DOH 320-030

Environmental Radiation Program

Hanford Environmental Oversight Program 2001 Data Summary Report

Washington State Department of Health

Environmental Health Programs

DOH 320-030

Environmental Radiation Program

Hanford Environmental Oversight Program 2001 Data Summary Report

Scott Van Verst
Lynn Albin

Washington State Department of Health

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

Environmental Radiation Section
Office of Radiation Protection
Department of Health
7171 Cleanwater Lane, Bldg. 5
P.O. Box 47827
Olympia WA 98504

360-236-3251
Email: ENVRAD@doh.wa.gov
FAX: 360-236-2255

Summary

The Washington State Department of Health (DOH) has operated an environmental radiation monitoring program since 1961. The early program looked primarily at atmospheric fallout and off-site environmental impacts related to Hanford operations. Currently, the 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 Oversight Program has participated with the U.S. Department of Energy (DOE) in the collection of environmental samples on or near the Hanford Site. The purpose of the program is to independently verify the quality of DOE environmental monitoring programs at the Hanford Site, and to assess the potential for public health impacts. This report is a summary of the data collected for the Hanford Environmental Oversight Program in 2001.

The Oversight Program's objectives are met through collection and analyses of environmental samples and interpretation of results. DOH samples are either split or co-located with samples collected by DOE contractors, and the results are compared to verify the quality of the DOE monitoring programs at Hanford. In 2001, samples of air, groundwater, surface water, riverbank seep water, drinking water, discharge water, soil, sediment, food and farm products, fish and wildlife, and vegetation were collected. In addition, dosimeters measuring ambient external radiation levels were collected.

Generally there is good agreement between DOH and DOE contractor split data. The good agreement between this limited split data gives confidence that the remainder of DOE's environmental radiation data is valid.

Discrepancies between DOH and DOE split data in 2001 included a systematic bias in results for gross beta activity in air samples, gross beta activity in water samples, and uranium activity in soil and sediment samples. The systematic bias indicates a probable difference in laboratory procedures. In the case of uranium, the discrepancy is understood as due to a difference in laboratory analytical methods. The discrepancy for gross beta in air and water samples is not understood at this time. DOH will investigate the gross beta discrepancy and report on the findings in a future report.

Most environmental samples analyzed by DOH had radioactivity concentrations either below detection limits or consistent with background. A few samples had concentrations elevated above background which are attributed to Hanford operations, however, in most cases the results are consistent with historical trends. For example, technetium 99 (Tc- 99), strontium 90 (Sr-90), iodine 129 (I-129), uranium isotopes, and tritium were detected above background levels in some Hanford Site groundwater wells in 2001. Tritium and uranium isotopes in some Columbia River water samples were also greater than background, but at concentrations well below water quality standards. While Hanford Site operations have resulted in radionuclides entering the environment, the DOH Oversight Program's data indicate that public exposure to radioactivity from Hanford is far below regulatory limits.

Contents

Figures

Tables

Acronyms

ALARA	As Low As Reasonably Achievable
ALE	Arid Land Ecology Reserve
CFR	Code of Federal Regulations
CSB	Canister Storage Building
CVDF	Cold Vacuum Drying Facility
DOE	Department of Energy (United States)
DOH	Department of Health (Washington State)
DNR	Department of Natural Resources
DWS	Drinking Water Standard
EML	Environmental Measurement Laboratory
LLD	Lower Limits of Detection
MAPEP	Mixed Analyte Proficiency Evaluation Program
MDA	Minimum Detectable Activity
NCRP	National Council on Radiation Protection and Measurements
PHL	Public Health Laboratories
PNNL	Pacific Northwest National Laboratory
PUREX	Plutonium Uranium Extraction Facility
QATF	Quality Assurance Task Force of the Pacific Northwest
SI	International Scientific Units
TEDF	Treated Effluent Disposal Facility
TLD	Thermoluminescent Dosimeters
TPA	Tri-Party Agreement
TWRS	Tank Waste Remediation System
WAC	Washington Administrative Code

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 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 legacy contamination. However, radioactive contamination remains and continues to move through the environment. DOE has extensive monitoring programs to characterize and track this contamination. The primary purpose of the DOH Hanford Environmental 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, co-located, and independent sampling at locations which have the potential to release radionuclides to the environment or locations which may be impacted by such releases.

- To use the DOH oversight data to assess impacts to the public. (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. Therefore, assessment of impacts to the public based on DOH data do not necessarily represent worst-case scenarios).

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

This report presents the results of environmental radiation measurements made by the Washington State Department of Health's Hanford Environmental Oversight Program for the calendar year 2001.

Section 2 describes the Hanford Environmental 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 *a priori* lower limits of detection are listed in Appendix B. Appendix C lists a glossary of radiation terms. Appendix D is a list of analytes.

2. The Hanford Environmental Oversight Program Description

The Oversight Program's objectives (see Section 1. Introduction) are met through collection and analyses of environmental samples and interpretation of results. DOH samples are either split or co-located with samples collected by the DOE contractors. In 2001, samples were split with the Pacific Northwest National Laboratory (PNNL), Duratek, and Waste Management Federal Services NW (WMFS).

Split samples are prepared by dividing a sample into two parts. Co-located 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 minute 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/m3); 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 milli-Roentgens per day (mR/day). Radiation exposure is defined in Appendix A.

2.2.1 Uncertainty in Radioactivity Measurements

All radioactivity measurements have an associated uncertainty. Counting uncertainty is the dominant source of measurement uncertainty. Counting uncertainty is an estimate of the possible range of radioactivity results due to the fact that radioactive decay is a random process. The uncertainties reported within this report are primarily counting uncertainties, although for gamma-emitting radionuclides the uncertainty associated with calibrating the detector is included. The uncertainties are given as "2-sigma" uncertainty. A 2-sigma uncertainty means there is 95% confidence that the true concentration in the sample lies somewhere between the measured concentration minus the uncertainty and the measured concentration plus the uncertainty.

2.2.2 Detection Limits

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

2.2.3 Background and Negative Results

The environmental results are reported as net sample activity, which is defined as gross sample activity minus background activity. Gross sample activity and background activity are measured separately. Gross sample activity results from the sum of radioactivity in the environmental sample and 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 Oversight Program is to verify DOE environmental monitoring programs, DOH either splits samples or collects co-located samples with DOE contractors. The DOH and DOE samples are independently analyzed and the results compared. Two techniques are used to compare the data; qualitative comparisons and linear regression analysis.

2.2.4.1 Qualitative Comparisons

All of the co-located or split data are sorted by sample type and analyte. Then, for each sample type and analyte, 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. The results of the assessment are discussed in the text of the report. When necessary or helpful to the reader, figures of the graphical representation of the data are included in the report.

2.2.4.2 Regression Analysis

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 is 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 co-located DOH and DOE results for a given sample type and analyte 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 analyte 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 no 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 co-located data is presented in this report. Also shown in the plot are straight lines 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.

3. Environmental Monitoring Results

This section presents the DOH and DOE contractor results for the Hanford Environmental 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 Air Monitoring

Major Findings:

- The DOH and PNNL split bi-weekly gross beta results are in fair agreement. The data follow the same trends, but there is a slight systematic discrepancy between the two data sets. The DOH and Duratek gross beta results are in good agreement.
- The DOH/PNNL and DOH/Duratek split quarterly and semi-annual composite air sample results are in good agreement.
- The gross beta results are consistent with background air concentrations.
- Most of the quarterly and semi-annual composite air concentrations for all radionuclides were below detection limits. The only exceptions include Cs-137; U-234, 238; and Pu-239/240 concentrations which were slightly higher than the detection limit at a few of the sample locations.

3.1.1 Purpose and General Discussion

Atmospheric releases of radioactive material from the Hanford Site are a potential source of human exposure. The Department of Health and DOE contractors monitor radioactivity in air to determine if the Hanford Site is contributing to airborne contamination. DOH collects air samples that are co-located with PNNL and Duratek. The primary purpose of the DOH program is to provide oversight of the DOE monitoring program. In addition, Hanford impacts are evaluated by comparing radioactivity in air at locations upwind and downwind of operating and contaminated facilities.

Sources of Hanford airborne emissions include resuspension of contaminated soil (caused by, for example, wind or cleanup activities) and escape of radioactive particulates and gasses. Sources of natural airborne radioactivity include natural radon gas and its decay products, resuspension of soil containing natural radionuclides such as uranium-234, 238 and potassium-40, and radioactive atoms generated in the atmosphere by interactions with cosmic radiation. Natural sources lead to airborne gross beta concentrations ranging from 0.01 to 0.1 pCi per cubic meter of air.

3.1.2 Monitoring Locations

In 2001, DOH collected air samples co-located with PNNL at five locations. These locations include the Wye Barricade, Benton City, and Station 8, which are in the prevailing downwind direction of most Hanford Site operating and contaminated facilities. Air sampling locations were also co-located at an area downwind of the 200 Area (200ESE), and at the Yakima Barricade which is upwind of operating and contaminated facilities.

DOH also collected air samples co-located with Duratek at the Wye Barricade and three locations near operating facilities that have the potential to emit radionuclides to the air. These locations include a tank farm in the 200 Area (C Farm), the environmental restoration disposal facility (ERDF), and the K Area fuel storage basins (KE Basin). All the DOH co-located air sampling sites are shown in Figure 3.1.1.

In addition to sites co-located with PNNL or Duratek, DOH also collected air samples at three locations in the prevailing downwind direction of most Hanford Site operating and contaminated facilities. These sites include Prosser B. Station 56, Ligo Facility, and Station 4. In addition, DOH collected air samples from SE Corner, a site in the 200 Area. These additional four sampling locations are also shown in Figure 3.1.1.

3.1.3 Monitoring Procedures

Airborne particles are sampled by continuously drawing air through a filter. DOH collects the filter at each sample location once a week, while PNNL and Duratek collect their co-located filters every other week (bi-weekly). The filters are stored for three days and then analyzed for gross beta 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 one or 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 weekly (or bi-weekly) filter samples for a three or six-month period are dissolved and combined into quarterly or semi-annual composite samples. The composite samples are analyzed for gamma emitting radionuclides and isotopes of uranium and plutonium. A summary of the monitoring program is shown in Table 3.1.1.

Type of Air Sample	**DOH / PNNL**	**DOH / Duratek**
Weekly (or Bi-Weekly) Filter	Gross Beta	Gross Beta
Quarterly Composite Filter	Co-60; Cs-134, 137; U-234, 235, 238	
Semi-Annual Composite Filter		Co-60; Cs-134, 137; Pu-238, 239/240; U-234, 235, 238

Table 3.1.1 Radionuclides Monitored in Air Samples

3.1.4 Comparison of DOH and Contractor Data

The DOH and PNNL gross beta results follow the same trend at each of the monitoring locations. The DOH/PNNL data at the Wye Barricade are shown in Figure 3.1.2. The

DOH and Duratek gross beta results also follow the same trend at each of the sites. The DOH/Duratek data at C Farm are shown in Figure 3.1.3. In general, the DOH and DOE contractor data sets are not expected to match identically because the sampling frequencies are different, and therefore the results correspond to an averaging of the air concentration over different time periods. The agreement between the DOH and DOE contractor gross beta results at the other sampling locations is similar to that at Wye Barricade and C Farm.

The DOH vs. PNNL scatter plot for co-located gross beta results are shown in Figure 3.1.4. The DOH vs. Duratek scatter plot is shown in Figure 3.1.6. The x-coordinate of each point represents the DOH result, while the y-coordinate represents the PNNL result. Ideally, if the DOH and PNNL results were identical, all the points would fall on the straight line with slope equal to unity and y-intercept equal to zero (shown as the solid black line in the figure).

Regression analysis was used to fit a straight line to the DOH vs. PNNL data (blue dashed line in Figure 3.1.4), and the resulting slope and y-intercept quantifies the agreement between the two data sets. Regression analysis was not carried out for the DOH and Duratek data (Figure 3.1.6) because, although the data sets are generally in good agreement, the correlation between the two data sets is not strong enough to produce a meaningful straight line fit to the data.

Figure 3.1.4 indicates that the DOH and PNNL data are in fair agreement. The slope of 0.6 and y-intercept of 0.0068 pCi/m^3 for the best-fit straight line indicate a systematic discrepancy between the two data sets. The regression analysis indicates that for gross beta concentrations below 0.02 pCi/m^3, PNNL on average reports higher concentrations than DOH. For gross beta concentrations greater than 0.02 pCi/m^3, DOH on average reports higher values than PNNL. In most cases, the discrepancy is less than a factor of two.

This systematic discrepancy in 2001 led to a re-examination of the 2000 data, which had shown good agreement between DOH and PNNL (Figure 3.1.6 in DOH 320-029). It was found that the regression analysis for the 2000 data was inadvertantly missing the data from one of the monitoring locations. With all the 2000 data included, the corrected regression analysis determined a slope of 0.8 and y-intercept of 0.0022 pCi/m^3 for the best-fit straight line, indicating a similar result to 2001. A regression analysis of DOH and PNNL gross beta in air data for the years 1999 - 2001 is shown in Figure 3.1.5, where the same systematic discrepancy is observed. DOH will investigate this discrepancy and report its findings in a future annual report.

The DOH and PNNL split quarterly composite air results for Co-60; Cs-134, 137; and U-234, 235, 238 are in good agreement. Of the 78 results, only two U-234 and two U-238 results are in disagreement. The DOH and PNNL split data for U-238 are shown in Figure 3.1.7. The results for U-234 are similar.

The DOH and Duratek split semi-annual composite air results for Co-60; Cs-134, 137; Pu-238, 239/240; and U-234, 235, 238 are in good agreement. Only one Pu-239/240 result is in disagreement. The DOH and Duratek split Pu-239/240 data are shown in Figure 3.1.8. Also shown is the DOH and Duratek split Cs-137 results (Figure 3.1.9).

A regression analysis on the split quarterly and semi-annual composite air data was not carried out because the criteria for such an analysis was not met. Either there were too few data points or the data were below detection limits.

3.1.5 Discussion of Results

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 daughter 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 1988 through 2001.

Gross beta results from locations upwind and downwind of the Hanford Site are compared to determine if Hanford is impacting air quality. Yakima Barricade is an upwind location, while Wye Barricade, Benton City, Prosser Barricade, Station 4, and Station 8 are downwind locations where the public may potentially be exposed. The minimum, maximum, and annual average concentrations for these sites are shown in Table 3.1.2, along with the statistics for locations on the Hanford Site (200 ESE, C Farm, ERDF-SE, KE Basin, Ligo Facility, and SE Corner).

Weekly air samples for 2001 at 200 ESE and Benton City were collected January through May, while samples at all other sites were collected over the entire year. The average air concentration at upwind sites and downwind sites are not significantly different, indicating that Hanford is not impacting air quality at locations where the public may be exposed. For the year 2001, all of the weekly DOH gross beta results ranged between 0.0024 and 0.064 pCi/m3, with an annual average of 0.016 pCi/m3.

Site	DOH (pCi/m^3)			Contractor (pCi/m^3)			
	Min	**Max**	**Average**	**Name**	**Min**	**Max**	**Average**
200 ESE	0.0034	0.040	0.017*	PNNL	0.0087	0.035	0.017
Benton City	0.0036	0.044	0.016*	PNNL	0.0089	0.039	0.020
C Farm	0.0040	0.041	0.015	Duratek	0.0085	0.037	0.017
ERDF-SE	0.0028	0.055	0.016	Duratek	0.0049	0.044	0.016
KE Basin	0.0040	0.039	0.014	Duratek	0.0064	0.056	0.019
Ligo Facility	0.0024	0.039	0.016				
Prosser B.	0.0037	0.049	0.014				
SE Corner	0.0040	0.064	0.019				
Station 4	0.0043	0.054	0.019				
Station 8	0.0030	0.057	0.014	PNNL	0.0053	0.036	0.015
Wye B.	0.0035	0.050	0.016	PNNL	0.0058	0.032	0.015
				Duratek	0.0074	0.041	0.017
Yakima B.	0.0034	0.051	0.015	PNNL	0.0060	0.036	0.015

* Weekly air samples at 200 ESE and Benton City were collected only from January through May in the year 2001. Samples at all other sites were collected for the entire year.

Table 3.1.2 Summary Statistics for Gross Beta Concentrations in Air

Most of the DOH results for Co-60; Cs-134, 137, Pu-238, 239/240; and U-234, 235, 238 concentrations in quarterly and semi-annual composite air samples are below laboratory detection limits. A few of the uranium, plutonium, and cesium results are above detection limits. Uranium-234 and U-238 concentrations of approximately 0.00004 pCi/m^3 were detected for all four samples at Station 8 and in one of the samples at Wye Barricade. The U-238 data are shown in Figure 3.1.7 (The U-234 data are similar). A Pu-239/240 concentration of 0.00001 pCi/m^3 was detected at ERDF-SE (Figure 3.1.8), and a Cs-137 concentration of 0.0004 pCi/m^3 was detected for the two samples at C Farm (Figure 3.1.9). These concentrations are very small, and are only a few times greater than the detection limits.

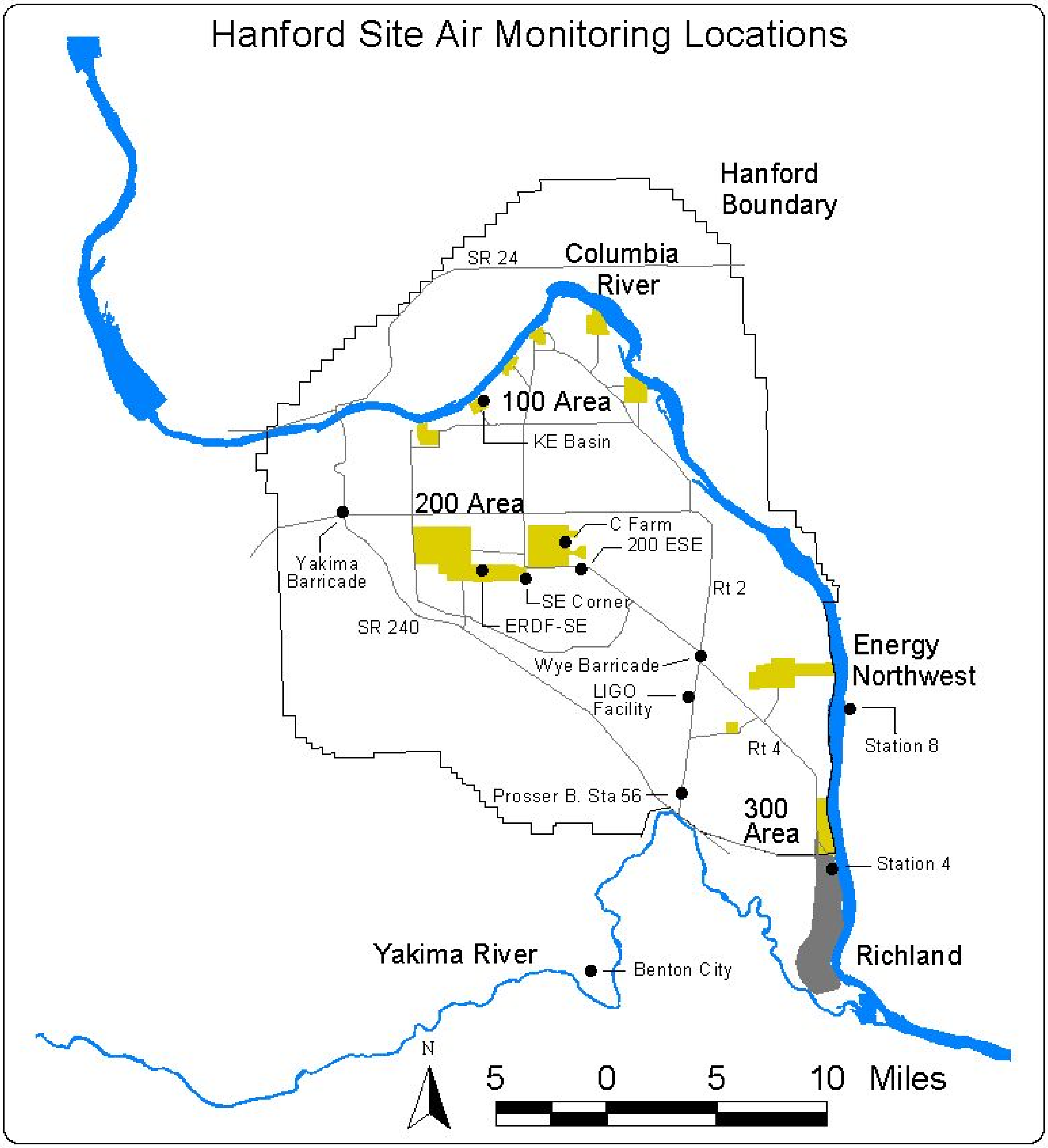

Figure 3.1.1 Air Monitoring Locations

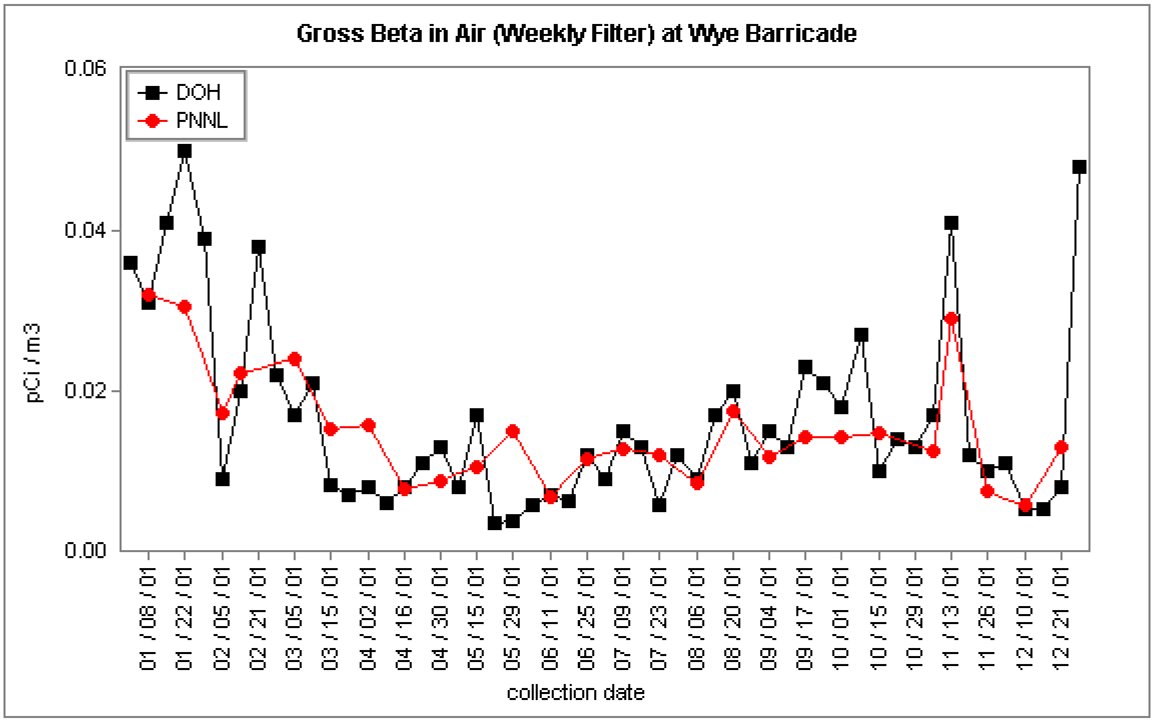

Figure 3.1.2 DOH and PNNL Gross Beta Concentrations in Air at Wye Barricade

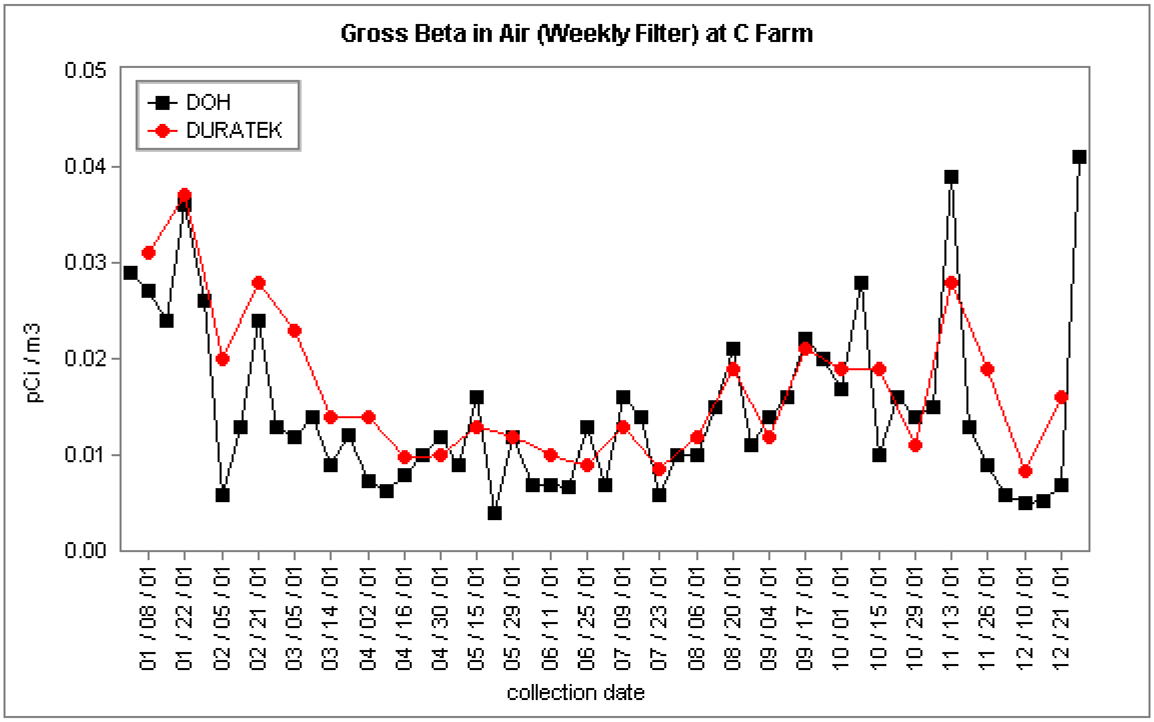

Figure 3.1.3 DOH and Duratek Gross Beta Concentrations in Air at C Farm

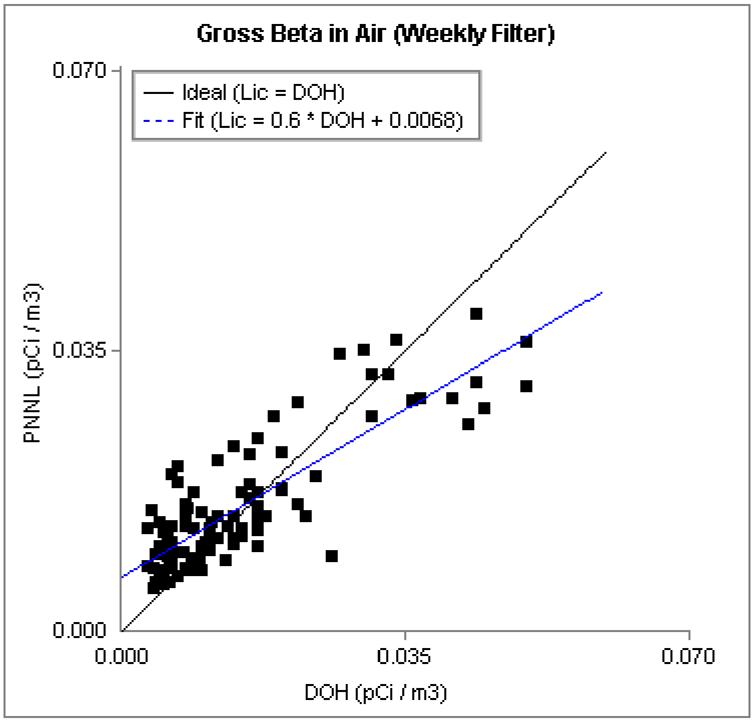

Figure 3.1.4 DOH and PNNL Scatter Plot for Gross Beta Concentrations in Air (2001)

