)
Alpha	Nat U	0.5	Alpha Spec	1.30E-01	
	U-234	0.5	Alpha Spec	8.00E-02	
	U-235	0.5	Alpha Spec	6.00E-02	
	U-238	0.5	Alpha Spec	8.00E-02	
	Ra-226	0.5	αβ Cntr		2.00E-01
	Pu-238	0.5	Alpha Spec	8.00E-02	
	Pu-239	0.5	Alpha Spec	6.10E-02	
	Th-230	0.5	Alpha Spec	1.00E-01	
	Th 232	0.5	Alpha Spec	1.00E-01	
	Am-241	0.5	Alpha Spec	8.00E-02	

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

Water (pCi/l) Continued

	Nuclide	Volume (L)	Method	Standard LLD (200 min.)	Standard LLD (100 min.)
Beta	H-3	0.010	Dist/LS	6.00E+01	
	C-14	0.010	LS	1.50E+02	
	Sr-90	1	Nitric Acid/ αβ Cntr		7.00E-01
	Tc-99	0.5	3M/LS		4.00E+00
Gross	Alpha	0.1	αβ Cntr		4.00E+00
	Beta	0.5	αβ 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
αβ 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 = $e^{-(\ln2/T1/2)(t)}$
E = counting efficiency: counts per disintegration
LLD = the a priori determination of the smallest concentration of radioactive material sampled that has a 95 percent probability of being detected, with only five percent probability that a blank sample will yield a response interpreted to mean that radioactivity is present above the system background
n = number of samples analyzed (number of data points)
RU = random uncertainty at the 95 percent confidence level (sometimes referred to as counting error)
s = sample standard deviation
S = one standard deviation of the background count rate (which equals $(BKG/T_2)^{1/2}$)
sample cpm = counts per minute of sample
t = elapsed time between sample collection and counting
T_1 = sample count time
T_2 = background count time
$T_{1/2}$ = half-life of radionuclide counted
U = uncertainty (standard error) of the sample mean
V = volume in liters (or mass in grams) of sample
Y = fractional radiochemical yield (when applicable)

Appendix C - Glossary of Terms

Alpha Particle	A heavy particle emitted from the nucleus of an atom. It consists of two protons and two neutrons, which is identical to the nucleus of a helium atom without orbital electrons. These heavy charged particles lose their energy very rapidly in matter. Thus, they are easily shielded by paper or the surface layer of skin. Alpha particles are only hazardous when they are internally deposited.
Analyte	The specific radioisotope measured in a radiochemical analysis. For example, tritium, Sr-90, and U-238 are analytes.
Background (Background Radiation)	Radiation that occurs naturally in the environment. Background radiation consists of cosmic radiation from outer space, radiation from the radioactive elements in rocks and soil, and radiation from radon and its decay products in the air we breathe.
Baseline Samples	Environmental samples taken in areas unlikely to be affected by any facilities handling radioactive materials.
Becquerel	A unit, in the International System of Units (SI), of measurement of radioactivity equal to one transformation per second.
Beta Particle	A high-speed particle emitted from the nucleus, which is identical to an electron. They can have a -1 or +1 charge and are effectively shielded by thin layers of metal or plastic. Beta particles are generally only hazardous when they are internally deposited.

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

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

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

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

Appendix D - List of Analytes

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