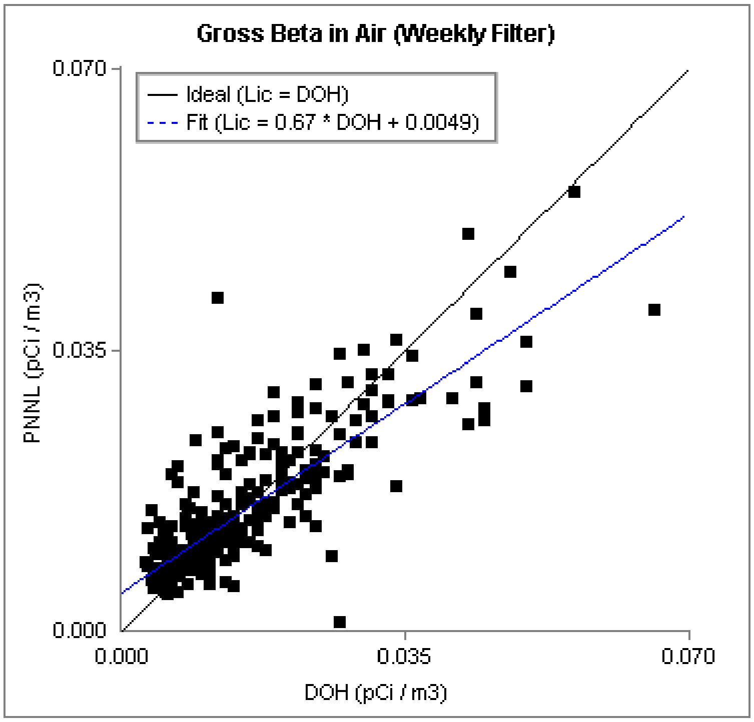

Figure 3.1.5 DOH and PNNL Scatter Plot for Gross Beta Concentrations in Air (1999 - 2001)

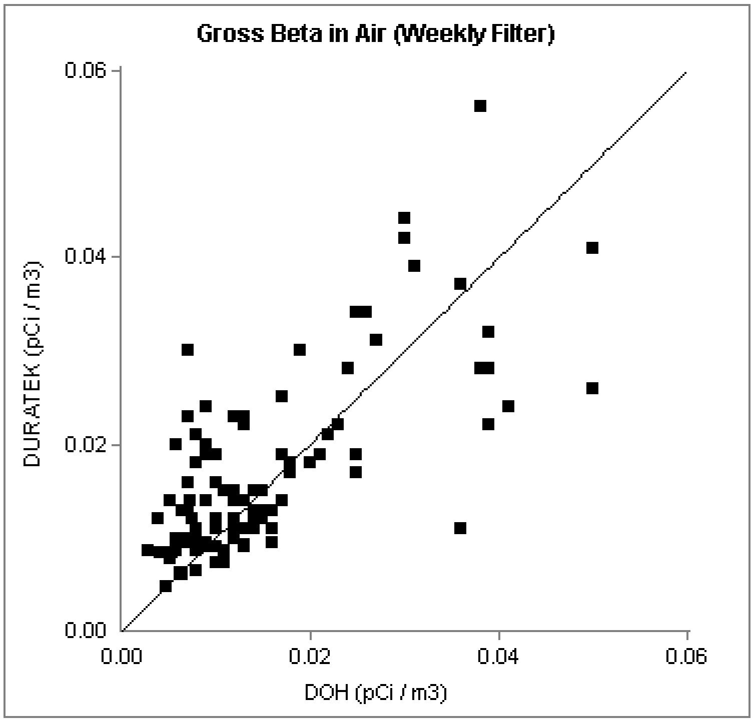

Figure 3.1.6 DOH and Duratek Scatter Plot for Gross Beta Concentrations in Air (2001)

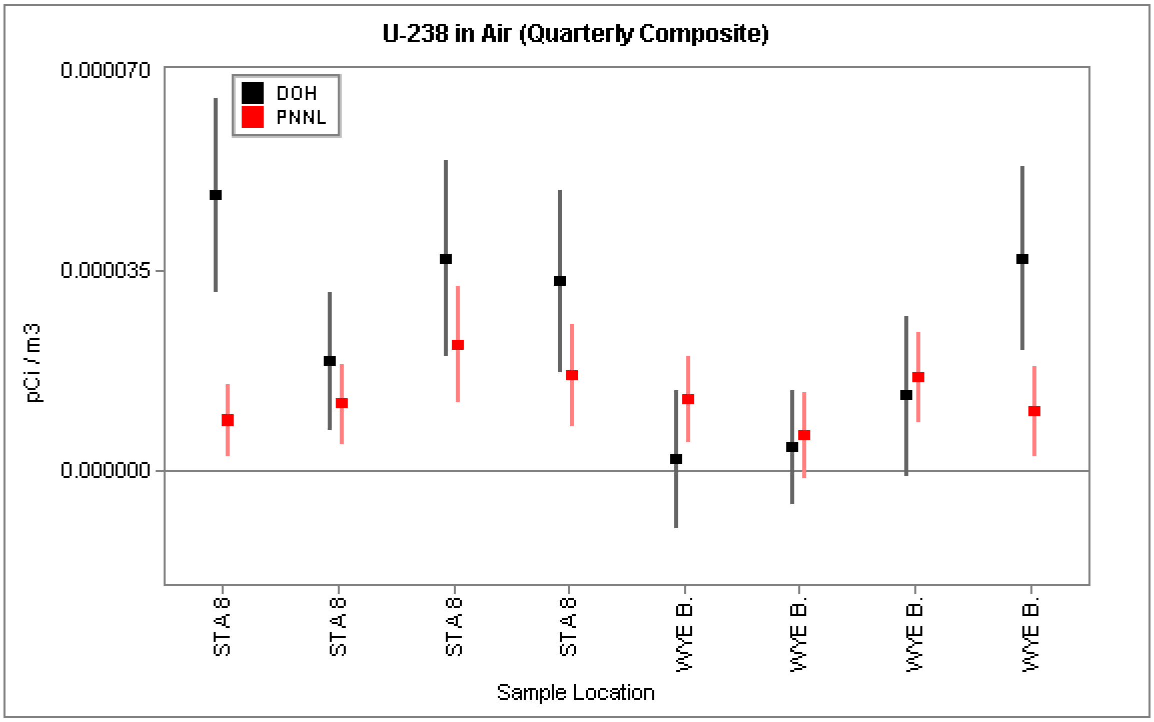

Figure 3.1.7 DOH and PNNL U-238 Concentrations in Air

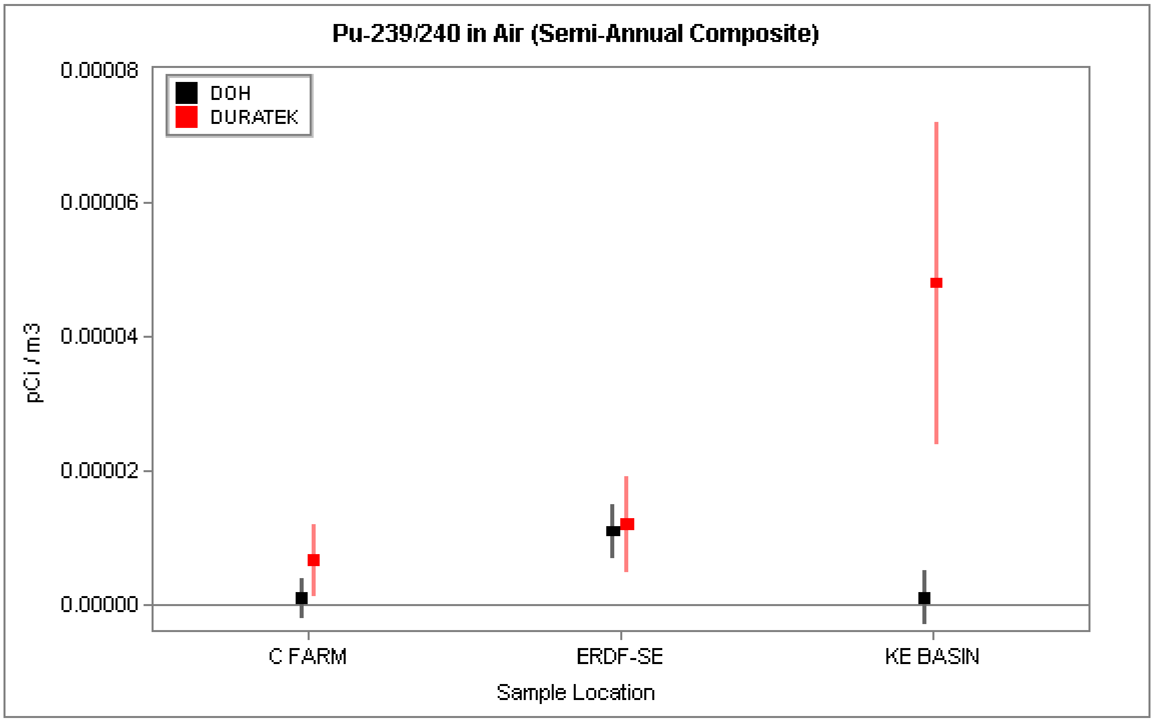

Figure 3.1.8 DOH and Duratek Pu-239/240 Concentrations in Air

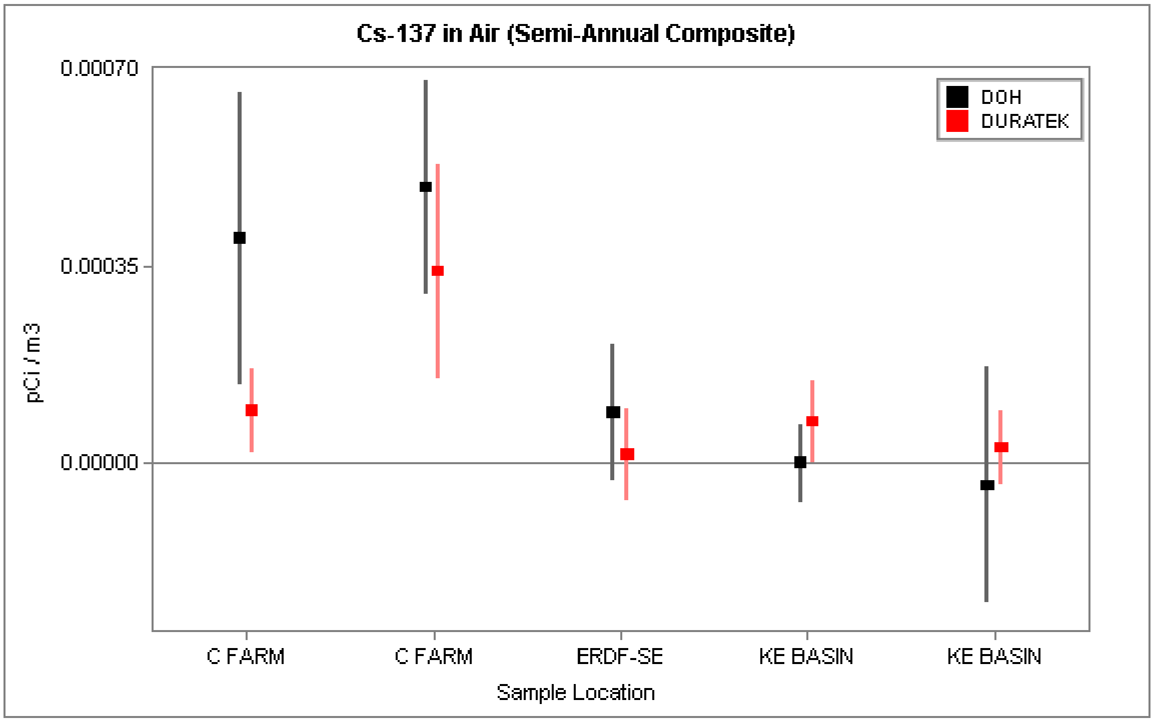

Figure 3.1.9 DOH and Duratek Cs-137 Concentrations in Air

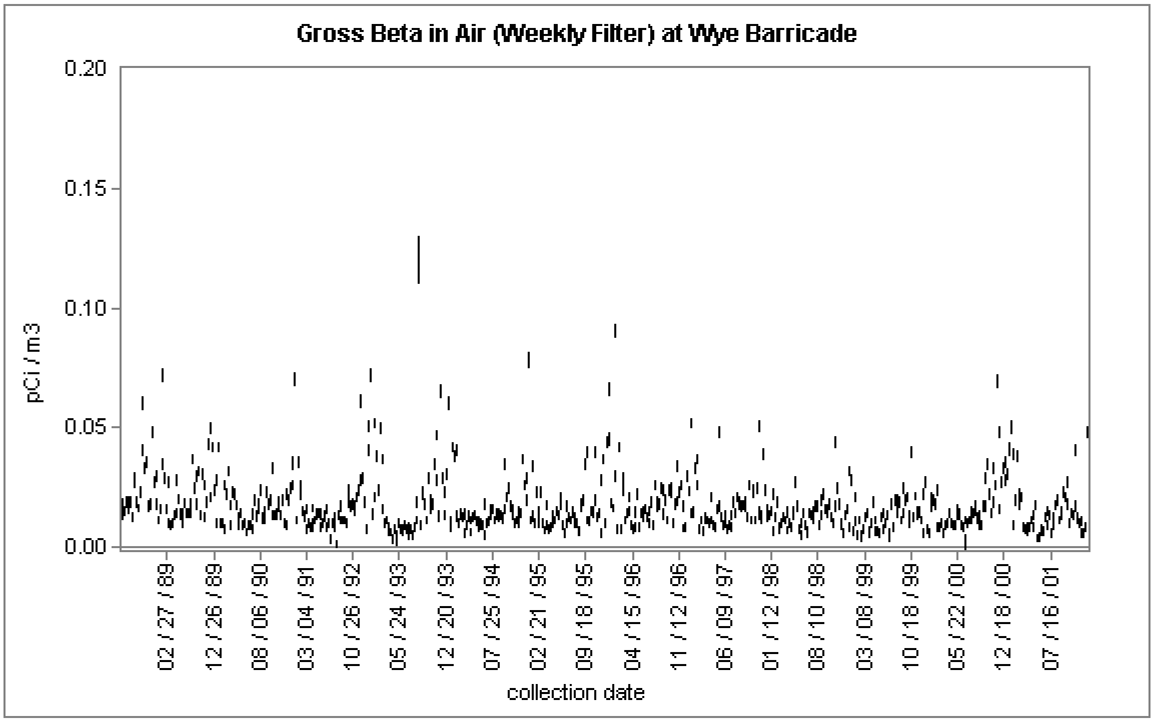

Figure 3.1.10 DOH Historical Gross Beta Concentrations in Air at Wye Barricade

3.2 Groundwater, Riverbank Seep, and Surface Water Monitoring

Major Findings:

- The DOH and PNNL split water results are in good agreement for gross alpha, C-14, Co-60, Cs-137, tritium (H-3), Sr-90, Tc-99, and isotopes of uranium. The agreement is poor for gross beta and I-129. Most of the DOH and WMFS split TEDF discharge water results are in good agreement.
- Water results in 2001 are consistent with historical data. 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.
- Gross alpha and uranium activity were detected in groundwater, riverbank seep water, and Columbia River surface water near the 300 Area.
- Gross beta, Sr-90, and Tc-99 activity was detected in groundwater, riverbank seep water, and Columbia River surface water near the 100K and 100N Areas and near the Old Hanford Townsite.
- Tritium was detected in groundwater throughout the Hanford Site and in riverbank seep water and Columbia River surface water near the Old Hanford Townsite and 300 Area.
- I-129 was detected near the 200 Area.
- Tritium concentrations in FFTF drinking water are below EPA drinking water standards.
- Radionuclide concentrations in TEDF discharge water are below limits set by the Department of Natural Resources.

3.2.1 Purpose and General Discussion

Operations at the Hanford Site have resulted in contaminated groundwater and Columbia River water. Radioactive contaminants have leached from waste sites in the soil to groundwater beneath the Site, and then have migrated with groundwater to the Columbia River. Occasionally, groundwater entering the Columbia River takes the form of 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 collects groundwater, surface water, riverbank seep water, and drinking water samples that are split with PNNL. PNNL monitors radioactivity in water to track contaminant plumes in groundwater, and to evaluate impacts to the public and environment. While the DOH program does not sample enough groundwater wells to track groundwater plumes, the riverbank seep and Columbia River data is adequate to understand impacts to the public. In addition, DOH and Waste Management Federal Services NW (WMFS) split discharge water samples from an effluent treatment facility.

3.2.2 Monitoring Locations

Groundwater

DOH collected 31 split samples from 22 groundwater wells in 2001. Most well locations sampled are on the Hanford Site, either within contaminated plumes, near waste sites, or along the Columbia River shoreline. A few of the well locations are off the Hanford Site, located just south of Hanford in the northern part of Richland and just across the Columbia River in Franklin County. Figure 3.2.1 shows the locations of the DOH groundwater sampling sites.

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 as spent nuclear fuel, shield water, and sludge are removed from the 100 KE Fuel Storage Basin.

The 200 Area consists of retired reactor fuel processing facilities located in the center of the Hanford Site on the central plateau. Common groundwater contaminants include tritium (H-3), I-129, Tc-99, uranium, and Sr-90. A primary objective of the groundwater collection in the 200 Area is to track plume movement and monitor potential leaks from contaminant 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 and is currently being deactivated. Tritium (H-3) 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 area.

The 600 Area includes all the land outside the operational areas of the Hanford Site. Tritium (H-3) 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 plumes originating in the 200 Area that may be moving offsite.

Riverbank Seeps

Groundwater enters the Columbia River through riverbank seeps. Historically, the predominant areas for discharge of riverbank seep water to the Columbia River were located at the 100N Area, the Old Hanford Townsite, and the 300 Area. In 2001, a total of nine split riverbank seep samples were collected from six sites. The sites were located at the 100B, 100N, and 100H Areas; the Old Hanford Townsite; and the 300 Area.

Surface and Discharge Water

A total of 32 split Columbia River water samples were collected from 15 sites. The sites were located at Priest Rapids Dam, Vernita Bridge, the 300 Area, and the Richland Drinking Water intake. Columbia River water near the 300 Area may be impacted by contaminants entering the river through riverbank springs. The Priest Rapids Dam and Vernita Bridge locations are upstream of the Hanford Site, while the Richland Drinking Water sample location is downstream. A comparison of contaminant concentrations at these sites gives an indication of Hanford's impact on the Columbia River.

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

The TEDF was constructed as part of a Tri-Party Agreement Milestone to cease discharges to the 300 Area Process Trenches. The facility began operation in December 1994 and effluent sampling has been conducted since that time. In 2001, DOH split 2 discharge samples from TEDF with WMFS.

Drinking Water

Drinking water for the 400 Area comes from groundwater wells in the area. In addition to sampling one of these wells, DOH samples the drinking water itself. In 2001, a single 400 Area drinking water sample was split with PNNL.

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 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 strontium, iodine, and uranium were added where appropriate.

Riverbank Seeps

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

Surface and Discharge Water

Columbia River surface water is monitored by collecting samples at several points spanning the width of the river. This technique is known as transect sampling. Columbia River transect samples were collected during a joint sampling trip with PNNL. Samples were split in the field and analyzed unfiltered. All samples were analyzed for isotopes of uranium, and most samples were also analyzed for tritium and Sr-90. Analyses for gross alpha, gross beta, and Tc-99 were added where appropriate. In addition, the discharge samples from the 310 Treated Effluent Disposal Facility were analyzed for gross alpha, gross beta, gamma emitting radionuclides, and tritium.

Drinking Water

Drinking water in the 400 area is monitored by sampling water from a tap in the Fast Flux Test Facility building.

Summary

A summary of the 2001 split water samples is presented in Table 3.2.1.

Water Matrix	DOE Contractor	Analytes	Number of Sample Sites	Number of Samples
Groundwater	PNNL	C-14, Co-60, Cs-137, gross alpha, gross beta, H-3, I-129, Sr-90, Tc-99, U-234, U-235, U-238	22	31
Riverbank Seep	PNNL	Co-60, Cs-137, gross alpha, gross beta, H-3, Sr-90, Tc-99, U-234, U-235, U-238	6	9
Surface Water	PNNL	gross alpha, gross beta, H-3, Sr-90, Tc-99, U-234, U-235, U-238	15	32
Discharge Water	WMFS	Co-60, Cs-137, gross alpha, gross beta, H-3	1	2
Drinking Water	PNNL	gross alpha, gross beta, H-3, Sr-90	1	1

Table 3.2.1 Summary of Split Water Samples

3.2.4 Comparison of DOH and Contractor Data

Overall, the DOH /PNNL and DOH/WMFS split water results are in good agreement. The only problems are a poor agreement for the DOH/PNNL I-129 results in groundwater, and a systematic discrepancy between the DOH and PNNL gross beta results (particularly in riverbank seep water). The details of the DOH and DOE contractor data are discussed below.

In 2001, the DOH Hanford Oversight Program split groundwater, surface water, drinking water, and riverbank seep water samples with PNNL. Laboratory techniques to analyze all these different types of water samples are identical. Therefore, the regression analysis, which is used to quantify the degree of agreement between DOH and the DOE contractor, included all of the different types of water samples. Regression analysis was carried out for gross alpha, gross beta, H-3, Sr-90, Tc-99, U-234, and U-238. The data for all other radionuclides measured in water samples did not meet the criteria for conducting regression analysis, either because there were too few data points, or most of the data are below detection limits.

DOH vs. PNNL scatter plots for split water samples were generated for gross alpha, gross beta, tritium, Sr-90, Tc-99, and U-238. The scatter plots combine groundwater, surface water, riverbank seep water, and drinking water. A scatter plot for U-234 is not shown because it is similar to U-238. The x-coordinate of each point represents the DOH result, while the y-coordinate represents the PNNL result. Ideally, if the DOH and PNNL results were identical, all the points would fall on the straight line with slope equal to unity and y-intercept equal to zero (shown as the solid black line in the figures). Regression analysis was used to find the best straight- line fit to the data (blue dashed line), and the resulting slopes and y-intercepts quantify the agreement between DOH and PNNL results.

The DOH and PNNL gross alpha scatter plot is shown in Figure 3.2.2. The slope of 0.82 and the y-intercept of 0.16 pCi/L in the regression analysis indicates that the DOH and PNNL data are in good agreement with a slight systematic bias. On average, the difference in concentrations reported by DOH and PNNL are less than 18%.

The DOH and PNNL gross beta scatter plot is shown in Figure 3.2.3. The slope of 1.13 and the y-intercept of 0.67 pCi/L in the regression analysis indicates that the DOH and PNNL data are in good agreement. However, inspection of the low concentration gross beta data indicate a systematic bias. The DOH and PNNL gross beta scatter plot for activity less than 100 pCi/L is shown in Figure 3.2.4. The slope of 0.46 indicates that the concentrations reported by PNNL are approximately half the values reported by DOH. DOH will investigate this discrepancy and report its findings in a future annual report.

The DOH and PNNL tritium (H-3) scatter plot is shown in Figure 3.2.5. The slope of 0.89 and the y-intercept of 402 pCi/L in the regression analysis indicates that the DOH and PNNL data are in good agreement. On average, the difference in concentrations reported by DOH and PNNL are less than 11%. Also shown in Figure 3.2.6 is the split tritium data in groundwater. As can be seen, most of the results are in good agreement.

The DOH and PNNL Sr-90 scatter plot is shown in Figure 3.2.7. The slope of 1.07 and the y-intercept of 2 pCi/L in the regression analysis indicates that the DOH and PNNL data are in good agreement. On average, the difference in concentrations reported by DOH and PNNL are less than 7%. Also shown in Figure 3.2.8 is the split Sr-90 data in groundwater. As can be seen, the results are in good agreement.

The DOH and PNNL Tc-99 scatter plot is shown in Figure 3.2.9. The slope of 0.9 and the y-intercept of 3 pCi/L in the regression analysis indicates that the DOH and PNNL data are in good agreement. On average, the difference in concentrations reported by DOH and PNNL are less than 10%. Also shown in Figure 3.2.10 is the split Tc-99 data in groundwater. As can be seen, the results are in good agreement.

The DOH and PNNL U-238 scatter plot is shown in Figure 3.2.11. The slope of 0.95 and the y-intercept of 0.15 pCi/L in the regression analysis indicates that the DOH and PNNL data are in good agreement. On average, the difference in concentrations reported by DOH and PNNL are less than 5%. Also shown in Figure 3.2.12 is the split U-238 data in riverbank seep water. As can be seen, the results are in good agreement. The U-234 data and regression analysis are similar to those for U-238.

The DOH and PNNL results for Co-60, Cs-137, and C-14 in water are all in good agreement, as all concentrations are less than detection limits. The DOH and PNNL results for I-129 in groundwater are shown in Figure 3.2.13. For samples where the results are above the detection limit, the agreement is poor. DOH will investigate this discrepancy and report its findings in a future report.

Summary

There is good agreement between DOH and PNNL results for gross alpha, Co-60, Cs-137, C-14, H-3, Sr-90, Tc-99, U-234, and U-238. The agreement is poor for gross beta, especially for concentrations below 100 pCi/L, and for I-129. DOH will investigate the discrepancies for gross beta and I-129, and report its findings in a future report.

The DOH and WMFS results for most of the discharge samples at TEDF are in good agreement. The only discrepancy is one of the two tritium samples, where DOH measured 200 pCi/L and WMFS measured 1800 pCi/L. Most of the data are below detection limits.

3.2.5 Discussion of Results

All DOH Co-60, Cs-137, and C-14 results were below detection limits. The results in 2001 for these radionuclides are similar to historical data.

Maximum gross alpha concentrations detected by DOH were 4 pCi/L in discharge water, 55 pCi/L in groundwater, and 120 pCi/L in riverbank seep water. Gross alpha activity was not detected in FFTF drinking water. Most Columbia River surface water samples were not analyzed for gross alpha. The highest concentrations were detected in 300 Area groundwater wells, 300 Area riverbank seeps, and Columbia River water near the 300

Area shoreline. The primary contribution to gross alpha activity in Hanford water samples typically comes from uranium activity. The 300 Area has a uranium groundwater plume that is migrating to the Columbia River in the form of riverbank seeps.

Maximum gross beta concentrations detected by DOH were 7 pCi/L in discharge water, 5 pCi/L in drinking water, 6000 pCi/L in groundwater, and 85 pCi/L in riverbank seep water. Most Columbia River surface water samples were not analyzed for gross beta. The highest groundwater concentrations were detected in 100K and 100N Area groundwater wells, and the highest riverbank seep concentrations were detected at river mile 28.2 near the Old Hanford Townsite. The primary components of gross beta activity in Hanford water samples consist of fission product activity, such as Co-60, Cs-137, Sr-90, and Tc-99. The 100K and 100N Areas have Sr-90 groundwater plumes, and the Old Hanford Townsite has a Tc-99 groundwater plume that is migrating to the Columbia River in the form of riverbank seeps.

Maximum tritium (H-3) concentrations detected by DOH were 200 pCi/L in discharge water, 3700 pCi/L in drinking water, 350,000 pCi/L in groundwater (see Figure 3.2.6), 115,000 pCi/L in riverbank seep water, and 400 pCi/L in Columbia River surface water. The highest groundwater concentration was found at well 699-35-70. Tritium is a highly mobile contaminant and is found throughout a wide area beneath the Hanford Site. Tritium concentrations in well 699-35-70 have typically been high and are influenced by the tritium plume emerging from the 200 Area. Over the past decade, DOH has observed a steady decline in the tritium concentrations at this location (Figure 3.2.14), as well as in groundwater from the 100K and 100N Areas.

The highest tritium concentration in riverbank seep water was found at river mile 28.2, near the Old Hanford Townsite. The concentration measured in 2001 is consistent with historical data. The highest tritium concentrations in Columbia River surface water were found at the 300 Area shoreline, where a known tritium plume is migrating to the Columbia River.

Maximum Sr-90 concentrations detected by DOH were 1800 pCi/L in groundwater (see Figure 3.2.8), and 3 pCi/L in riverbank seep water. Strontium-90 was not detected by DOH in drinking water or Columbia River surface water samples. The 2001 Sr-90 concentrations in groundwater are consistent with historical data. The highest groundwater concentration was found at well 199-K-109A in the 100K Area. Strontium-90 concentrations have been decreasing at this well for the last several years. Concentrations of 1000 pCi/L were found in well 199-N-14 in the 100N Area. Strontium-90 concentrations have been constant at this well for over a decade (see Figure 3.2.15).

Maximum Tc-99 concentrations detected by DOH were 200 pCi/L in groundwater (see Figure 3.2.10), and 100 pCi/L in riverbank seep water. Most Columbia River surface water samples were not analyzed for Tc-99. The 2001 Tc-99 concentrations in water are consistent with historical data. Technetium-99 is typically detected in 100H Area groundwater wells (199-H4-4), and in groundwater wells (699-41-1A) and seeps near the

Old Hanford Townsite. Historical Tc-99 results in riverbank seep water at site Spring 28.2 near the Old Hanford Townsite are shown in Figure 3.2.16.

Uranium was detected by DOH in 300 Area groundwater wells, riverbank seeps, and Columbia River surface water. Results found in 2001 are similar to historical data. Uranium-238 concentrations ranged from 15 to 20 pCi/L in 300 Area groundwater. Historical results at well 399-1-17A are shown in Figure 3.2.17. Concentrations are declining at this site since discharge to the nearby process trenches was discontinued in 1997. Uranium-238 concentrations in riverbank seep water ranged from 15 to 45 pCi/L in 300 Area shoreline seeps (see Figure 3.2.12). The maximum U-238 concentration in Columbia River surface water was 0.7 pCi/L at the 300 Area shoreline, which is approximately three times greater than background values measured at Priest Rapids Dam.

Iodine-129 was detected by DOH at groundwater well 699-35-70 in the vicinity of an I-129 plume in the 200 Area (see Figure 3.2.13). Concentrations ranged form 5 to 35 pCi/L, which are consistent with historical data at this site.

Summary

Radionuclides detected in groundwater wells include gross alpha, gross beta, tritium, Sr-90, Tc-99, I-129, and isotopes of uranium. Radionuclide concentrations in 2001 were similar to historical data, and were detected in the vicinity of known groundwater plumes.

Radionuclides detected in riverbank seep water include gross alpha, gross beta, tritium, Sr-90, Tc-99, and isotopes of uranium. The highest gross alpha and uranium activity was detected in seeps entering the Columbia River near the 300 Area. The highest gross beta, Sr-90, and Tc-99 activity was detected near the 300 Area and the Old Hanford Townsite. Tritium was detected in seeps entering the river near the 300 Area and the Old Hanford Townsite.

Most radioactivity concentrations in Columbia River surface water samples were either below detection limits or were similar to background concentrations detected at Priest Rapids Dam upstream of the Hanford Site. Exceptions include low, but detectable concentrations of tritium and uranium in near-shore Columbia River surface water collected near the 300 Area.

Drinking water for the 400 Area Fast Flux Test Facility (FFTF) is obtained from two groundwater wells. The water at this location is contaminated with tritium and is monitored to ensure that Environmental Protection Agency (EPA) Drinking Water Standards are not exceeded. Historical tritium results for tap water at FFTF are shown in Figure 3.2.18. The tritium drinking water limit is 20,000 pCi/L, and FFTF drinking water is approximately 20% of the allowable limit.

Gross alpha, gross beta, and tritium activity were detected in 300 Area TEDF discharge water samples, but all concentrations were below limits set by the Department of Natural Resources. These limits are: 15 pCi/L gross alpha, 50 pCi/L gross beta, and 20,000 pCi/L tritium.

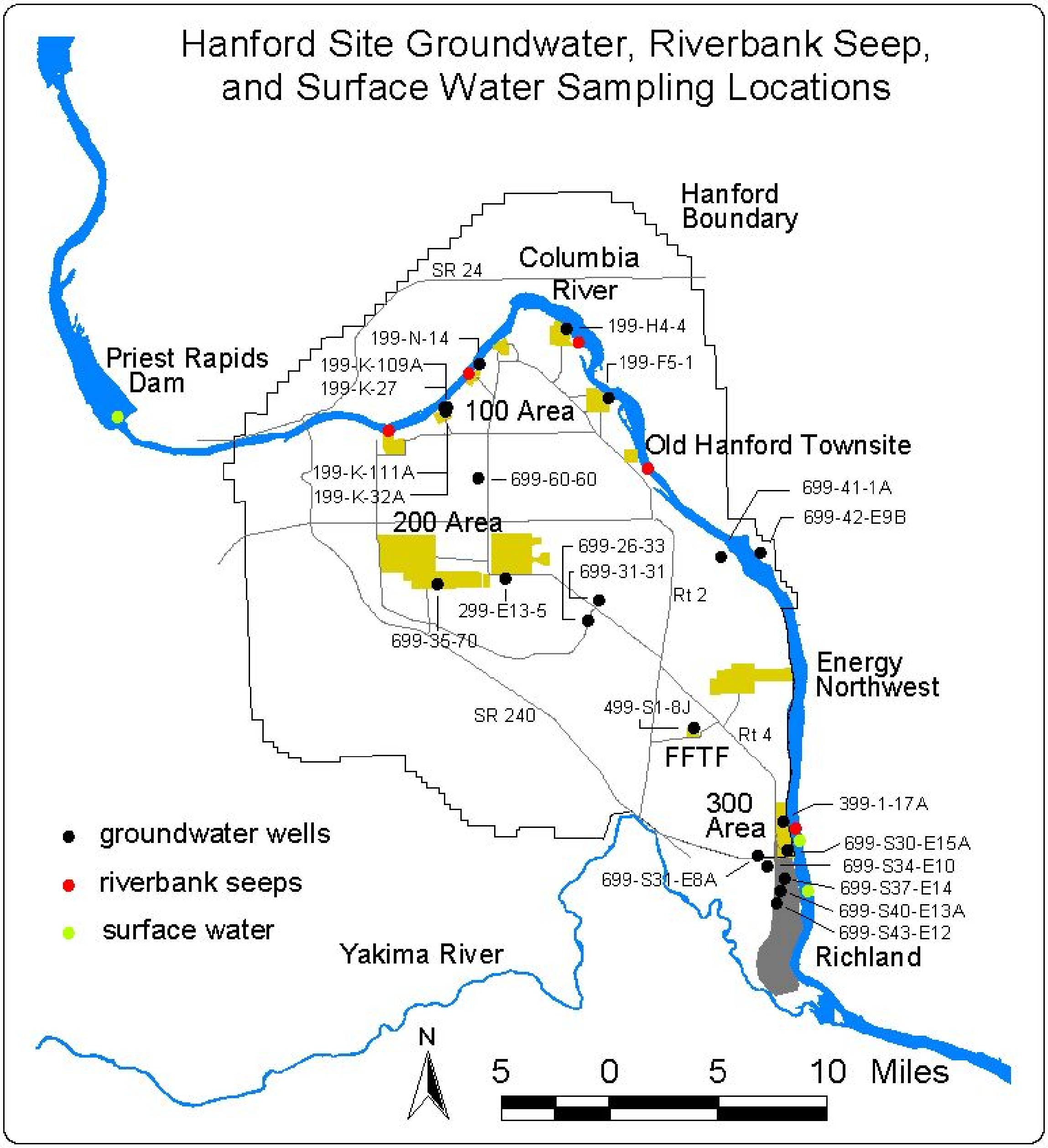

Figure 3.2.1 Water Monitoring Locations

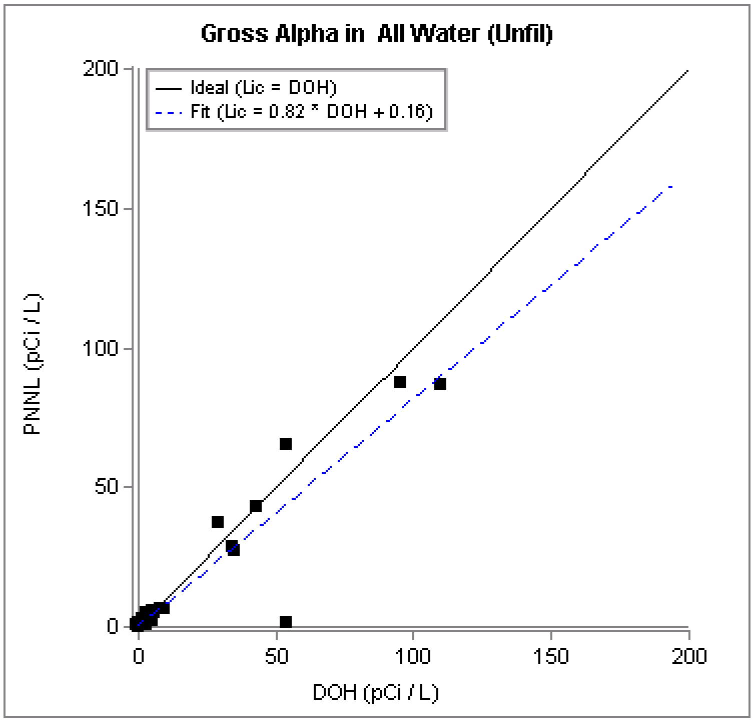

Figure 3.2.2 DOH and PNNL Scatter Plot for Gross Alpha Concentrations in Water Samples

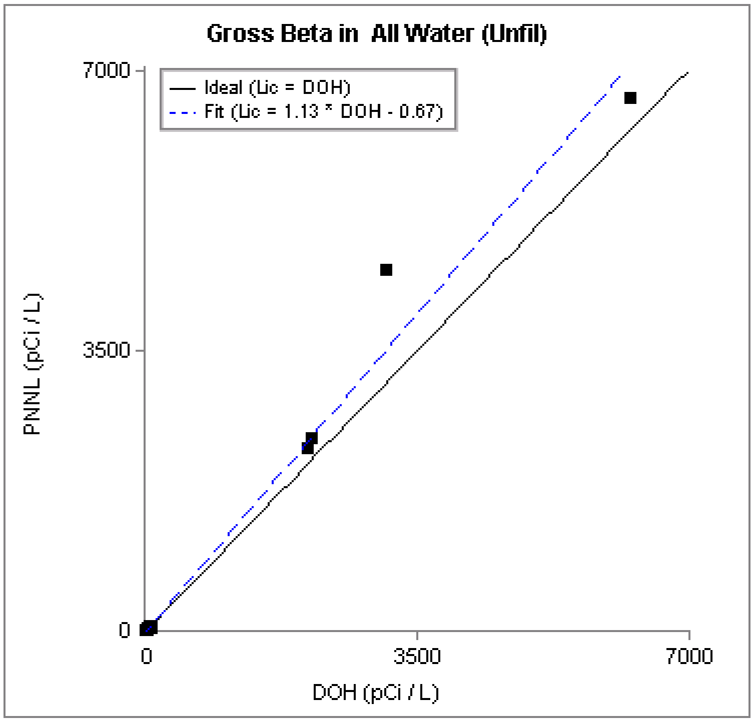

Figure 3.2.3 DOH and PNNL Scatter Plot for Gross Beta Concentrations in Water Samples

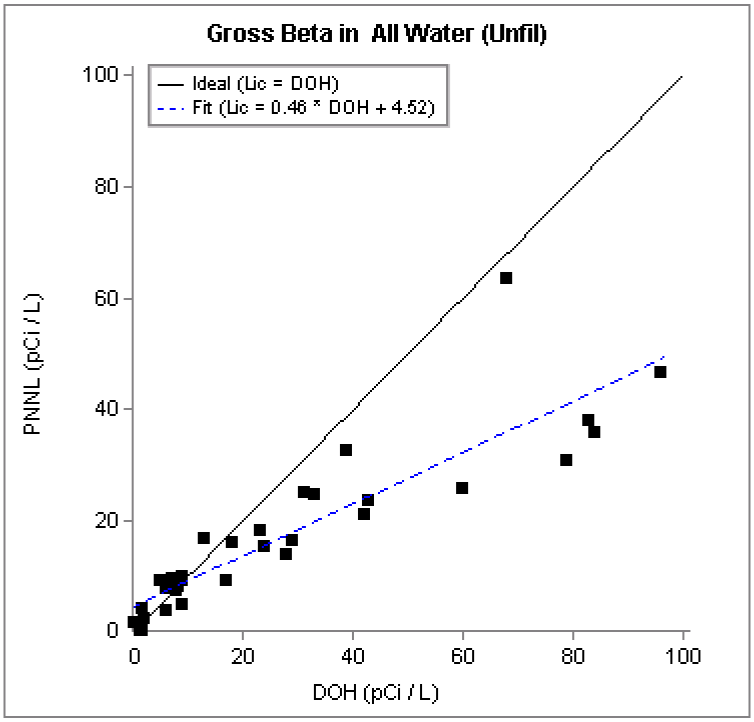

Figure 3.2.4 DOH and PNNL Scatter Plot - Low Activity Gross Beta in Water Samples

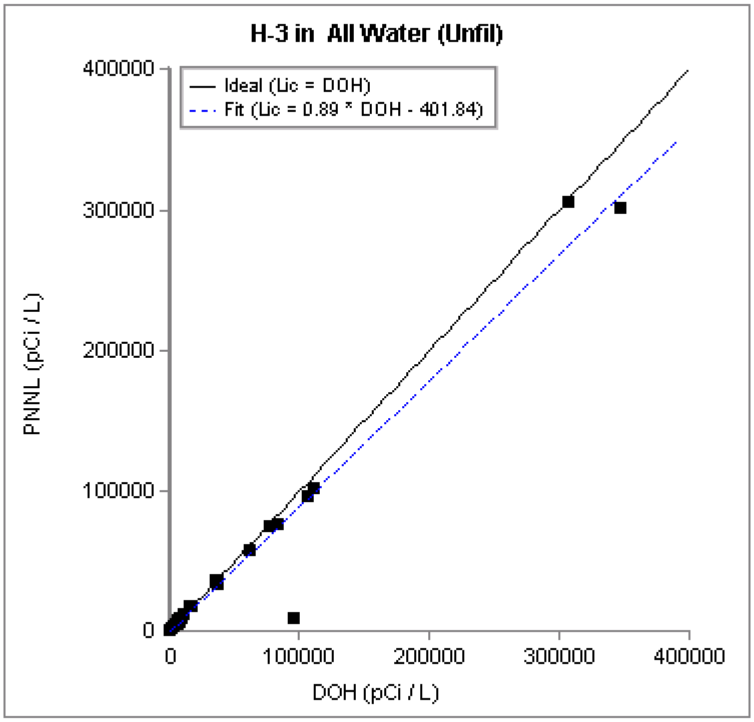

Figure 3.2.5 DOH and PNNL Scatter Plot for Tritium Concentrations in Water Samples

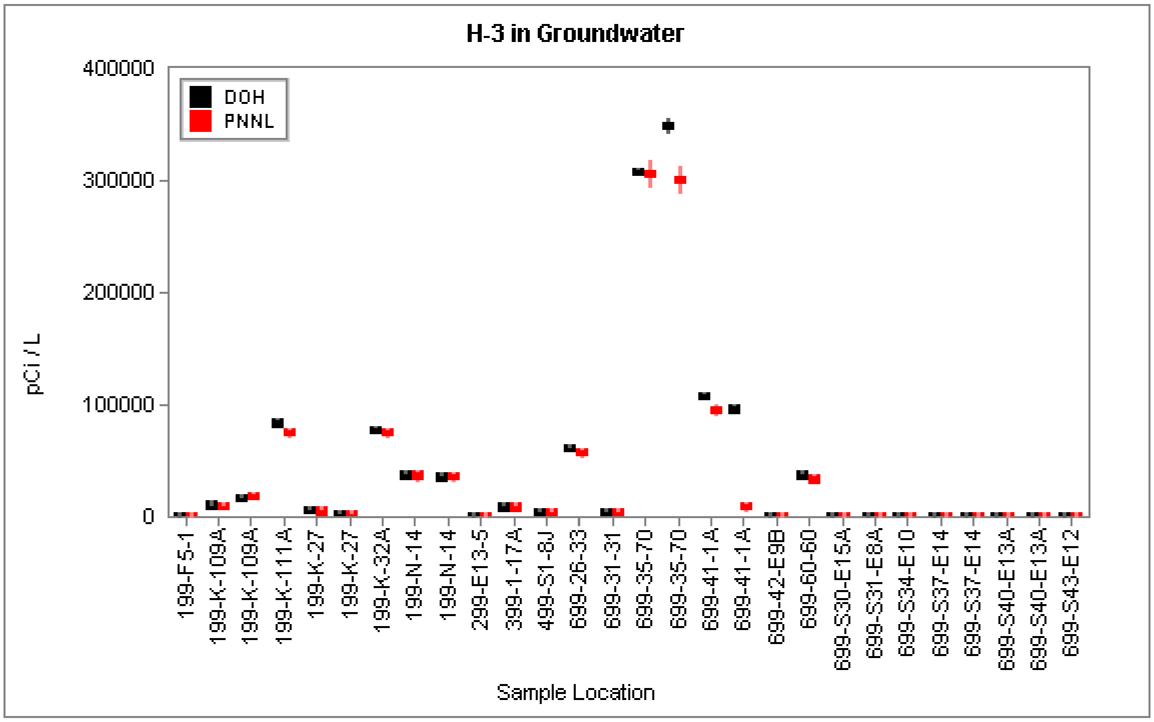

Figure 3.2.6 DOH and PNNL Tritium Concentrations in Groundwater

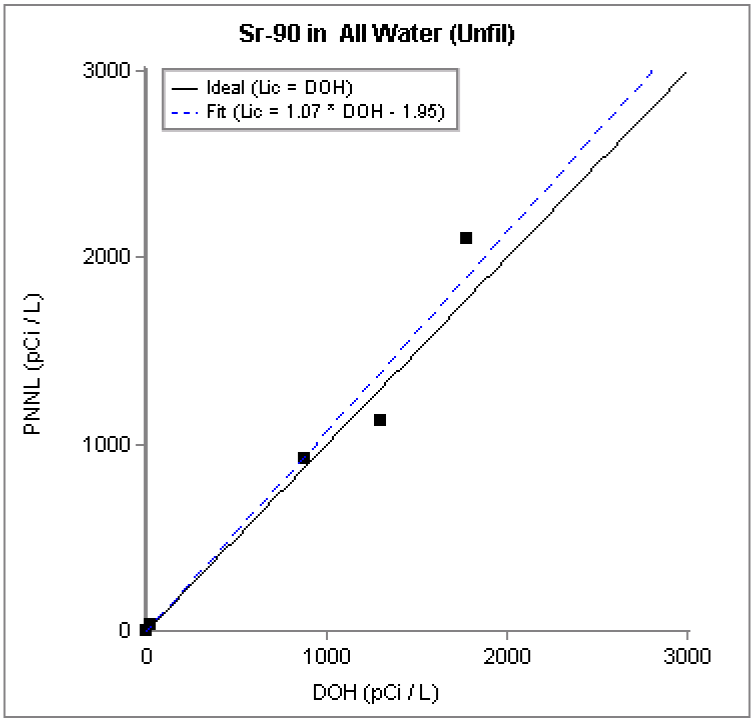

Figure 3.2.7 DOH and PNNL Scatter Plot for Sr-90 Concentrations in Water Samples

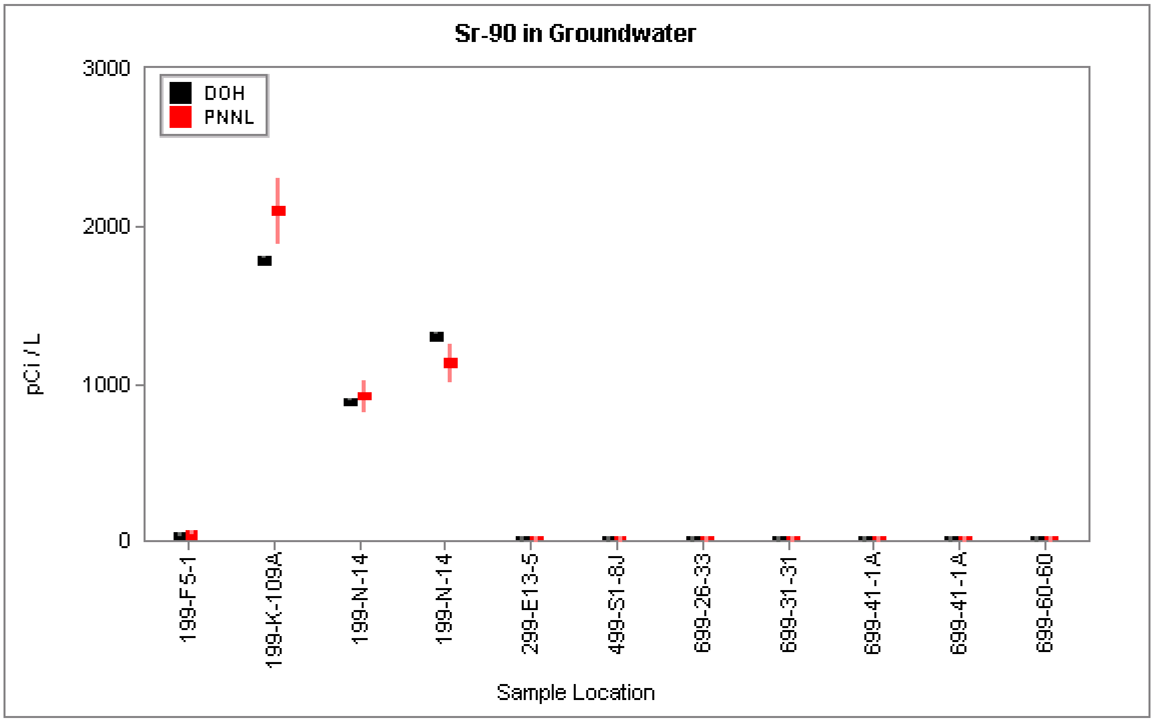

Figure 3.2.8 DOH and PNNL Sr-90 Concentrations in Groundwater

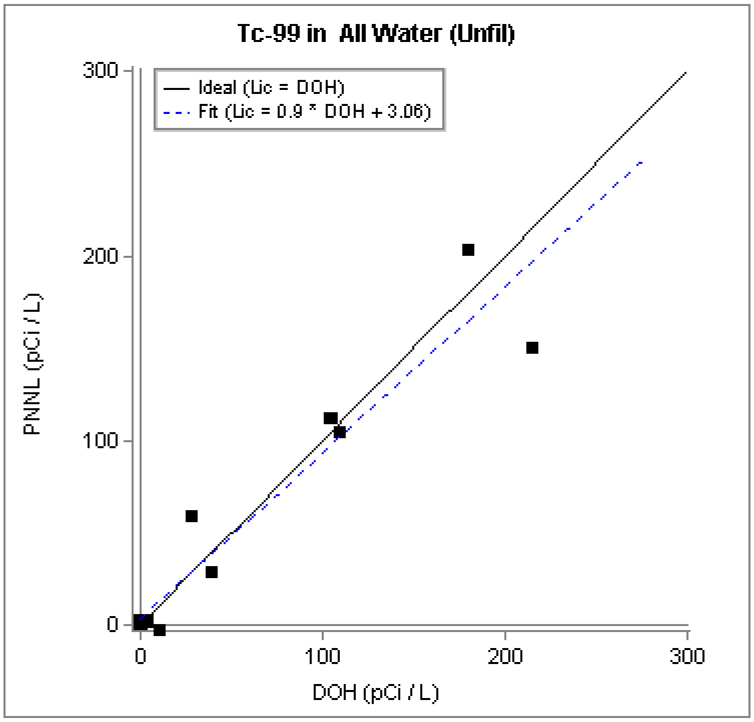

Figure 3.2.9 DOH and PNNL Scatter Plot for Tc-99 Concentrations in Water Samples

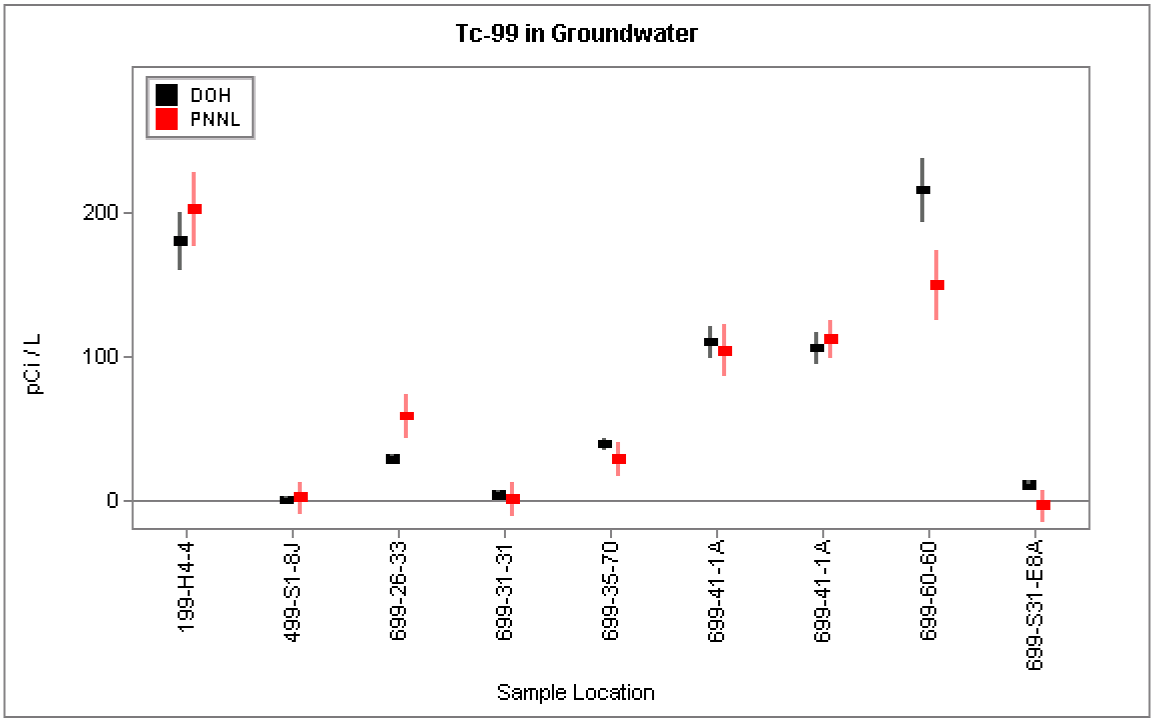

Figure 3.2.10 DOH and PNNL Tc-99 Concentrations in Groundwater

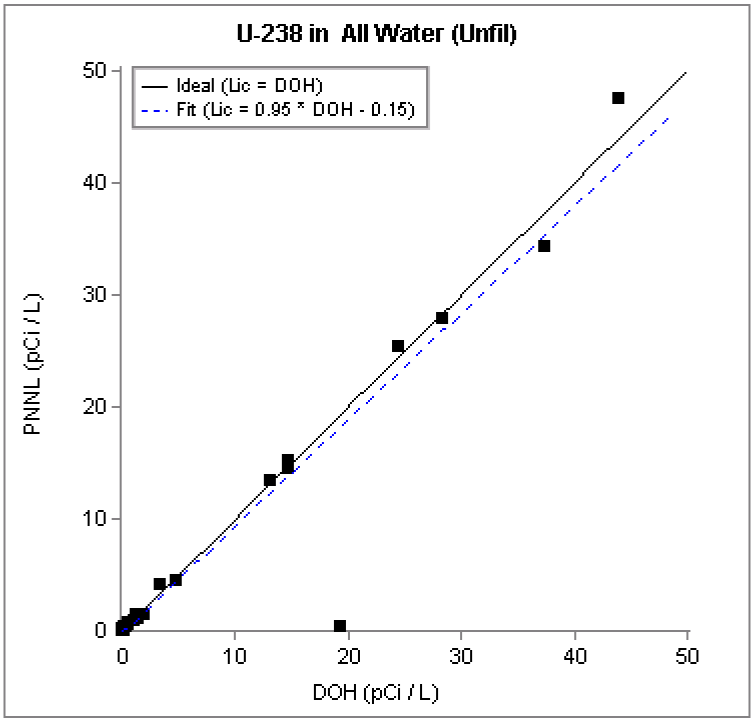

Figure 3.2.11 DOH and PNNL Scatter Plot for U-238 Concentrations in Water Samples

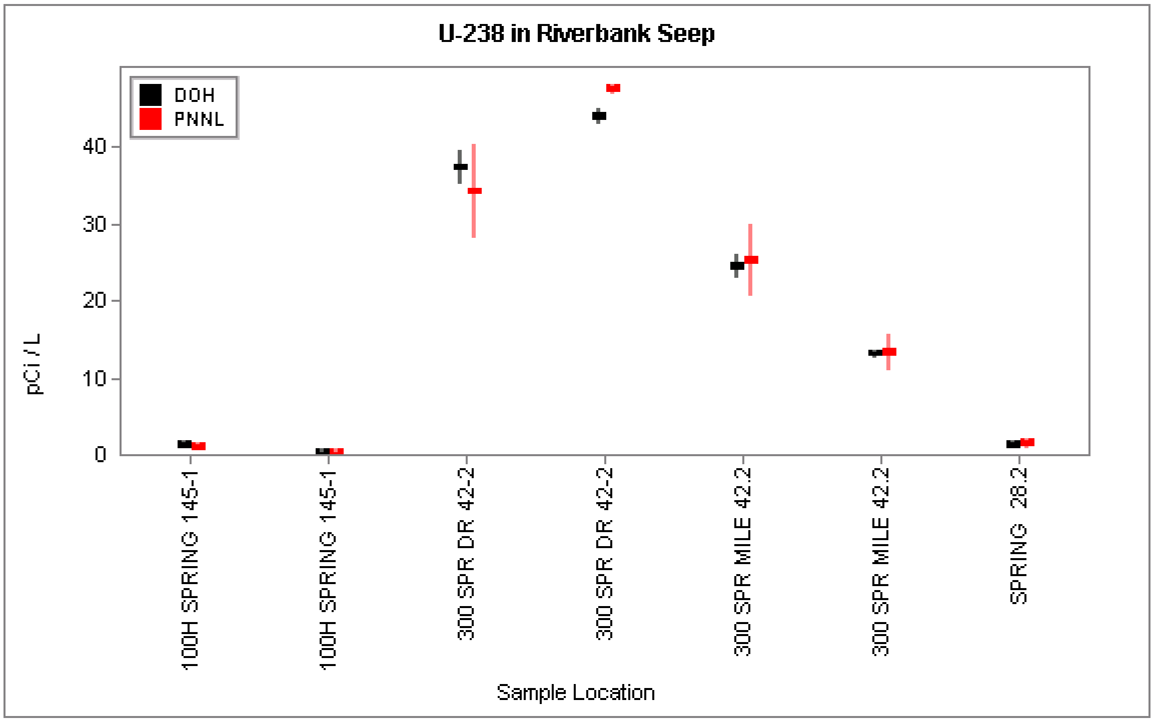

Figure 3.2.12 DOH and PNNL U-238 Concentrations in Groundwater

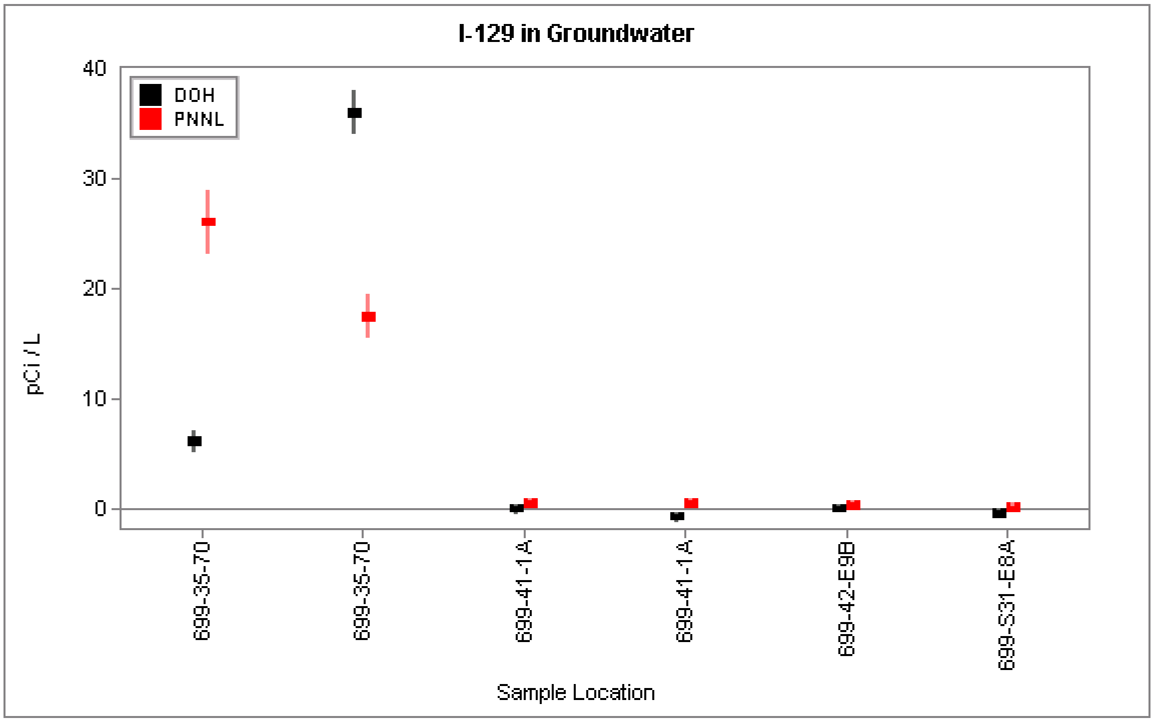

Figure 3.2.13 DOH and PNNL I-129 Concentrations in Groundwater

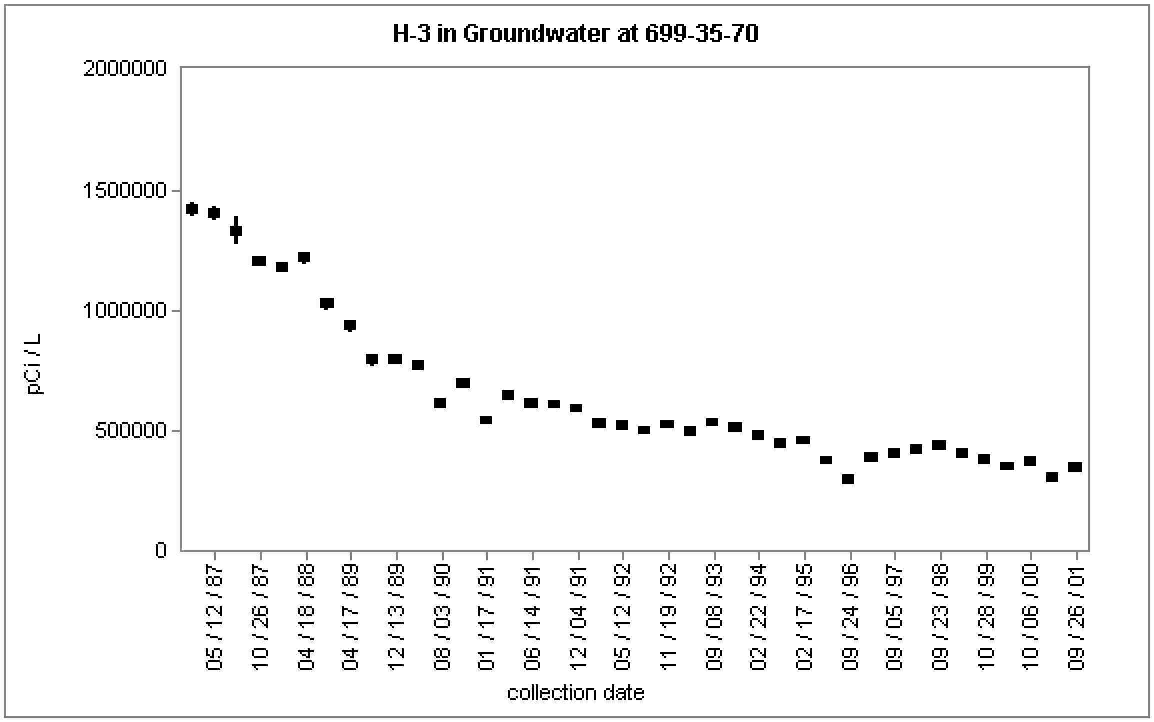

Figure 3.2.14 Historical DOH Tritium Concentrations in Groundwater Well 699-35-70

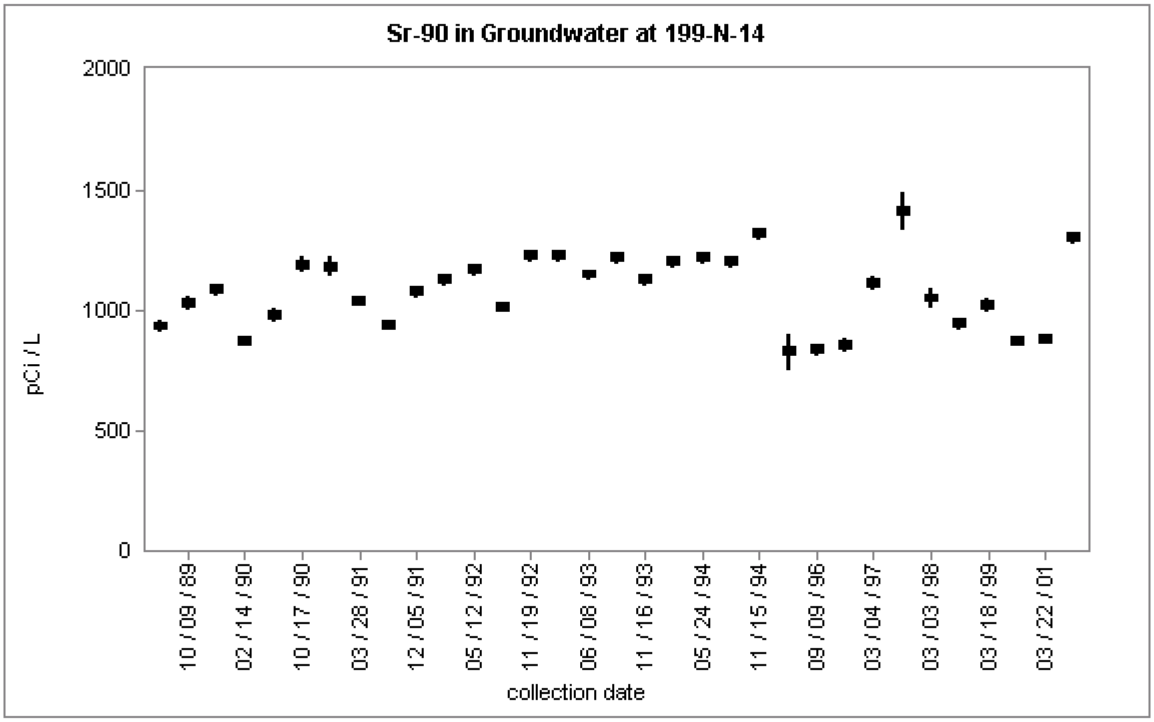

Figure 3.2.15 Historical DOH Sr-90 Concentrations in Groundwater Well 199-N-14

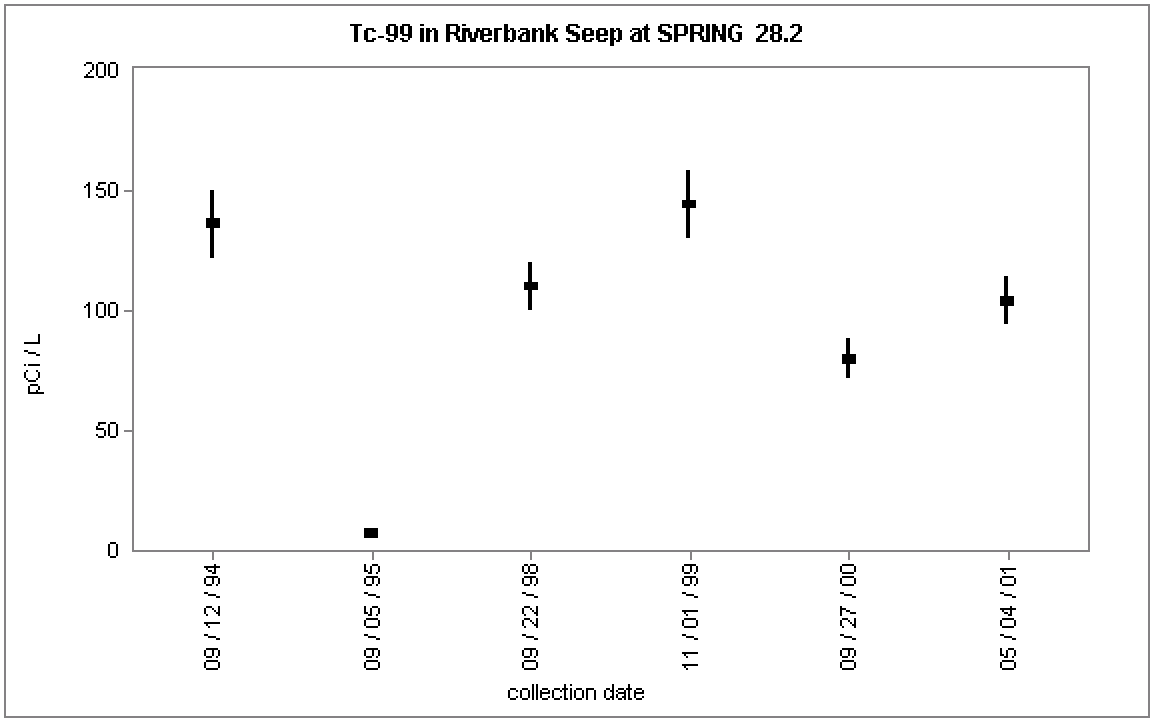

Figure 3.2.16 Historical DOH Tc-99 Concentrations in Riverbank Seep Water at Spring 28.2

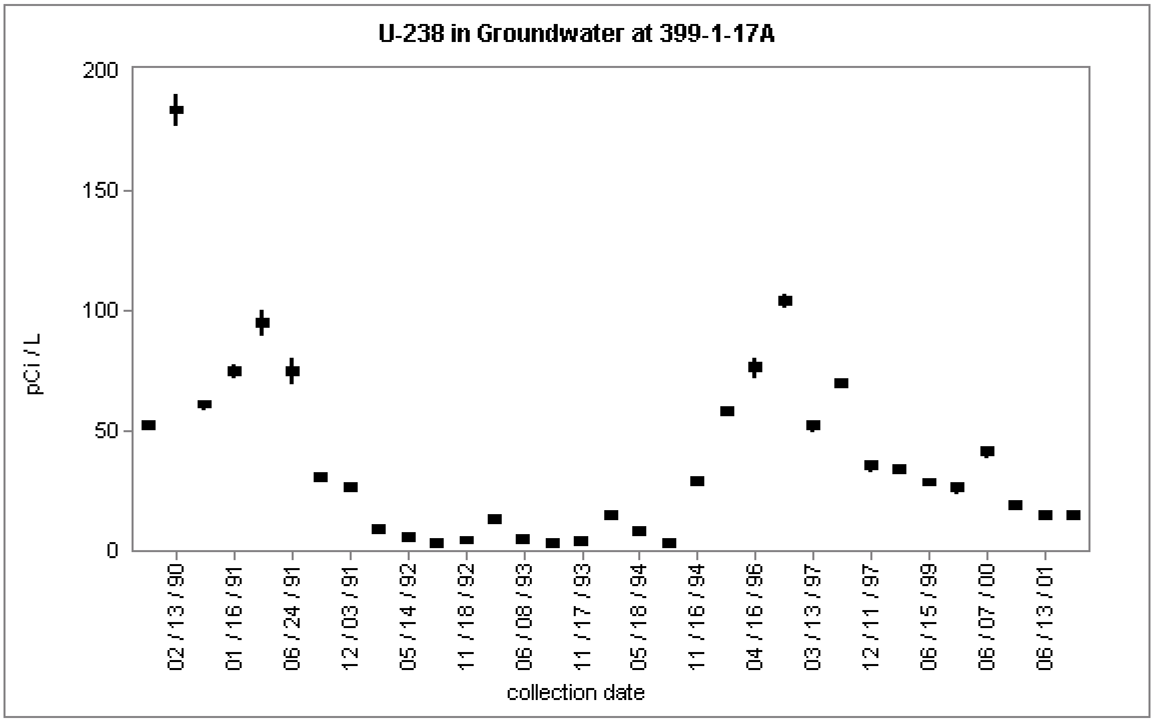

Figure 3.2.17 Historical DOH U-238 Concentrations in Groundwater Well 399-1-17A

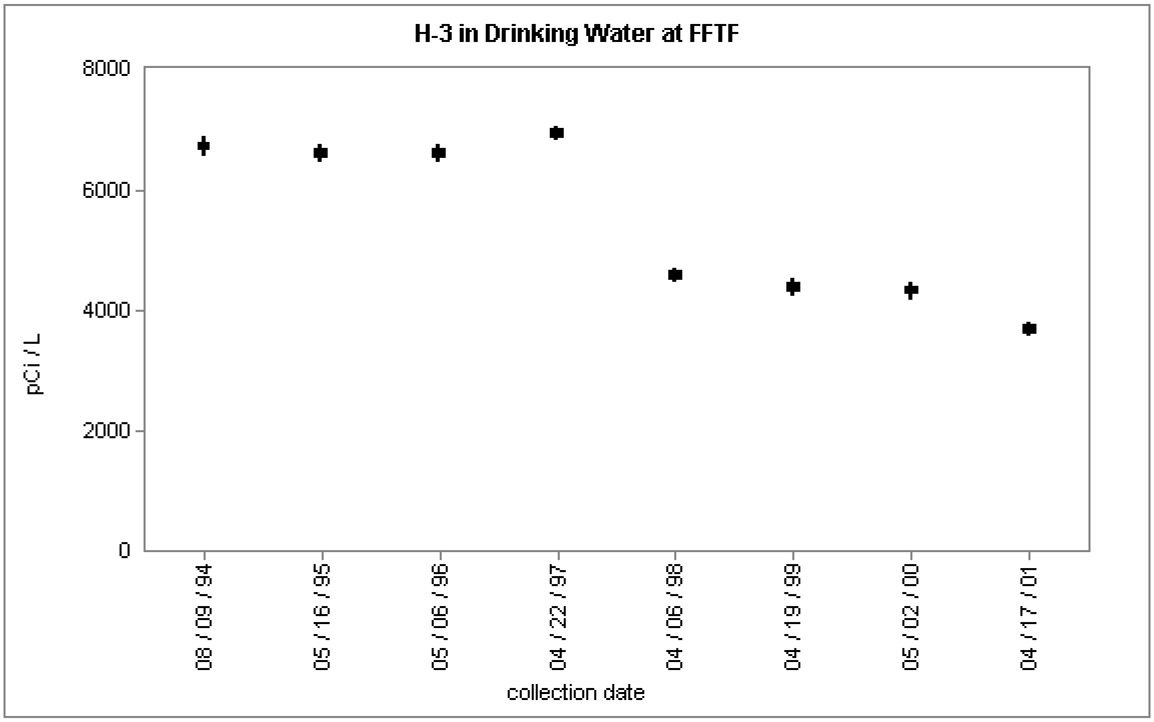

Figure 3.2.18 Historical DOH Tritium Concentrations in Drinking Water at FFTF

3.3 External Gamma Radiation Monitoring

Major Findings:

- The DOH and DOE contractor results are in good agreement.
- Most radiation exposure rates at locations on the Hanford Site are consistent with background exposure rates.
- One site near known surface contamination in the 100 N Area has radiation exposure rates 60% higher than natural background, but below regulatory limits.

3.3.1 Purpose and General Discussion

The Department of Health and DOE contractors monitor external gamma radiation levels with Thermoluminescent Dosimeters (TLDs). TLDs measure the time-integrated exposure to gamma radiation at their location. Sources of background gamma radiation include natural cosmic and terrestrial radiation as well as fallout from atmospheric testing of nuclear weapons. Contamination from the Hanford Site contributes to man-made sources of gamma radiation. The primary purpose of the DOH TLD program is to provide oversight of the DOE monitoring program. In addition, DOH compares it's onsite and offsite TLD results to determine if Hanford is impacting workers or the public.

3.3.2 Monitoring Locations

In 2001, DOH operated 20 ambient gamma radiation monitoring sites under the Hanford Environmental Oversight Program, 5 of which are co-located with Duratek, and 15 of which are co-located with PNNL. The site locations are shown in Figure 3.3.1. Most of the TLD sites are located near Hanford operational or contaminated facilities. Several of the sites (Wye Barricade; Stations 4, 8, and 56; and Benton County Shops) are located in the predominant downwind direction of impacted areas. Sites not expected to be impacted by Hanford operations include Yakima Barricade which is located at the northwest Hanford Site perimeter; and Othello, Toppenish, and Yakima Airport which are distant from the Hanford Site. Many of the TLD sites are co-located with air monitoring sites.

3.3.3 Monitoring Procedures

TLDs are deployed on a quarterly basis. The TLDs are retrieved at the end of each calendar quarter and sent to the State Public Health Laboratory where the time-integrated gamma radiation exposure is determined for the three month period. The results are then converted to an average daily radiation exposure rate and reported in units of milli-Roentgen per day (mR/day). At the same time the TLDs are retrieved, a new TLD is placed at each site.

3.3.4 Comparison of DOH and Contractor Data

The DOH and Duratek TLD results for the 5 co-located sites are shown in Figure 3.3.2, and the DOH and PNNL TLD results for the 15 co-located sites are shown in Figure 3.3.3. Each of these figures show the four quarterly results for each site. As can be seen, there is excellent agreement between the two programs.

DOH vs. Duratek TLD scatterplot results for the combined co-located sites are shown in Figure 3.3.4. The x-coordinate of each point represents the DOH result, while the y-coordinate represents the contractor result. Ideally, if the DOH and contractor results were identical, all the points would fall on the straight line with slope equal to unity and y-intercept equal to zero (shown as the solid black line in the figure). Regression analysis was used to fit a straight line to the data (blue dashed line), and the resulting slope (0.93) and y-intercept (0.03) indicate excellent agreement between DOH and Duratek results.

DOH vs. PNNL TLD scatterplot results for the combined co-located sites are shown in Figure 3.3.5. The correlation coefficient for this data set is weak because the range of results is small. Therefore, it is not meaningful to carry out regression analysis. However, a qualitative comparison indicates excellent agreement between the DOH and PNNL data sets.

3.3.5 Discussion of Results

Most of the external radiation exposure rates at locations on the Hanford Site are consistent with the average offsite perimeter (considered background) radiation exposure rate of 0.24 mR/day. The annual average exposure rate at 100N-1, located at the 100 N Area, is 60% higher than background; and the exposure rate at the Waste Receiving and Packaging WRAP facility, located in the 200 West Area, is 20% higher than background.

Most of the offsite perimeter results are obtained from sampling sites operated by Energy Northwest and are not the subject of this report. However, Energy Northwest has a TLD site at Wye Barricade co-located with DOH and PNNL. The results from all three data sets are in excellent agreement at Wye Barricade, resulting in confident use of Energy Northwest results to determine offsite background.

The results at 100N-1, which average 0.39 mR/day, are 1.6 times higher than background, resulting in an annual exposure rate of 55 mR/yr above background. An exposure rate of 55 mR/year is well below radiation exposure limits for workers, and is also below the DOE limit of 100 mrem/yr to the public from DOE operations (1 mrem is approximately equal to 1 mR). There is no public access to this region of the Hanford Site.

Yakima Barricade is a Hanford Site perimeter location, while Othello, Toppenish, and Yakima Airport are distant offsite locations. The exposure rates at the distant locations (average of 0.20 ± 0.02 mR/day) are slightly lower than the perimeter locations, most likely due to different concentrations of naturally occurring radioactivity at the distant locations.

Historical DOH TLD data were examined for all of the TLD sites to determine if any new trends are present. All sites, except 100N-1, show consistent exposure rates over time. The historical data for site 100N-1 is shown in Figure 3.3.6. Exposure rates at this site continue to decrease over time, in part due to the decay of Co-60 (half life = 5 years) surface contamination at 100 N Area.

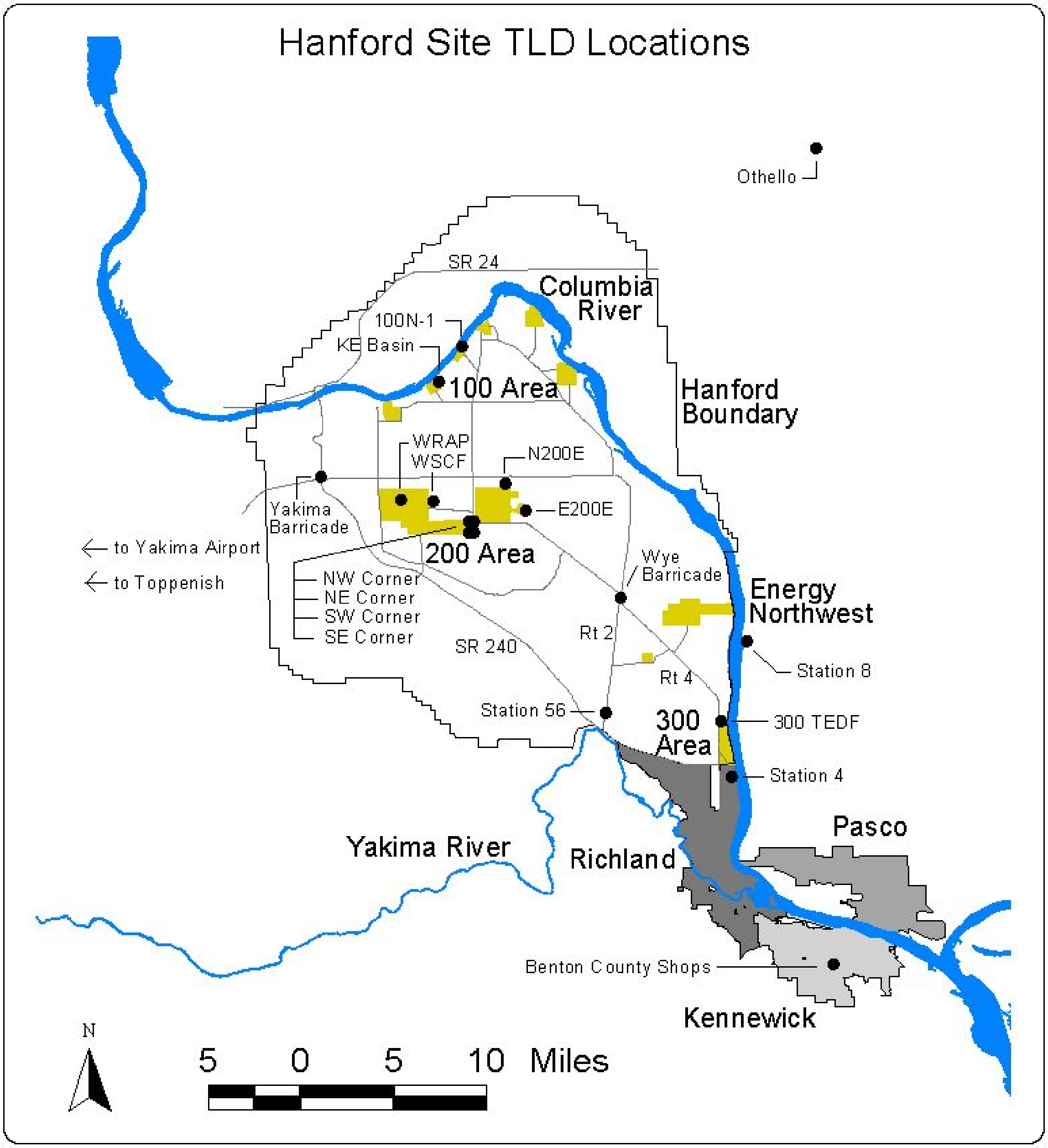

Figure 3.3.1 External Radiation Monitoring (TLD) Locations

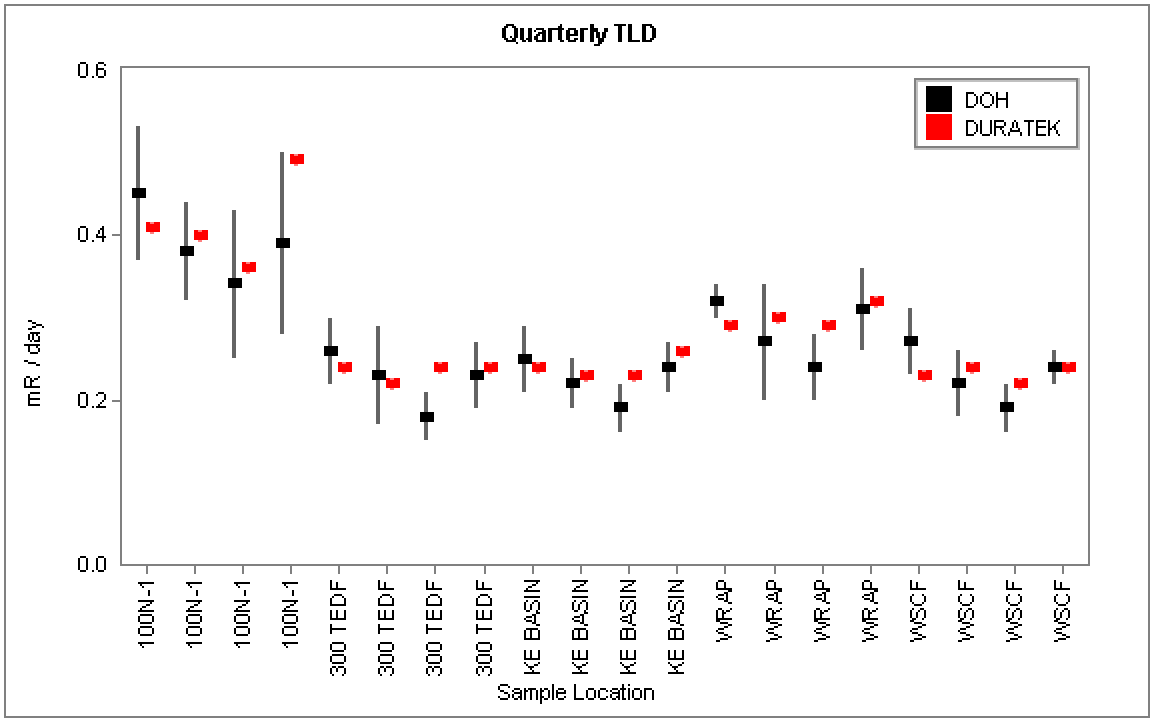

Figure 3.3.2 DOH and Duratek Quarterly TLD Results

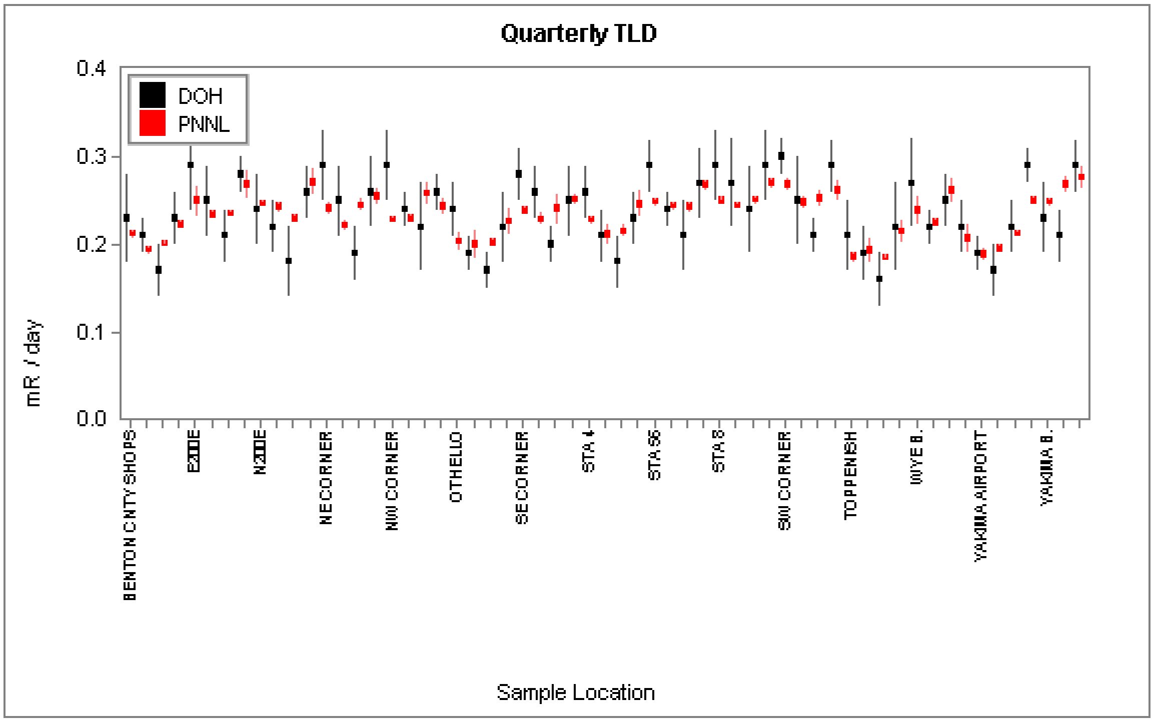

Figure 3.3.3 DOH and PNNL Quarterly TLD Results

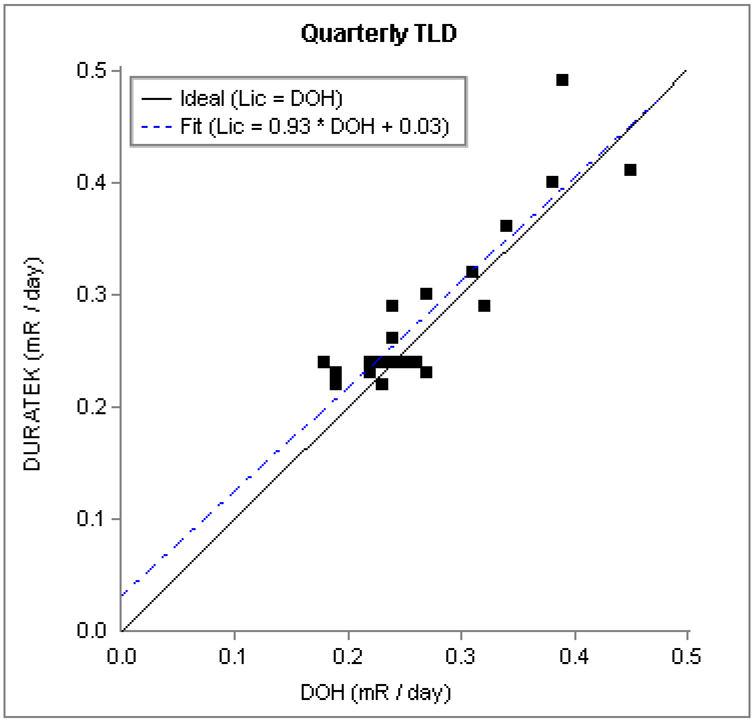

Figure 3.3.4 DOH and Duratek Scatter Plot for TLD Results

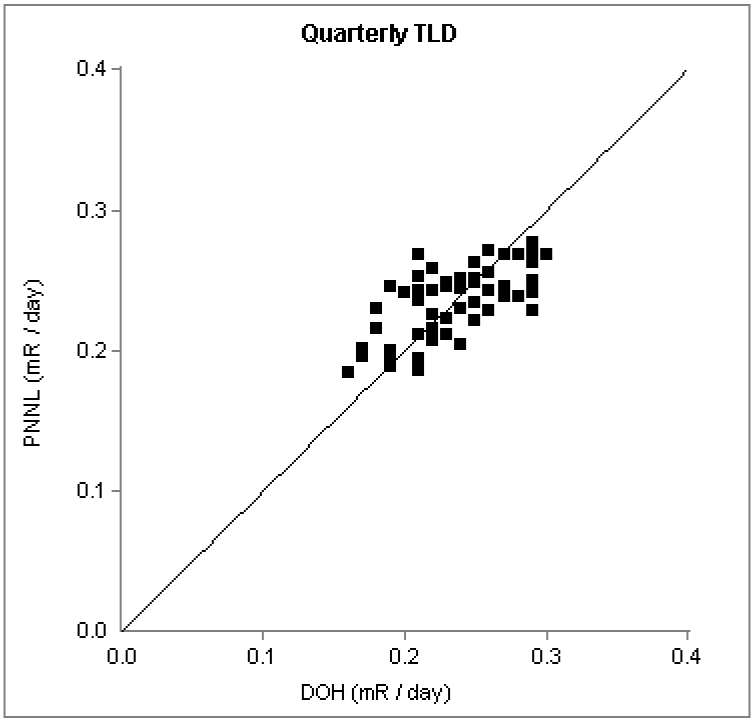

Figure 3.3.5 DOH vs. PNNL Scatter Plot for TLD Results

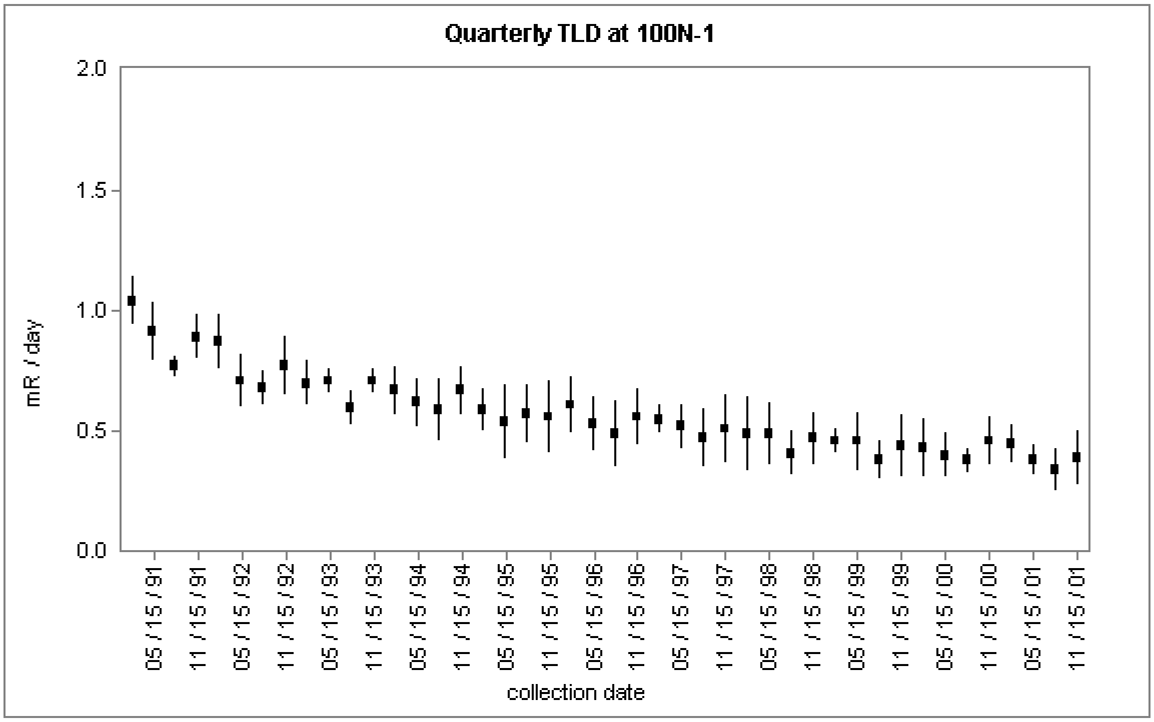

Figure 3.3.6 Historical DOH TLD Results at Location 100N-1 in the 100 N Area

3.4 Soil and Sediment Monitoring

Major Findings:

- DOH and PNNL results in soil and sediment are in good agreement for all radionuclides, except for isotopes of uranium. The discrepancy in uranium results is understood, and originates from a difference in DOH and PNNL laboratory analytical methods.
- Concentrations of radionuclides detected in soil and sediment are either consistent with background or are in the range of activity that is typically observed at Hanford.
- The highest sediment concentrations occur at McNary Dam, where sediments contaminated primarily from past Hanford operations have accumulated.

3.4.1 Purpose and General Discussion

Contaminated soil and river sediment 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 since they exist in worldwide fallout as well as in effluents from the Hanford Site. Uranium, also consistently seen in soil and sediment, occurs naturally in the environment in addition to being present from Hanford operations.

PNNL monitors soil and Columbia River sediments to evaluate Hanford's impact on the environment. DOH splits soil and sediment samples with PNNL to provide oversight of the DOE monitoring program.

3.4.2 Monitoring Locations

Soil samples were collected from eleven locations in 2001; one site near a reactor along the Columbia River, five sites on the central plateau near the 200 Area, three sites in the predominant downwind direction from the 200 Area (southeast quadrant of the Site), and two sites near the 300 Area.

Sediment samples were collected from eight Columbia River locations; two from Priest Rapids Dam, three from shoreline locations along the Hanford Site, one near the city of

Richland, and two from McNary Dam. Priest Rapids Dam is upstream from the Hanford Site and is considered a background location. McNary Dam prohibits sediment transport further downstream and, therefore this site is used to assess radionuclide accumulation. Sediment locations within the Hanford boundary change from year to year and are chosen to monitor areas where contaminants may be discharged into the river, areas where deposits could accumulate, or areas where the public may gain access to the shoreline. Soil and sediment locations are shown in Figure 3.4.1.

3.4.3 Monitoring Procedures

Soil samples were collected by compositing four one-square foot areas, each excavated to a depth of one inch. The composited samples were split with PNNL and dried prior to analysis. Samples were analyzed for radionuclides that are most likely present in the area sampled. This includes gamma-emitting radionuclides, Sr-90, isotopic uranium, and isotopic plutonium.

Sediment samples represent surface sediments and were collected with either a clam-shell style sediment dredge or, in the case of shoreline sediments, a plastic spoon. All sediment samples were split with PNNL and dried prior to analysis. Samples were analyzed for gamma-emitting radionuclides, strontium 90, isotopic uranium, and isotopic plutonium. Analytical methods for soil and sediment are identical.

3.4.4 Comparison of DOH and DOE Contractor Data

DOH and PNNL split soil results are in good agreement for all radionuclides reported, except for isotopes of uranium. Soil sample results for Co-60, Cs-137, Sr-90, Pu-239/240, Am-241, and U-238 are shown in Figures 3.4.2 through 3.4.7. Only one of the eleven Cs-137 results, one of the ten Sr-90 results, and one of the eleven Pu-239/240 results are in disagreement. All Pu-238 results are below detection limits, and these data are not shown.

The U-238 results (Figure 3.4.7) display a systematic bias in which DOH consistently reports higher concentrations than PNNL. This discrepancy occurs historically, and originates from different laboratory procedures. DOH completely dissolves soil samples prior to analysis and reports uranium present in the entire soil sample, whereas the contractor laboratory reports only the uranium that can be leached from the surface of the soil granules. A similar discrepancy is seen in the U-235 and U-234 soil results (not shown).

Similarly, the DOH and PNNL split sediment results are in good agreement for all radionuclides reported, except for isotopes of uranium. Sediment sample results for Co-60, Cs-137, Sr-90, Pu-238, Pu-239, and U-238 are shown in Figures 3.4.8 through 3.4.13. The discrepancy in the uranium sediment results has the same origin as the discrepancy in soil. A similar discrepancy is seen in the U-235 and U-234 sediment results (not shown). A single Eu-154 result (0.12 pCi/g) was reported at McNary WA Shore, and the DOH and PNNL results are in good agreement.

DOH vs. PNNL scatter plots for Cs-137, Sr-90, and Pu-239/240 in soil and sediment are shown in Figures 3.4.14 through 3.4.16. Laboratory analysis methods are identical for soil and sediment, and therefore soil and sediment data were combined in the scatter plots. The x-coordinate of each point represents the DOH result, while the y-coordinate represents the PNNL result. Ideally, if the DOH and contractor results were identical, all the points would fall on the black straight line with slope equal to unity and y-intercept equal to zero.

The regression analysis (best-fit straight line to the data, shown as the blue dashed line in the figures) indicates good agreement between DOH and PNNL for Cs-137, Sr-90, and Pu-239/240. Scatter plots for isotopes of uranium (not shown) show the typical systematic bias between DOH and PNNL uranium results discussed earlier. Scatter plots and regression analysis for other radionuclides are not shown because either most of the data are below detection limits or there is not enough data for a meaningful analysis.

3.4.5 Discussion of Results

Contaminants consistently identified by DOH in 2001 soil samples include Cs-137 (Figure 3.4.3), Sr-90 (Figure 3.4.4), and Pu-239/240 (Figure 3.4.5). Two of the three samples analyzed for Am-241 (Figure 3.4.6) had detectable concentrations. In addition, all soil samples had detectable concentrations of U-234 and 238 (U-238 shown in Figure 3.4.7. U-234 results were similar to U-238.). Most U-235 concentrations were near the detection limit of approximately 0.02 pCi/g. Other isotopes of uranium were not detected. One Co-60 sample collected east of the 100N Area had a detectable concentration of 0.012 pCi/g (see Figure 3.4.2). All other Co-60 results, as well as all Pu-238 results reported by DOH are below detection limits.

The concentrations of uranium isotopes found in soil samples are consistent with background concentrations. Most Cs-137, Sr-90, and Pu-239/240 soil concentrations reported by DOH in 2001 are in the range of activity that has been observed in the past for these radionuclides. The highest concentrations of Pu-239/240 (0.07 pCi/g) and Am-241 (0.02 pCi/g) were found at the site E of 200 W Gate. Similar concentrations of these transuranic isotopes have been found in the past at this site.

Contaminants consistently identified by DOH in 2001 sediment samples include Cs-137 (Figure 3.4.9) and Pu-239/240 (Figure 3.4.12). In addition, all sediment samples had detectable concentrations of U-234 and 238 (U-238 shown in Figure 3.4.13, U-234 results were similar to U-238.). Most U-235 concentrations were near 0.04 pCi/g, slightly above the detection limit of approximately 0.02 pCi/g. Other isotopes of uranium, including U-233 (lower limit of detection approximately 0.1 pCi/g), were not detected. Other radionuclides identified in some of the sediment samples were Co-60 (Figure 3.4.8), Sr-90 (Figure 3.4.10), and Pu-238 (Figure 3.4.11). The sample at McNary WA Shore had a Eu-154 (not shown) concentration of 0.1 pCi/g. For most of the detected radionuclides, the highest concentrations were observed at McNary WA Shore.

The concentrations of uranium isotopes found in sediment samples are consistent with background concentrations. The concentrations of other radionuclides detected in 2001 are consistent with those historically observed by DOH. Concentrations of all detected radionuclides in sediment at McNary WA Shore in 2001 are consistent with historical concentrations at that site. Historical sediment concentrations reported by DOH at McNary WA Shore for Co-60, Sr-90, and Pu-239/240 are shown in Figures 3.4.17 through 3.4.19.

In addition to the results where DOH and PNNL both report a radionuclide concentration, DOH reported Eu-152 in Columbia River sediment at McNary Oregon, McNary WA Shore, and Richland (Figure 3.4.20). The Eu-152 concentration at McNary WA Shore is 1.2 pCi/g, and concentrations at the other two sites are near the detection limit of 0.02 pCi/g. Historical sediment concentrations reported by DOH at McNary WA Shore for Eu-152 are shown in Figure 3.4.21.

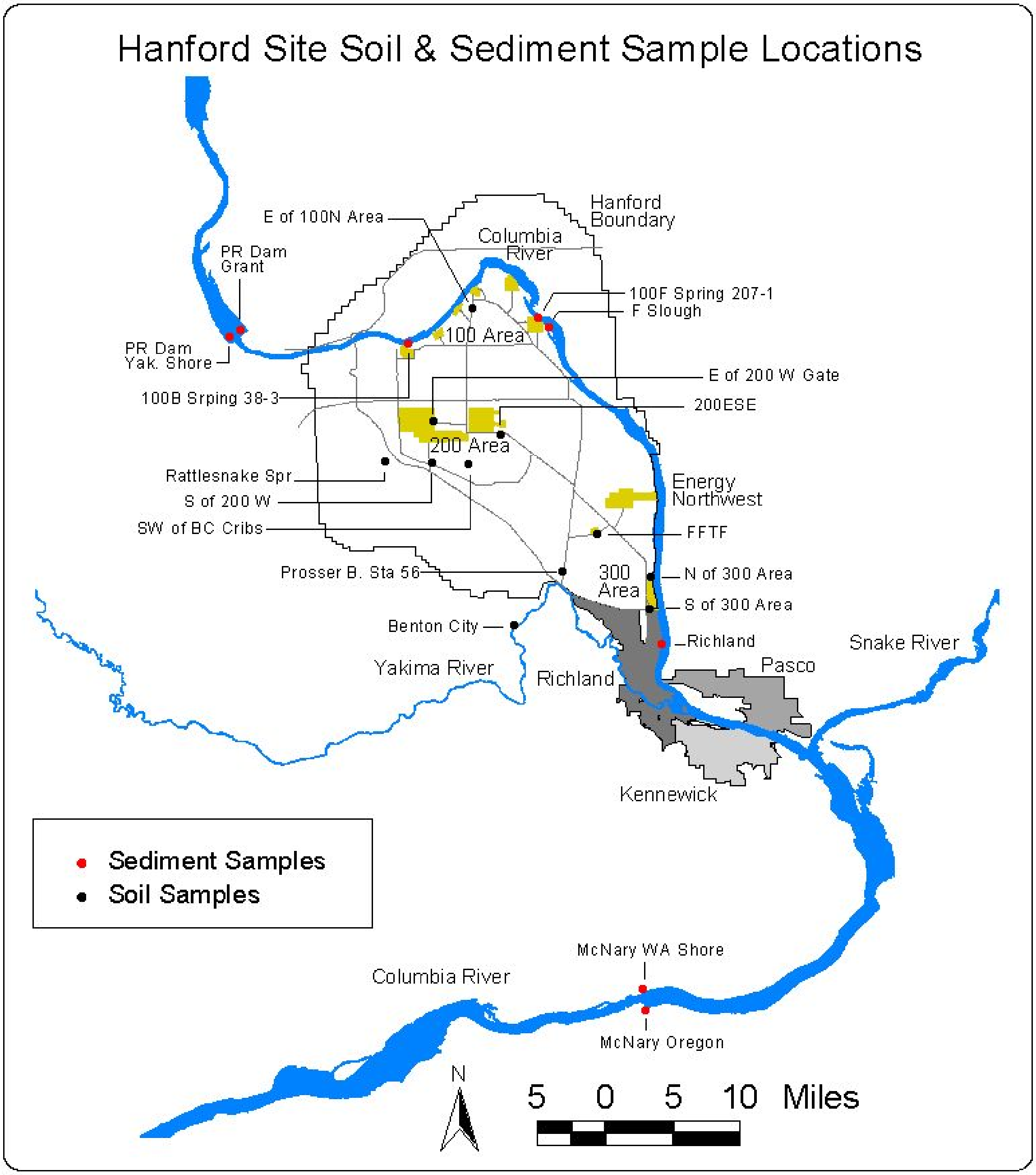

Figure 3.4.1 Soil and Sediment Monitoring Locations

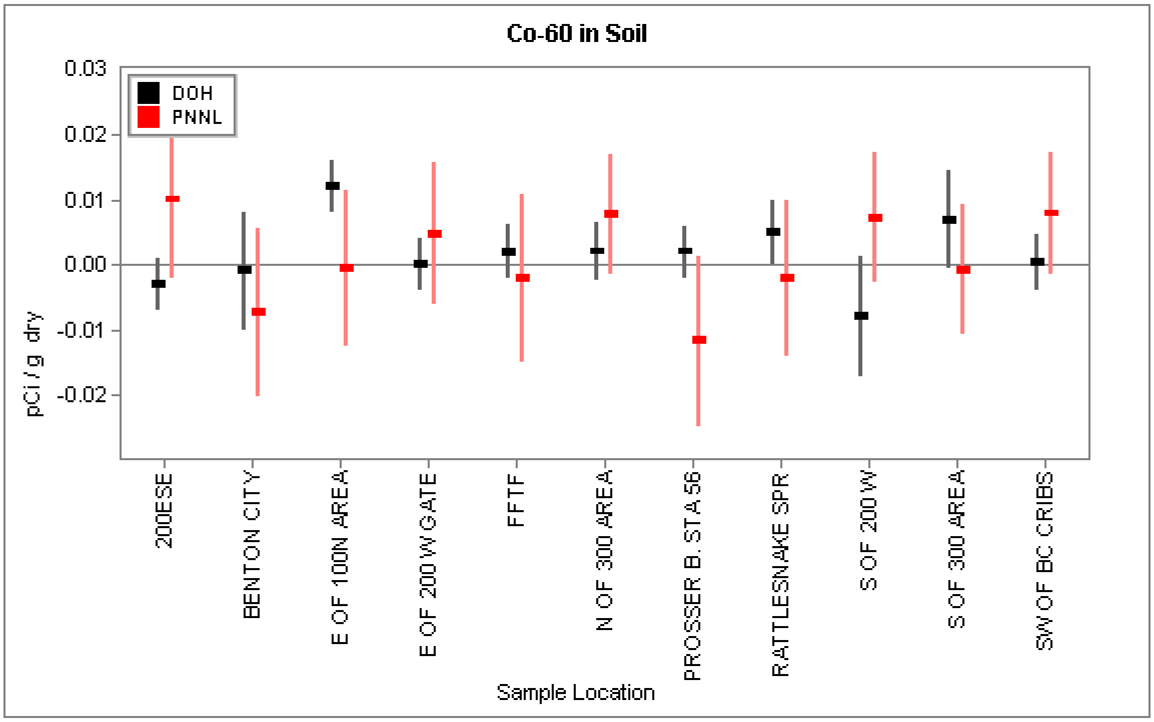

Figure 3.4.2 DOH and PNNL Co-60 Concentrations in Soil

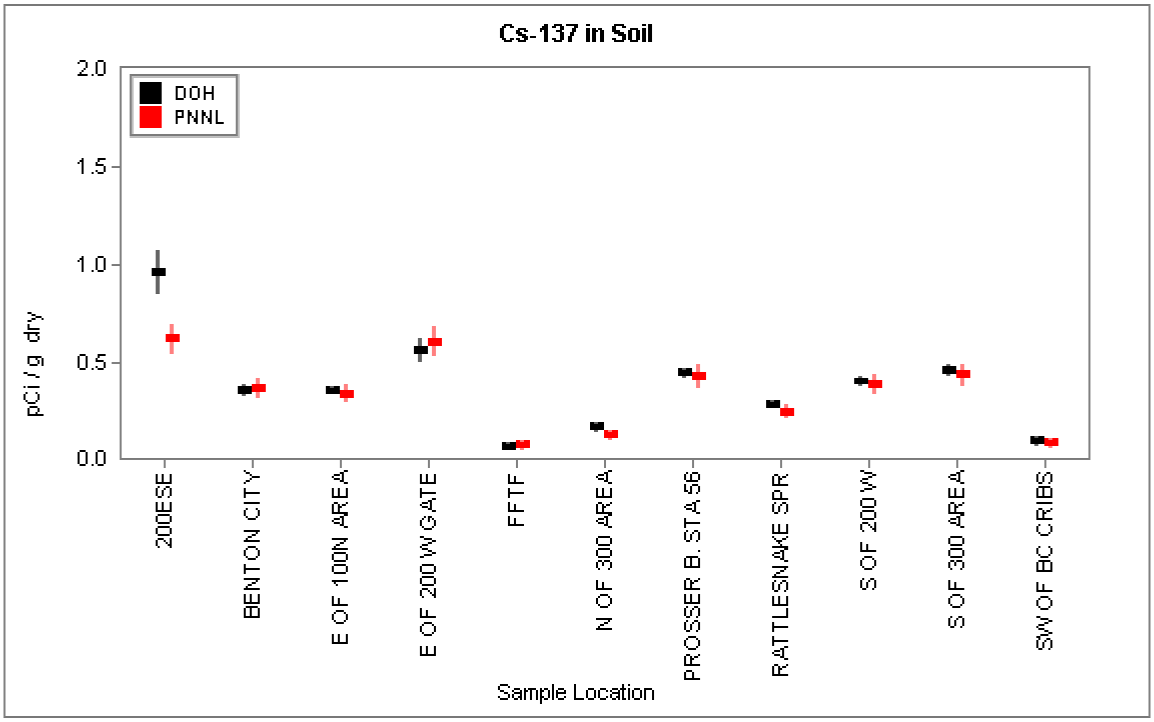

Figure 3.4.3 DOH and PNNL Cs-137 Concentrations in Soil

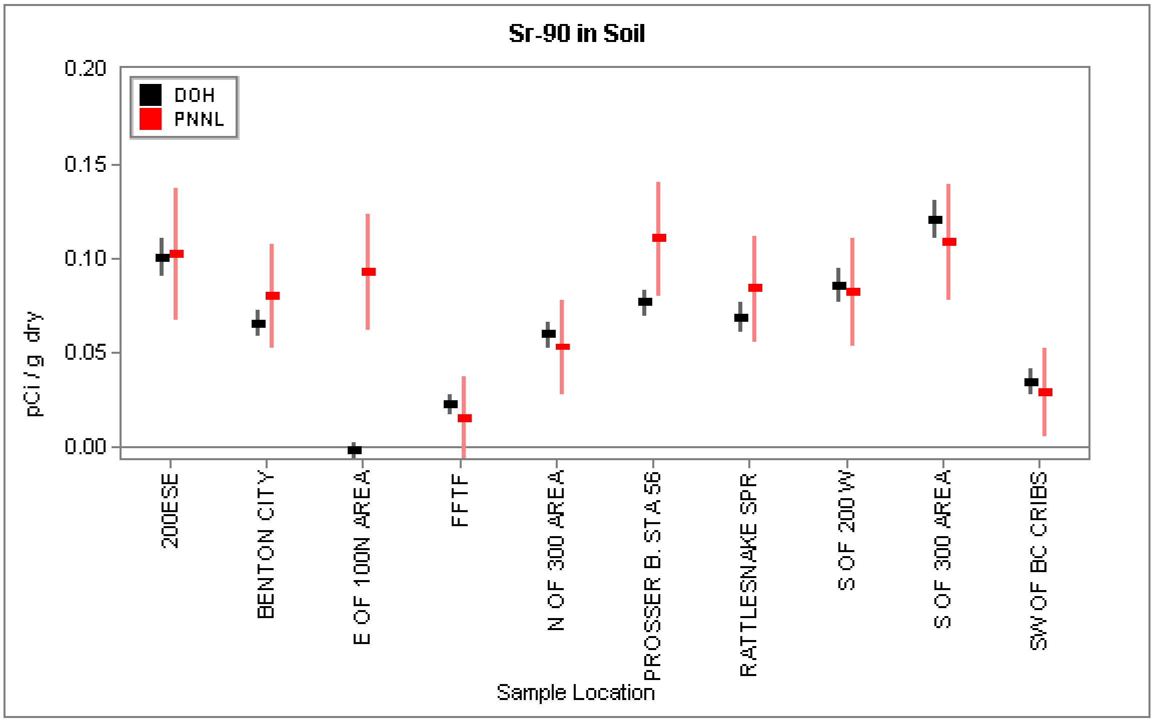

Figure 3.4.4 DOH and PNNL Sr-90 Concentrations in Soil

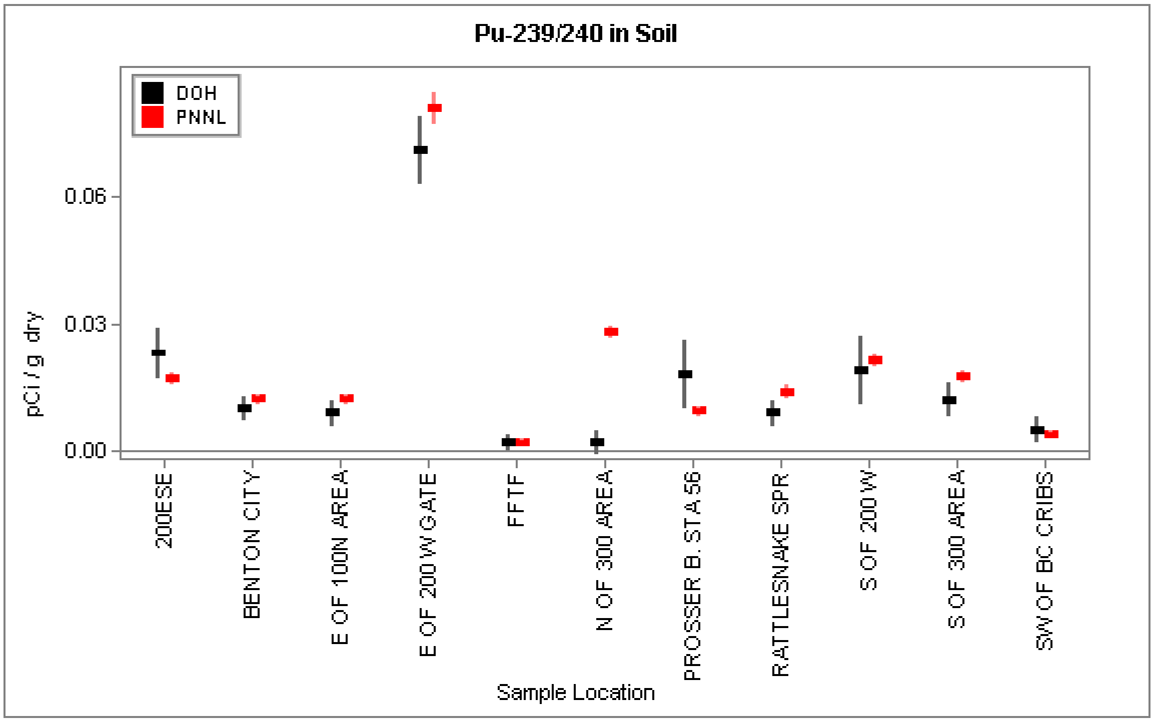

Figure 3.4.5 DOH and PNNL Pu-239/240 Concentrations in Soil

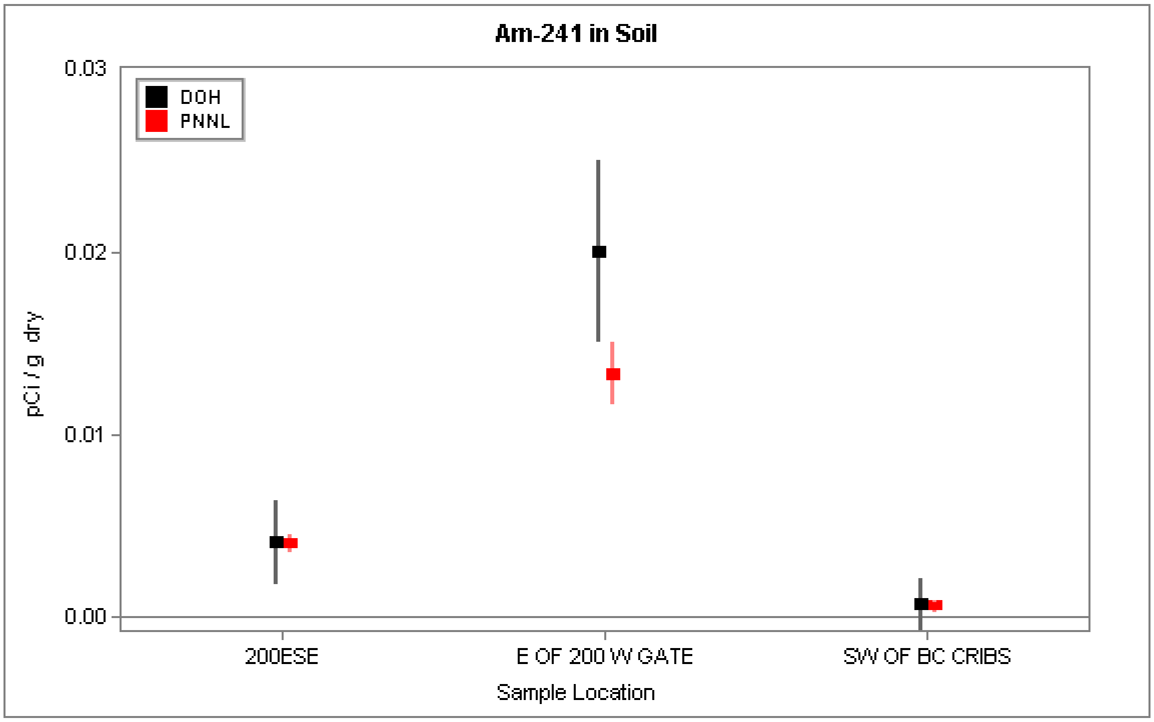

Figure 3.4.6 DOH and PNNL Am-241 Concentrations in Soil

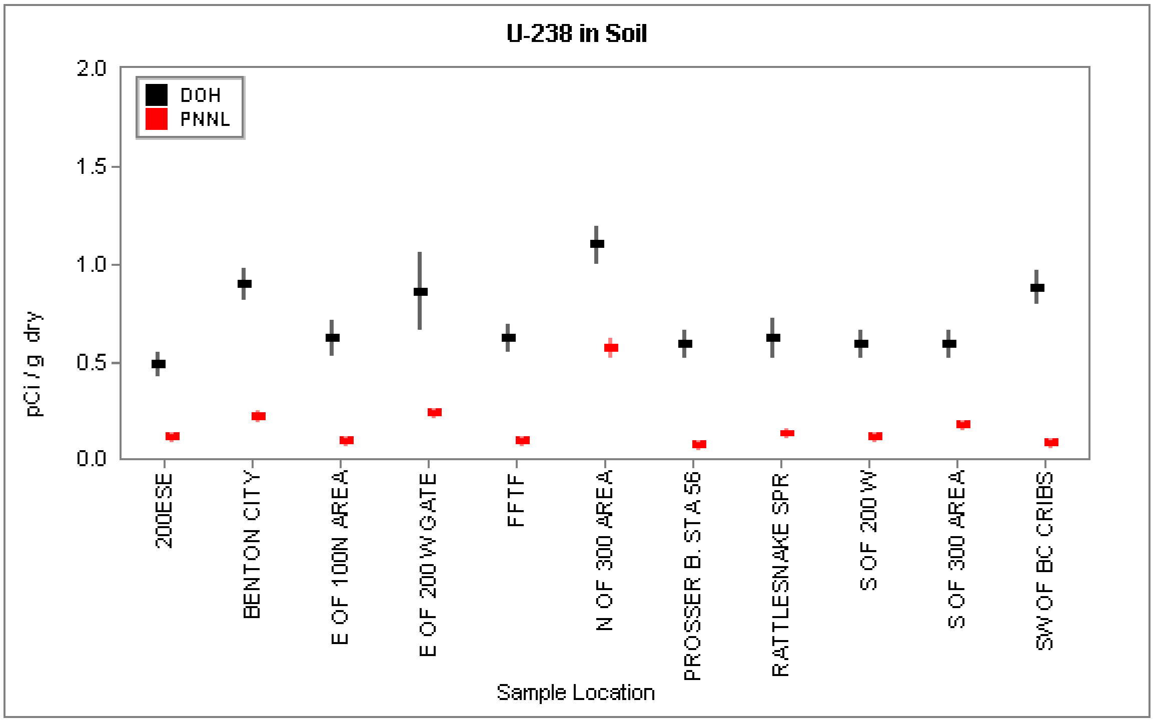

Figure 3.4.7 DOH and PNNL U-238 Concentrations in Soil

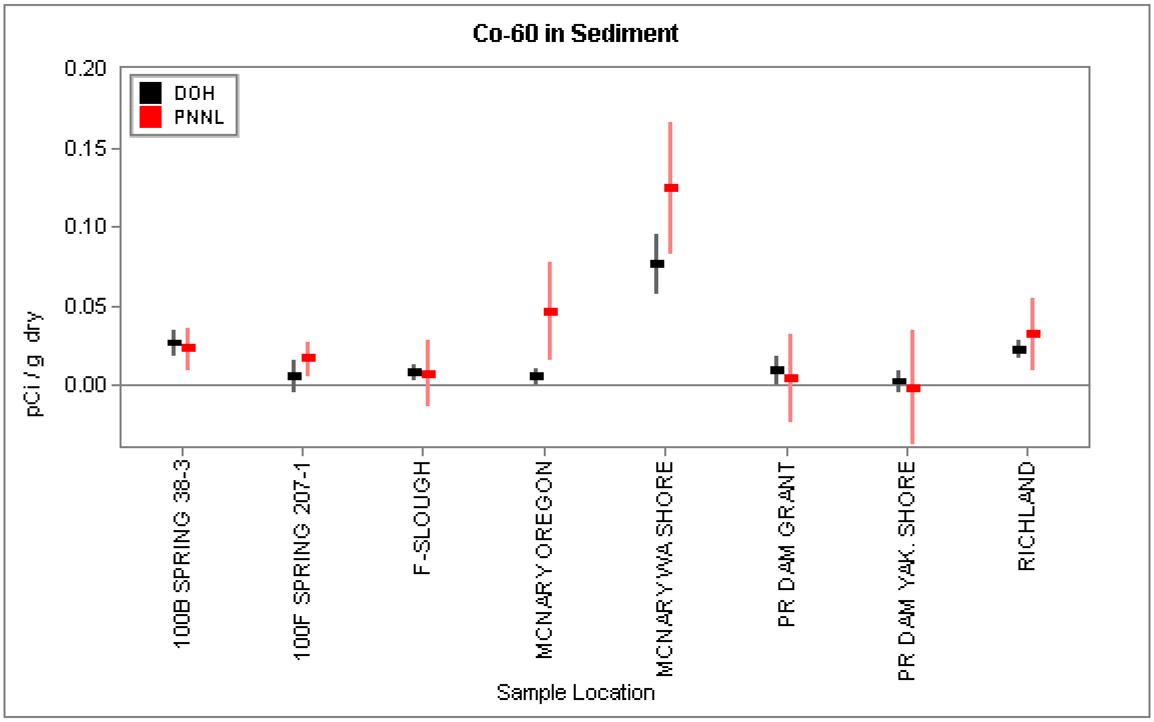

Figure 3.4.8 DOH and PNNL Co-60 Concentrations in Sediment

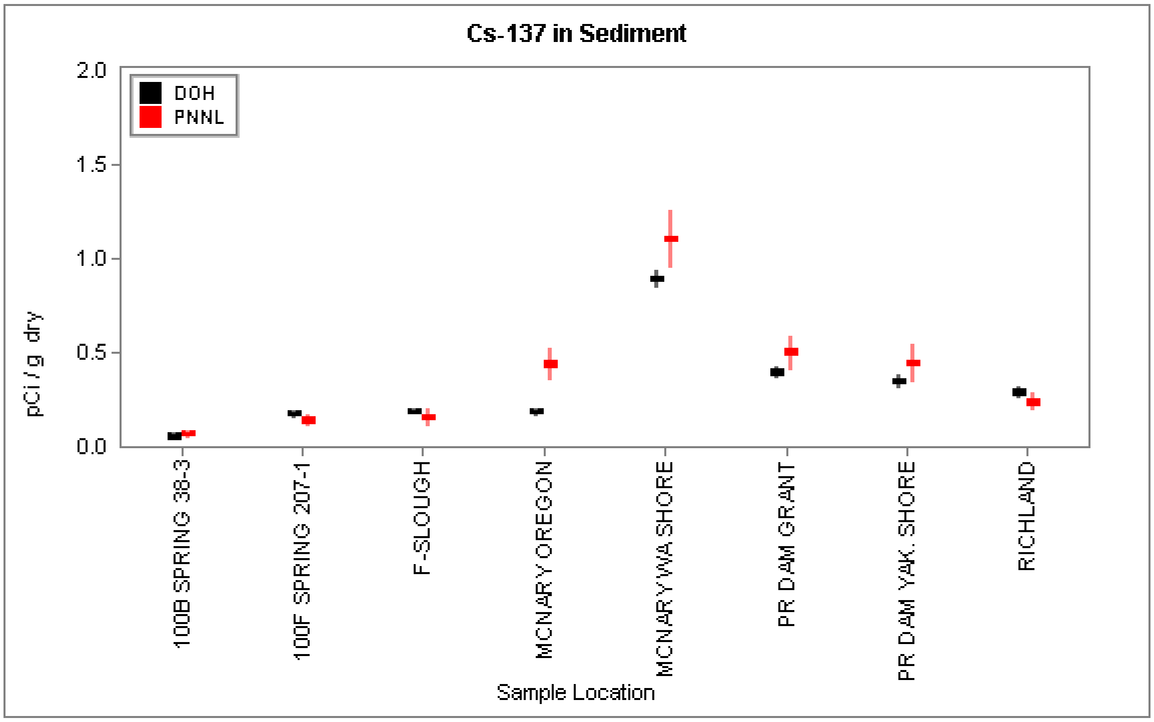

Figure 3.4.9 DOH and PNNL Cs-137 Concentrations in Sediment

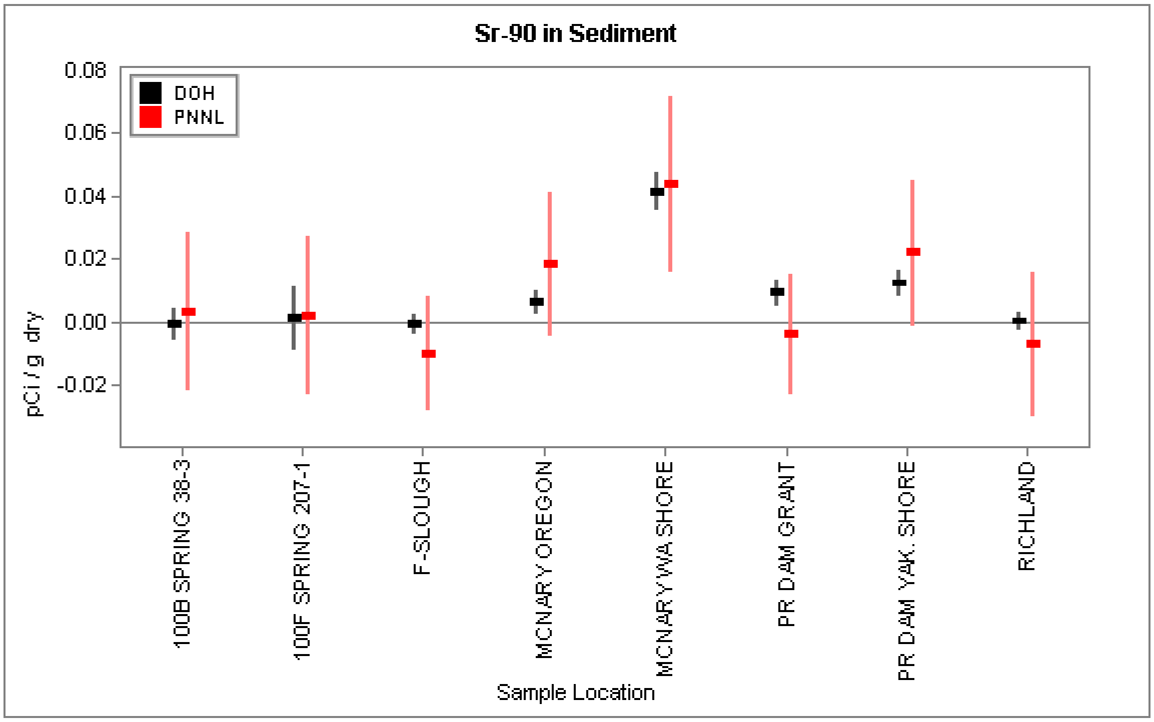

Figure 3.4.10 DOH and PNNL Sr-90 Concentrations in Sediment

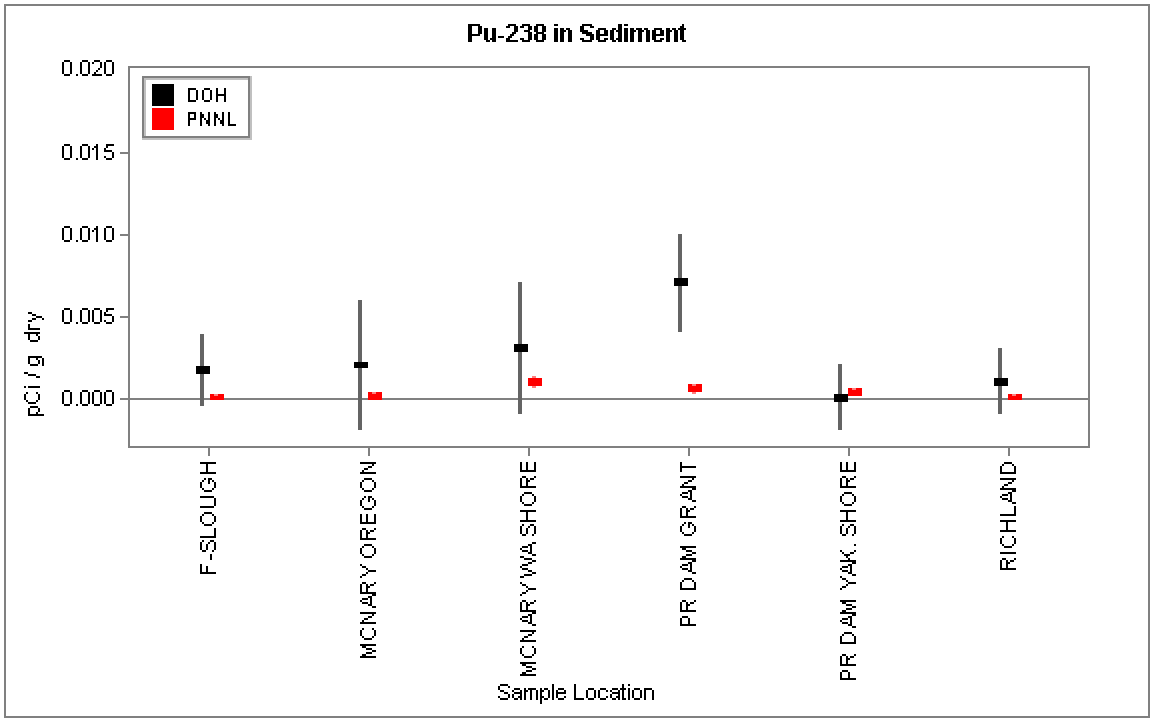

Figure 3.4.11 DOH and PNNL Pu-238 Concentrations in Sediment

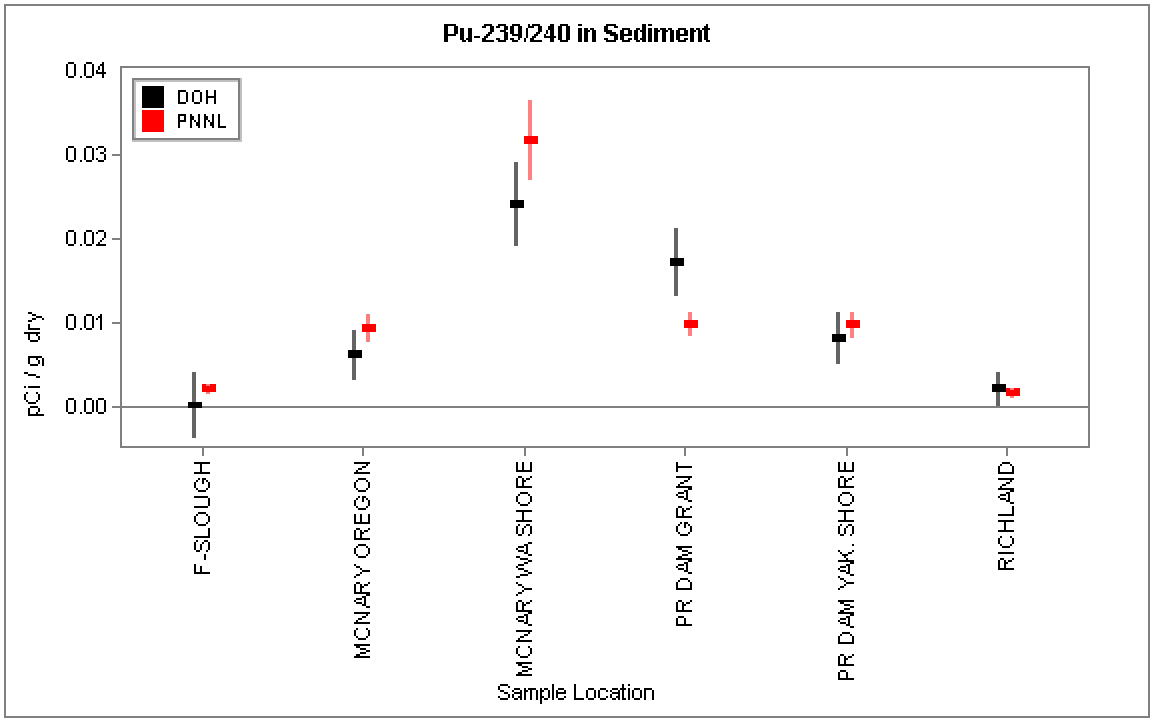

Figure 3.4.12 DOH and PNNL Pu-239/240 Concentrations in Sediment

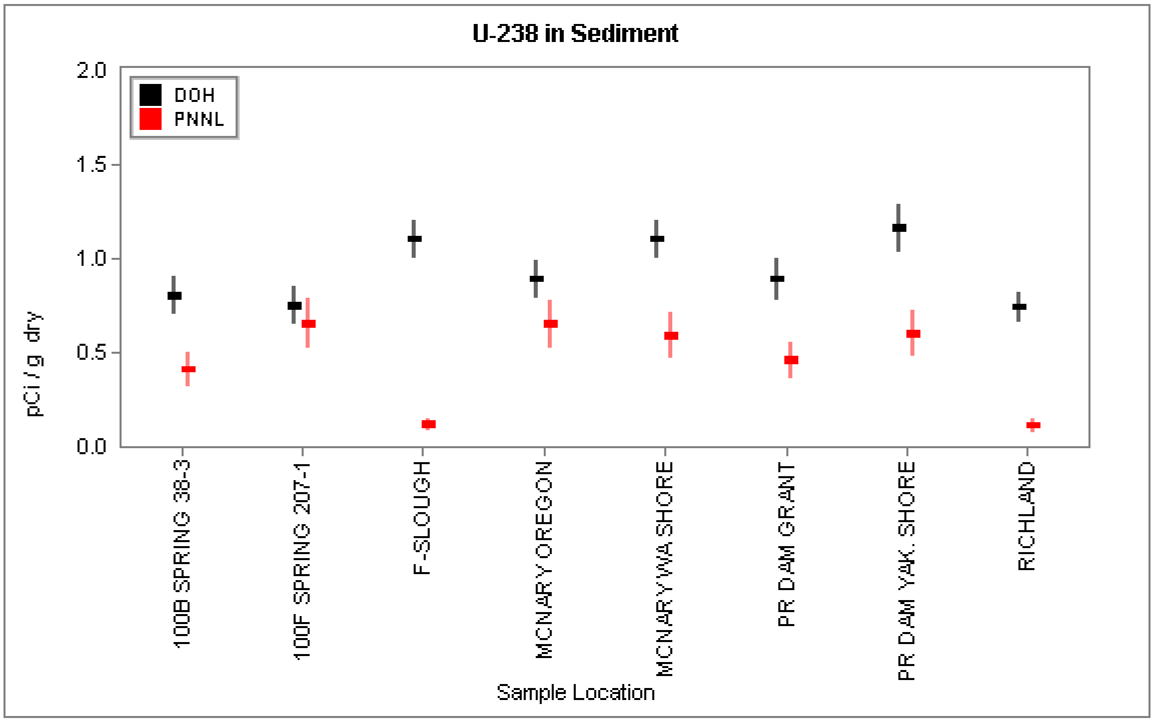

Figure 3.4.13 DOH and PNNL U-238 Concentrations in Sediment

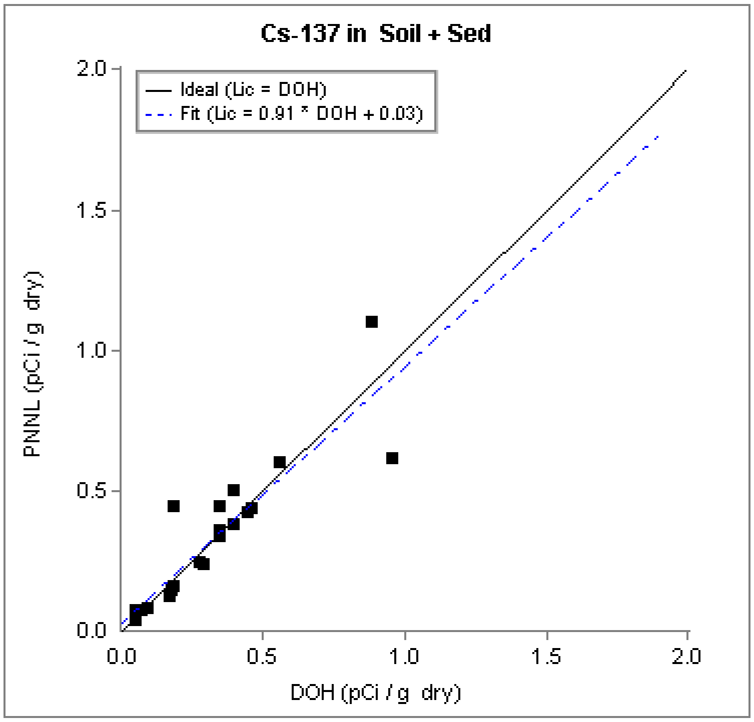

Figure 3.4.14 DOH and PNNL Scatter Plot for Cs-137 Concentrations in Soil and Sediment

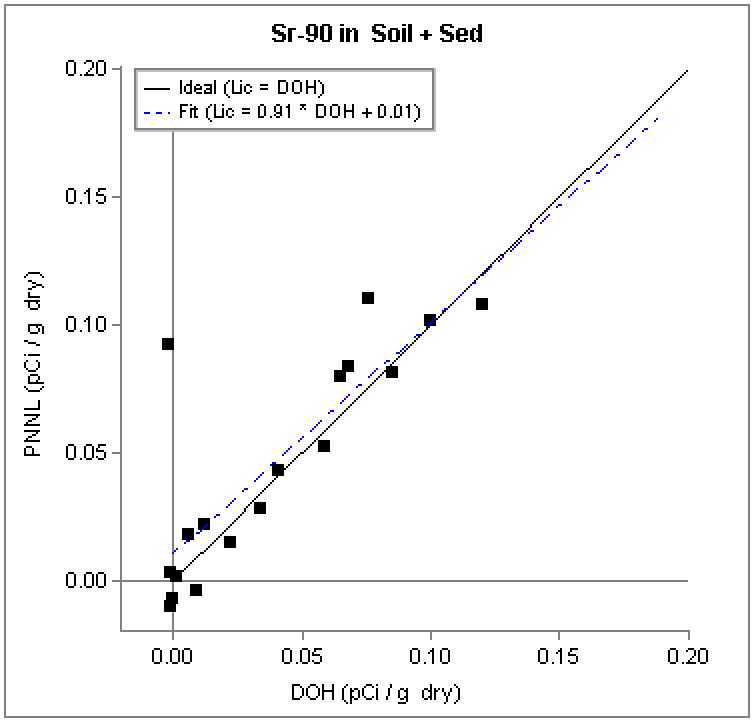

Figure 3.4.15 DOH and PNNL Scatter Plot for Sr-90 Concentrations in Soil and Sediment

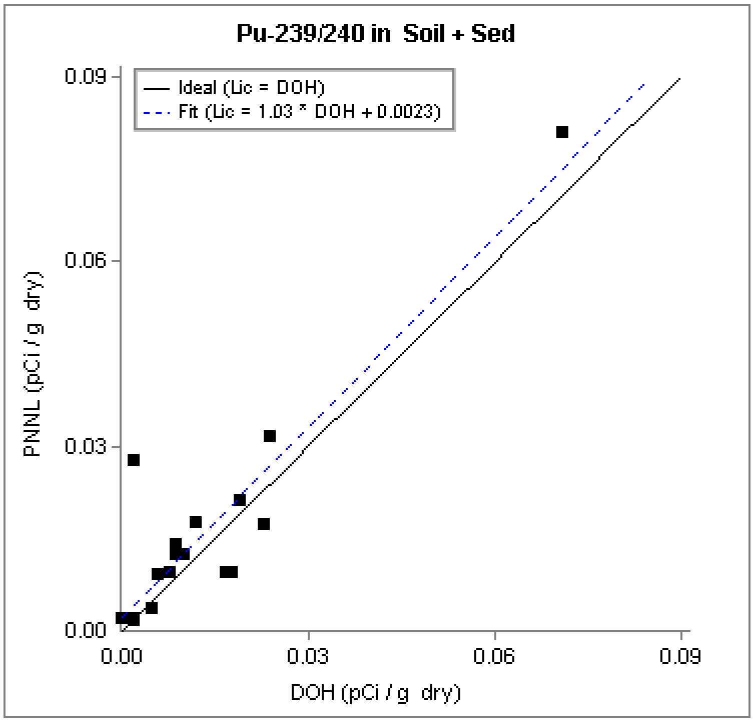

Figure 3.4.16 DOH and PNNL Scatter Plot for Pu-239/240 Concentrations in Soil and Sediment

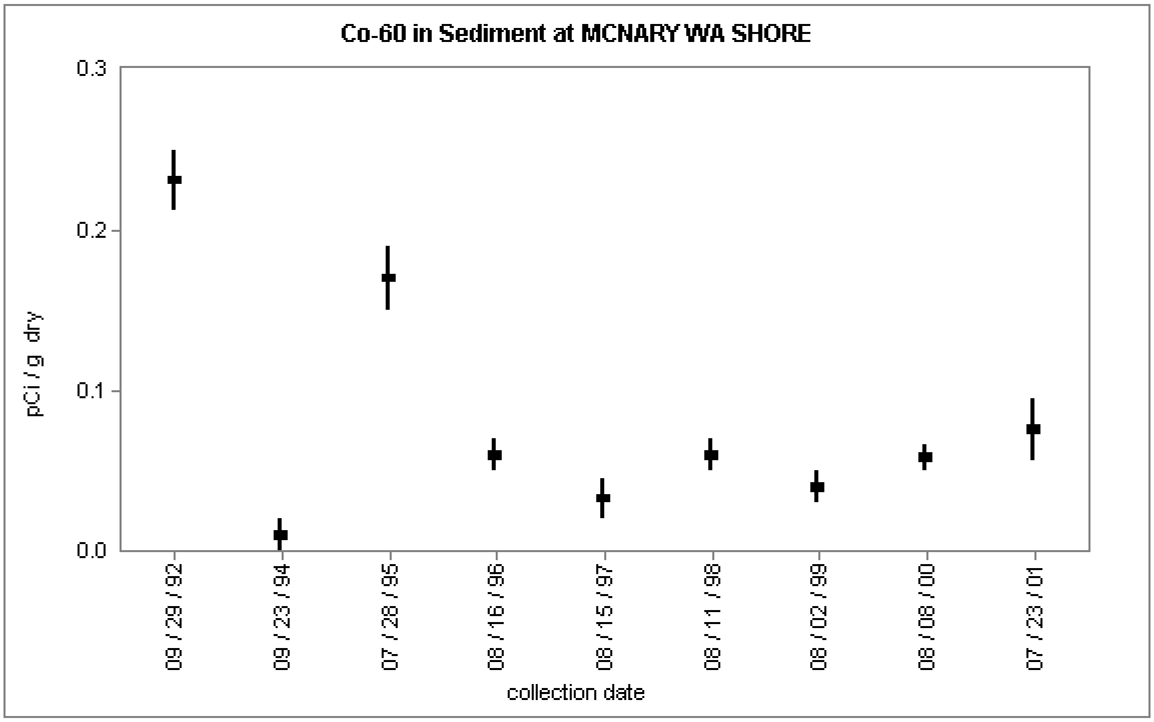

Figure 3.4.17 Historical DOH Co-60 Concentrations in Sediment at McNary WA Shore

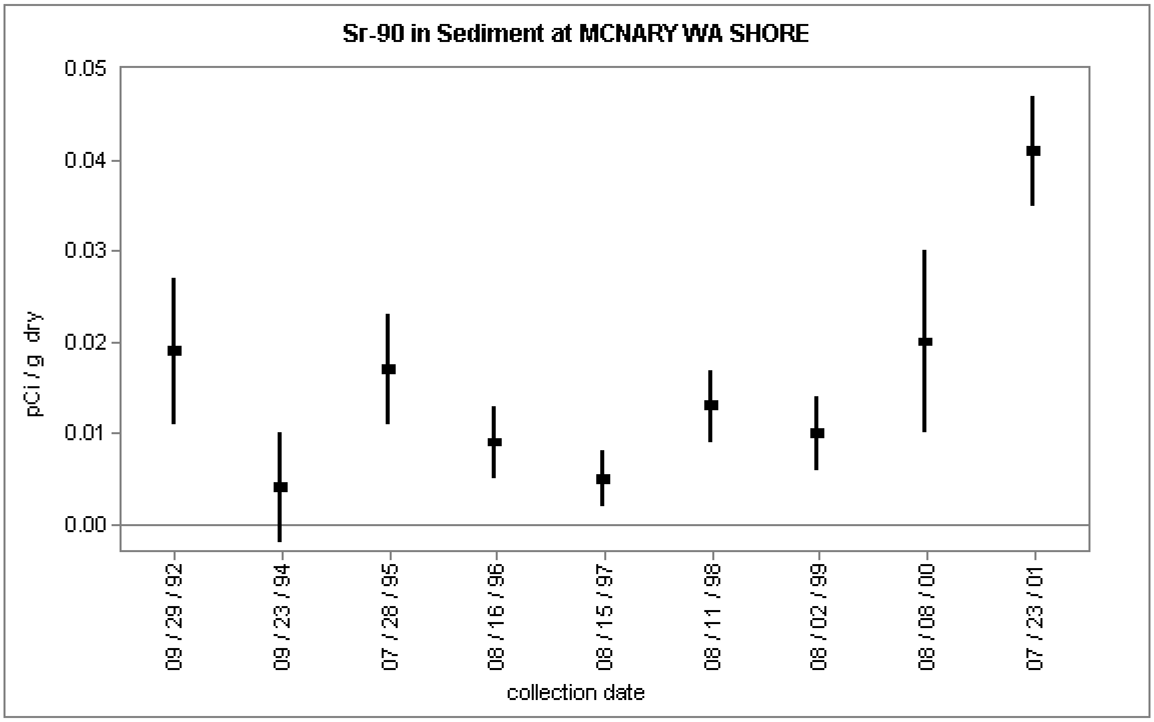

Figure 3.4.18 Historical DOH Sr-90 Concentrations in Sediment at McNary WA Shore

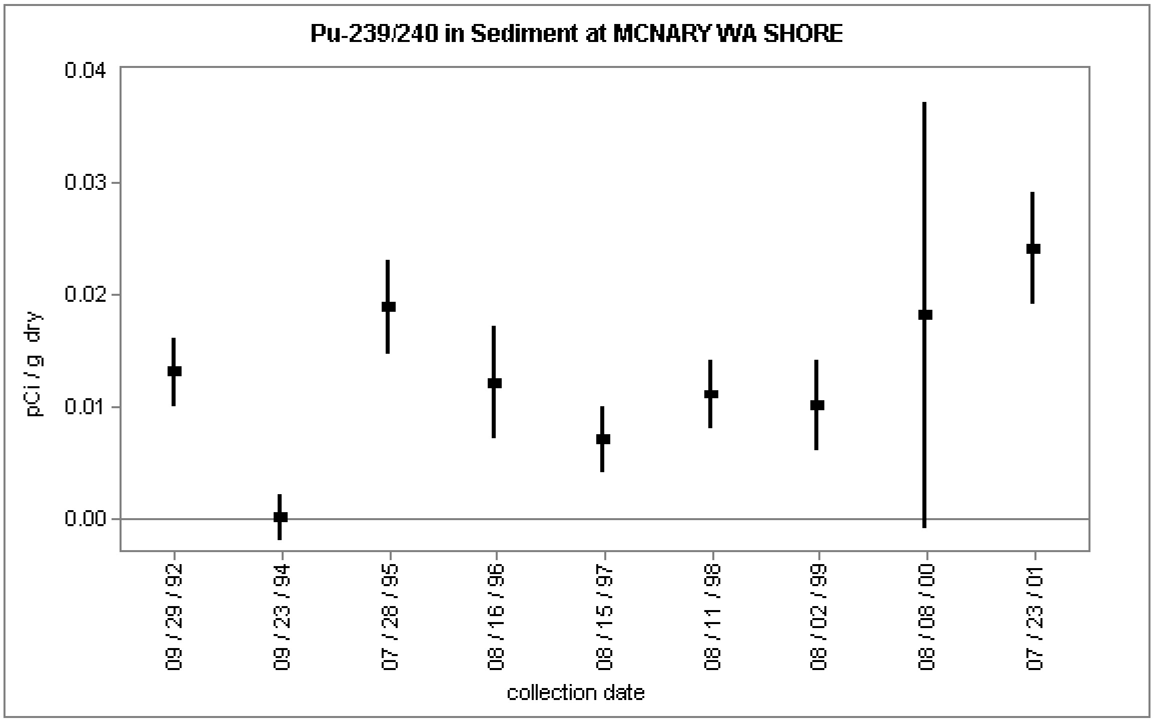

Figure 3.4.19 Historical DOH Pu-239/240 Concentrations in Sediment at McNary WA Shore

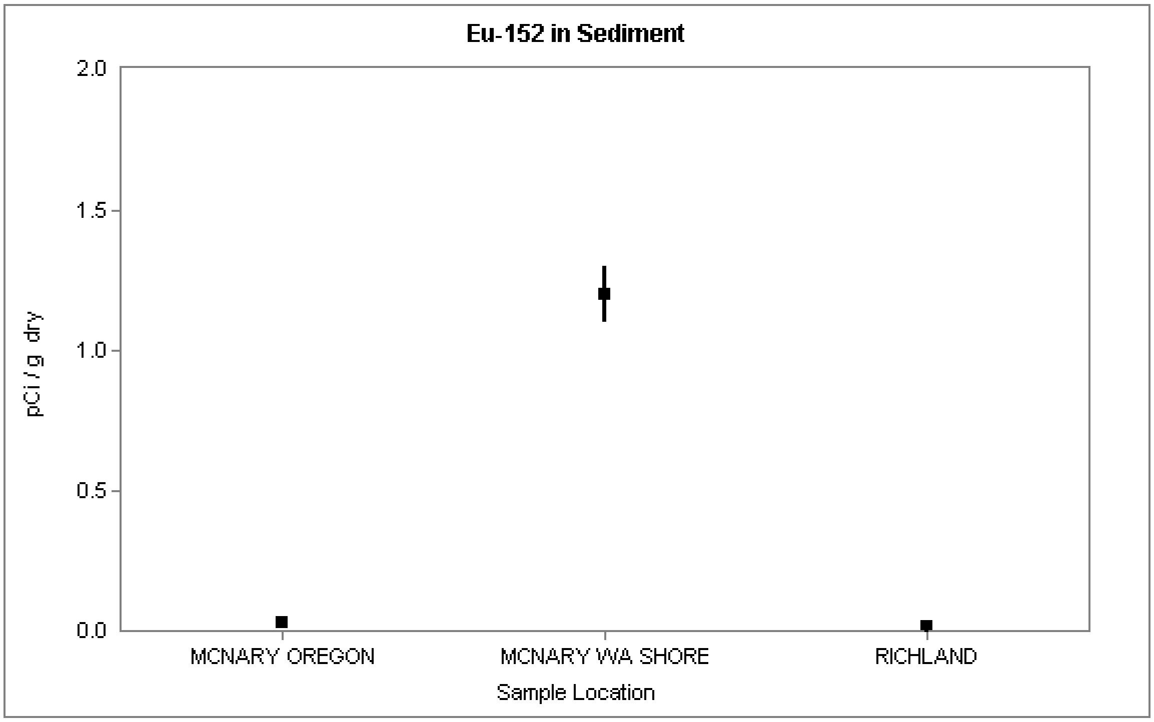

Figure 3.4.20 DOH Eu-152 Concentrations in Sediment (2001)

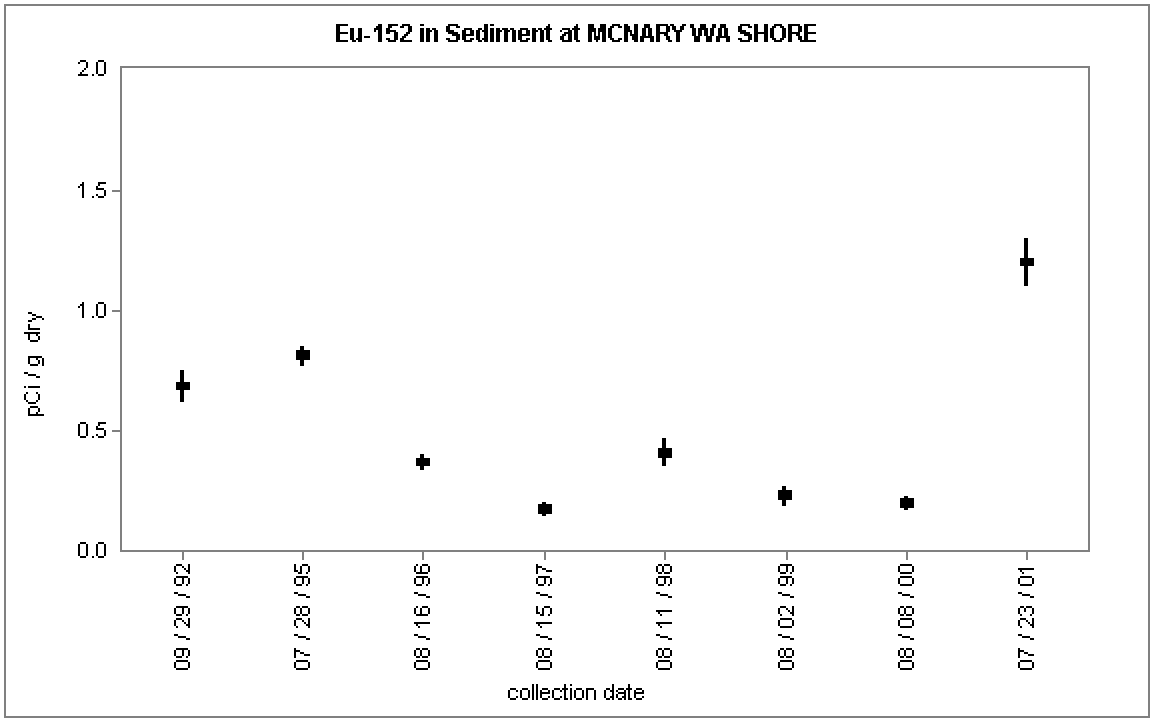

Figure 3.4.21 Historical DOH Eu-152 Concentrations in Sediment at McNary WA Shore

3.5 Food and Farm Products Monitoring

Major Findings:

- The DOH and DOE contractor results are in good agreement.
- Most radioactivity concentrations are below detection limits.

3.5.1 Purpose and General Discussion

The Department of Health and DOE contractors monitor food and farm products to determine if airborne contamination has deposited on plants that may be consumed by people. The primary purpose of the DOH program is to provide oversight of the PNNL monitoring program. In addition, Hanford impacts are evaluated by comparing radioactivity in food products collected upwind and downwind of the Hanford Site. The food products, monitored analytes, and number of samples are listed in Table 3.5.1.

Food Product	Analyte	Number of Samples
Grapes	Co-60, Cs-137, Sr-90	4
Cabbage	Co-60, Cs-137, Sr-90	1
Spinach	Co-60, Cs-137, Sr-90	1
Tomato	Co-60, Cs-137, H-3, Sr-90	2
Red Wine	Co-60, Cs-137, H-3	2
White Wine	Co-60, Cs-137, H-3	2

Table 3.5.1 Analytes Monitored in Food and Farm Products

3.5.2 Monitoring Locations

All of the food products were collected at locations which are offsite of the Hanford Site, with locations in both the prevailing upwind and downwind directions from the Site. Control locations are those upwind of the Site, while the locations most likely to be impacted from Hanford are those downwind of the Site. For example, for the data shown in Figure 3.5.1, the sites FARM A and FARM-A are located downwind in the Sagemoor and Riverview area, while the other sites are located upwind of Hanford.

3.5.3 Monitoring Procedures

Food and farm product samples were collected and split with PNNL. Samples are generally collected once a year in the fall when the products are being harvested. DOH and PNNL independently analyze the samples and then compare results. Results for wine are reported in pCi/L, while all other results, except for tritium (H-3), are reported in pCi/g. Water extracted from the plants is analyzed for tritium, and the results are reported in pCi/L.

3.5.4 Comparison of DOH and Contractor Data

Most of the DOH and PNNL split results in food and farm products are in good agreement. As an example, Co-60 results in grape samples are shown in Figure 3.5.1. Of the 38 food and farm product results, only two of the four tritium (H-3) results in wine show a small discrepancy, in which DOH reports non-detect results and PNNL reports values of 20 and 40 pCi/L. Since most of the results are below detection limits, a regression analysis is not meaningful, and therefore is not carried out for food product data.

3.5.5 Discussion of Results

Most of the radioactivity concentrations, both upwind and downwind of the Hanford Site, are below detection limits. The only exception is a Sr-90 concentration of 0.008 pCi/g (wet weight) in a cabbage sample collected from a farm in Riverview. DOH has historically detected small concentrations of Sr-90 in cabbage from farms around the Hanford Site. The food and farm product results for all radionuclides analyzed in 2001 are consistent with historical DOH results.

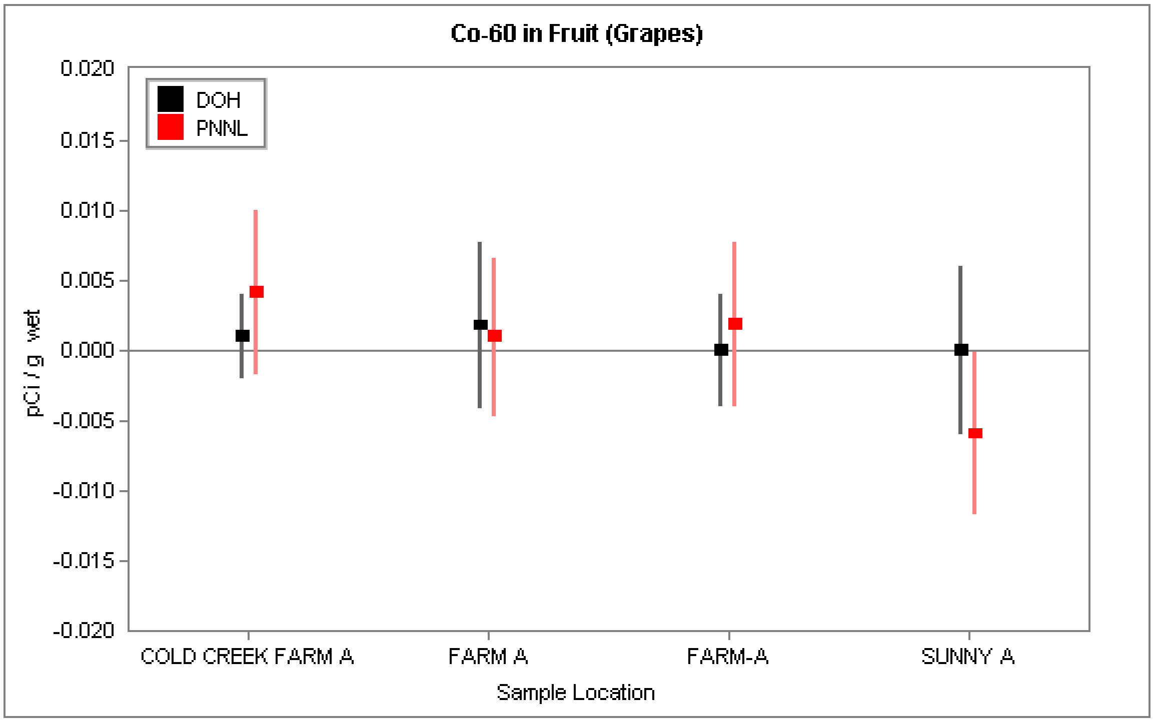

Figure 3.5.1 DOH and PNNL Co-60 Concentrations in Off-Site Grapes

3.6 Fish and Wildlife Monitoring

Major Findings:

- DOH and DOE contractor results are in good agreement for Co-60 and Cs-137. There is poor agreement in one of the two Sr-90 results.
- The Co-60 and Cs-137 results are all below detection limits. Sr-90 was not detected in the Columbia River fish sample, but was detected in the bone of a Hanford rabbit.

3.6.1 Purpose and General Discussion

The Department of Health and DOE contractors monitor fish and wildlife to determine if contaminants have migrated into the food chain. Contaminants in fish arise from fish swimming in contaminated water and ingesting contaminated sediments. Contaminants in wildlife arise from ingestion of contaminated soil and vegetation. The primary purpose of the DOH program is to provide oversight of the PNNL monitoring program. In 2001, DOH split one fish sample, one Canadian goose sample, and one rabbit sample with PNNL. The type of samples, monitored analytes, and number of samples are listed in Table 3.6.1.

Sample Type	Analyte	Number of Samples
Whitefish Carcass	Sr-90	1
Whitefish Meat	Co-60, Cs-137	1
Goose Meat	Co-60, Cs-137	1
Rabbit Bone	Sr-90	1
Rabbit Meat	Co-60, Cs-137	1

Table 3.6.1 Analytes Monitored in Fish and Wildlife

3.6.2 Monitoring Locations

Whitefish was collected from the Columbia River near the 100N Reactor Area. The rabbit was collected from the 100N Reactor Area, and the Canadian goose sample was collected from the general vicinity of the 100 Area. No background samples were collected in 2001.

3.6.3 Monitoring Procedures

Fish and Wildlife samples were collected by PNNL and given to DOH for analyses. Carcass and bone samples were analyzed for Sr-90 while the meat samples were analyzed for gamma emitting radionuclides, primarily Co-60 and Cs-137.

3.6.4 Comparison of DOH and Contractor Data

DOH and PNNL split results for fish and wildlife are in good agreement for Co-60 and Cs-137. DOH and PNNL results for Co-60 in goose meat are shown in Figure 3.6.1. DOH and PNNL results for Sr-90 in whitefish carcass are in good agreement, while the Sr-90 results in rabbit bone are in poor agreement (Figure 3.6.2). For rabbit bone, PNNL reports a concentration close to zero, while DOH reports a concentration near 5 pCi/g. In this case, the DOH result is significantly greater than PNNL. In 2000, there was also a discrepancy between DOH and PNNL for a game animal bone analysis, however in that case it was the PNNL result that was greater than DOH. The discrepancy in the Sr-90 results is not understood at this time, and is currently under investigation.

3.6.5 Discussion of Results

The Co-60 and Cs-137 results are all below detection limits. Strontium 90, which originates from worldwide fallout as well as Hanford operations, was not detected in the whitefish sample, but was detected at 4.7 pCi/g in rabbit bone collected from the 100N Reactor Area (see Figure 3.6.2).

Since 1996, 14 wildlife bone samples from animals collected on the Hanford Site have been analyzed by DOH for Sr-90. The minimum, maximum, and average concentrations are 0.04, 4.7, and 0.6 pCi/g.

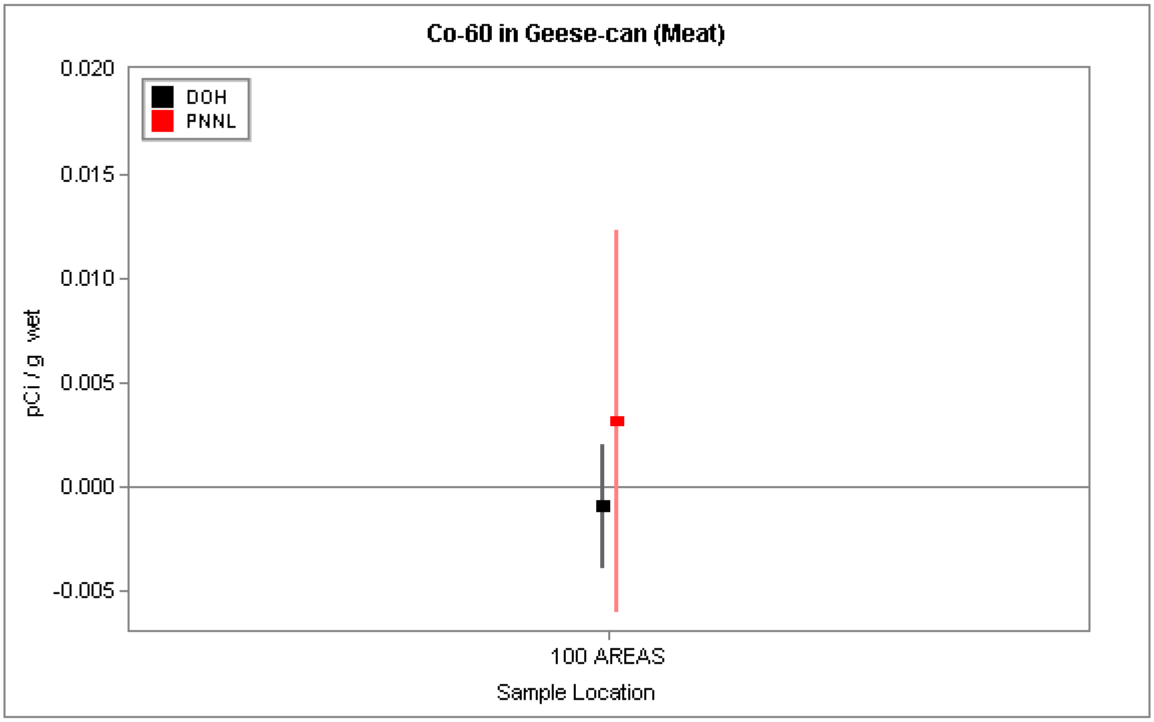

Figure 3.6.1 DOH and PNNL Co-60 Concentrations in Canadian Goose Meat

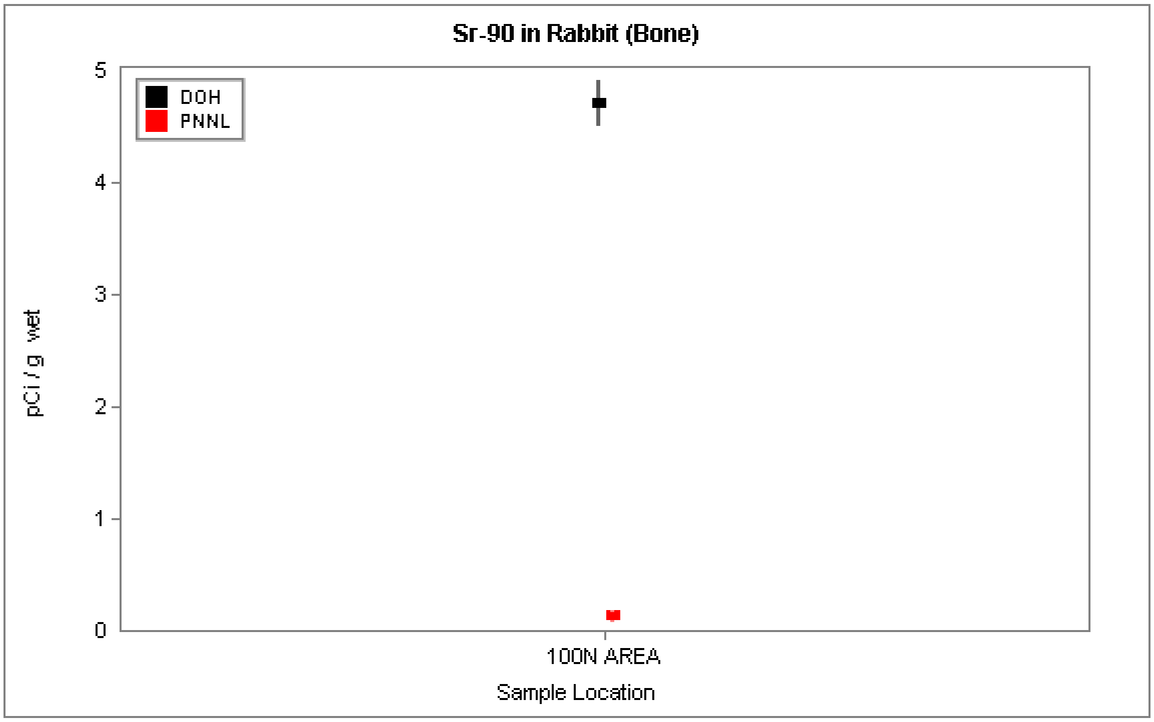

Figure 3.6.2 DOH and PNNL Sr-90 Concentrations in Rabbit Bone

3.7 Vegetation Monitoring

Major Findings:

- DOH and DOE contractor results are in good agreement.
- Most radioactivity concentrations are below detection limits.
- A low concentration of Sr-90 was detected in two offsite alfalfa samples.

3.7.1 Purpose and General Discussion

The Department of Health and DOE contractors monitor vegetation to evaluate contaminants that are incorporated into plants that, in turn, may be consumed by animals and potentially reach the public. Contaminants in vegetation arise from airborne deposition and from soil to plant transfer via root uptake. The primary purpose of the DOH program is to provide oversight of the PNNL monitoring program. In 2001, DOH split four vegetation samples with PNNL. The type of vegetation, monitored analytes, and number of samples are listed in Table 3.7.1.

Type of Vegetation	Analyte	Number of Samples
Alfalfa	Co-60, Cs-137, Sr-90	2
Rabbit Brush	Co-60; Cs-137; Pu-238, 239/240; Sr-90; U-234, 235, 238	1
Sagebrush	Co-60; Cs-137; Pu-238, 239/240; Sr-90; U-234, 235, 238	1

Table 3.7.1 Analytes Monitored in Vegetation

3.7.2 Monitoring Locations

The alfalfa sample was collected from two farms located downwind of the Hanford Site. The rabbit brush sample was collected from the Columbia River shoreline near the 100N reactor. The sagebrush sample was collected from the Columbia River near the Old Hanford Townsite.

3.7.3 Monitoring Procedures

The vegetation samples were collected in the fall of 2001 and split with PNNL. DOH and PNNL independently analyzed the samples, and then compared results. The results are reported in pCi/g.

3.7.4 Comparison of DOH and Contractor Data

Most (21 of 22) of the DOH and PNNL split vegetation results are in good agreement. As an example, the DOH and PNNL Cs-137 results in alfalfa are shown in Figure 3.7.1. The only discrepancy is for one of the Sr-90 alfalfa results, where the DOH result is 4 times greater than the PNNL result (Figure 3.7.2).

3.7.5 Discussion of Results

All results are below detection limits, except for the two Sr-90 alfalfa samples collected from offsite farms, where concentrations of 0.2 pCi/g were detected. The source of the Sr-90 is not known, since Sr-90 originates from worldwide fallout as well as Hanford operations. Historically, DOH has detected small concentrations of Sr-90 in alfalfa at Farm:A since 1995, as seen in Figure 3.7.3. Prior to the sample collected in 2001, all previous concentrations of Sr-90 in alfalfa at Farm-A have been below detection limits.

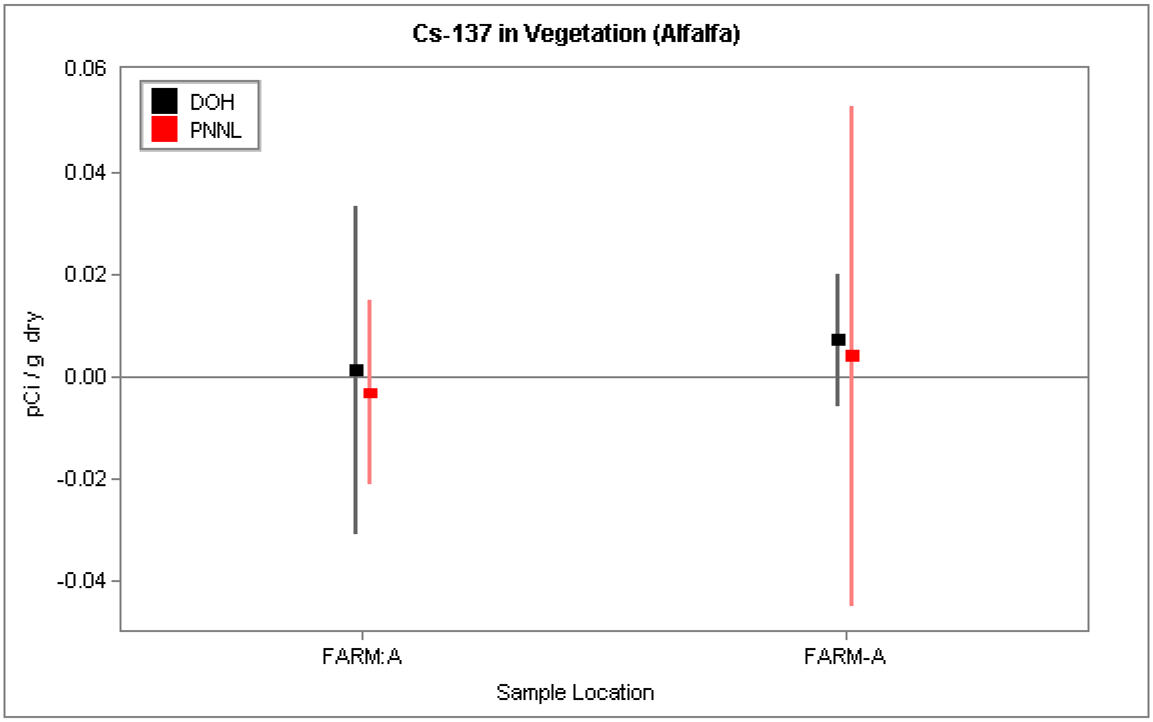

Figure 3.7.1 DOH and PNNL Cs-137 Concentrations in Off-Site Alfalfa

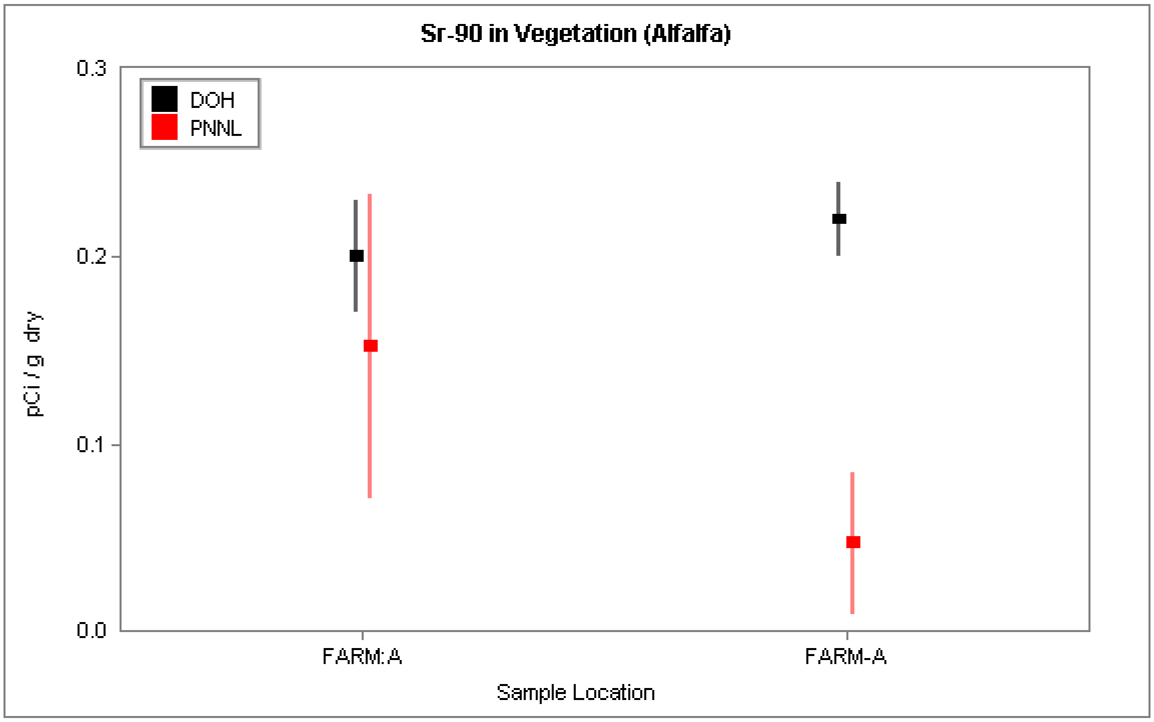

Figure 3.7.2 DOH and PNNL Sr-90 Concentrations in Off-Site Alfalfa

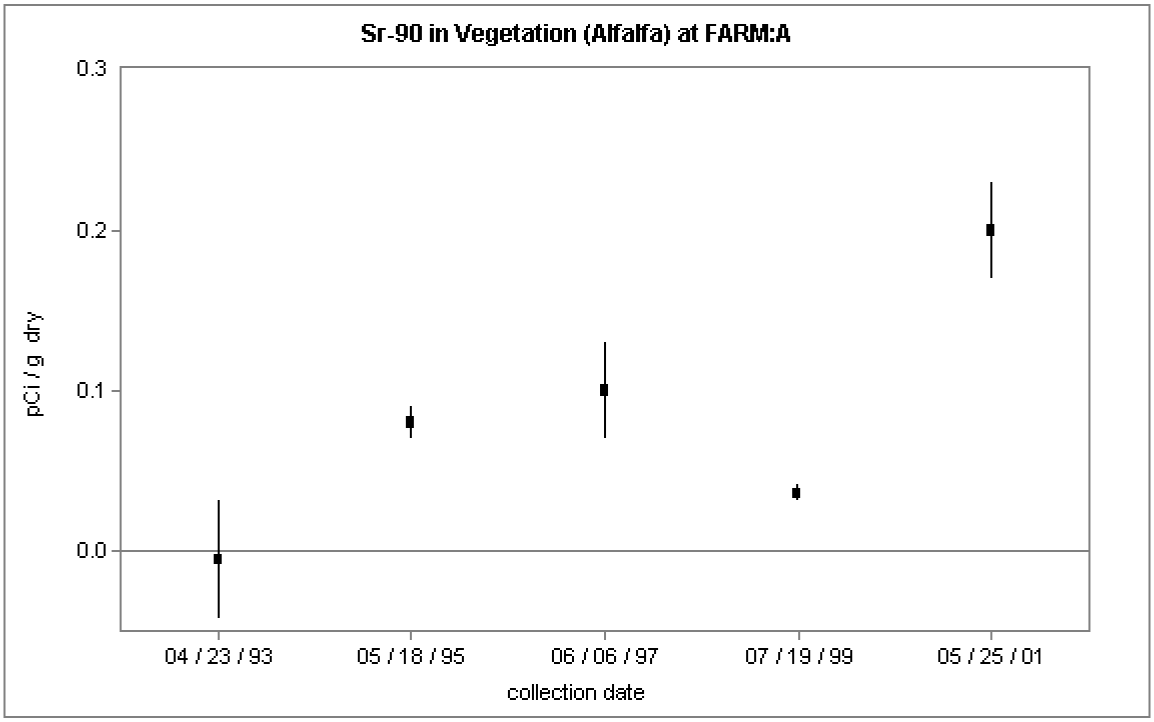

Figure 3.7.3 Historical DOH Sr-90 Concentrations in Alfalfa at Farm:A

4. Follow-up Investigations

This section summarizes follow-up investigations on results reported in past Hanford Oversight Program Data Summary Reports. For the year 2000 Report, a discrepancy between results reported by DOH and Duratek for Sr-90 concentrations in soil was reported. Section 4.1 presents the findings of an investigation carried out by DOH.

4.1 Sr-90 in Soil

The DOH Hanford Environmental Oversight Program 2000 Data Summary Report (DOH 320-029) described a discrepancy in Sr-90 soil concentrations reported by DOH and Duratek. The discrepancy is observed as a consistent difference in concentration, and suggests a systematic bias in procedure for either the DOH laboratory or the Duratek contract laboratory. Figure 4.1 plots the year 2000 split soil concentrations, along with their associated error and detection limit. Duratek's contract laboratory reports an error that includes both the two-sigma counting and laboratory systematic errors, while DOH reports only the two-sigma counting error. Strontium-90 was detected in all samples analyzed by Duratek's contract laboratory and in six of the eight samples analyzed by DOH. Strontium-90 is considered detected if the result is greater than the detection limit.

A follow-up investigation was conducted to determine the origin of the systematic difference. Sampling techniques, data reduction calculations, quality control tests, and analytical methods were reviewed. No anomalies were found in the sampling techniques or data reduction calculations. Quality control tests, as measured through independent performance evaluation programs, were adequate for both laboratories.

The analytical methods for Sr-90 analysis are different for the two laboratories. Both DOH and Duratek's contract laboratory use accepted procedures for chemically separating strontium from soil and quantifying the activity in the sample. The DOH method is based on acid leaching followed by cold fuming nitric acid and oxalic acid precipitations. The Duratek contract laboratory method is based on acid leaching, precipitation of strontium by carbonate, followed by extraction chromatographic Sr-resin^{TM} for separation of strontium from other cations. Both laboratories use strontium and barium carriers as well as a tracer to monitor the performance of the method. The difference in Sr-90 concentrations reported by DOH and Duratek is likely due to a systematic bias introduced into one or both of the laboratories' analytical procedures.

One consequence of the different analytical methods is that each laboratory uses a different sample size for their analysis. The extraction chromatographic method is limited by the amount of sample that can be used. Typically, the Duratek contract laboratory uses 1 gram of sample, whereas the DOH laboratory uses between 100 and 150 grams. Because sample size is inversely related to detection limit, the Duratek detection limit is expected to be 100 times larger than the DOH detection limit. This difference in detection limits is seen in Figure 4.1. Although the different detection limits indicate a difference in capability to detect low-level environmental concentrations, it is not believed to contribute to the systematic difference in results.

DOH splits soil samples containing low-levels of Sr-90 with other laboratories, and most results are in good agreement. For example, in this report for year 2001, DOH split soil samples with PNNL (see Figure 3.4.4). The 2001 DOH/PNNL split results are in good agreement, and do not show the same systematic difference observed in the 2000 DOH/Duratek split data. This suggests confidence in the DOH results, yet no problems were identified in the Duratek contract laboratory's analytical method.

In summary, DOH and Duratek split eight Hanford soil samples in the year 2000. Strontium-90 was detected in most samples at low concentrations near both laboratories' detection capabilities. However, the DOH and Duratek results are not in agreement, showing a systematic difference between the two data sets. A DOH investigation determined that the laboratories used different methods for analysis of Sr-90, however, the source of the discrepancy was not identified. This issue will continue to be investigated with comparison of results from samples collected in 2002, and from samples planned to be collected in 2004. Results of these analyses will be included in future reports.

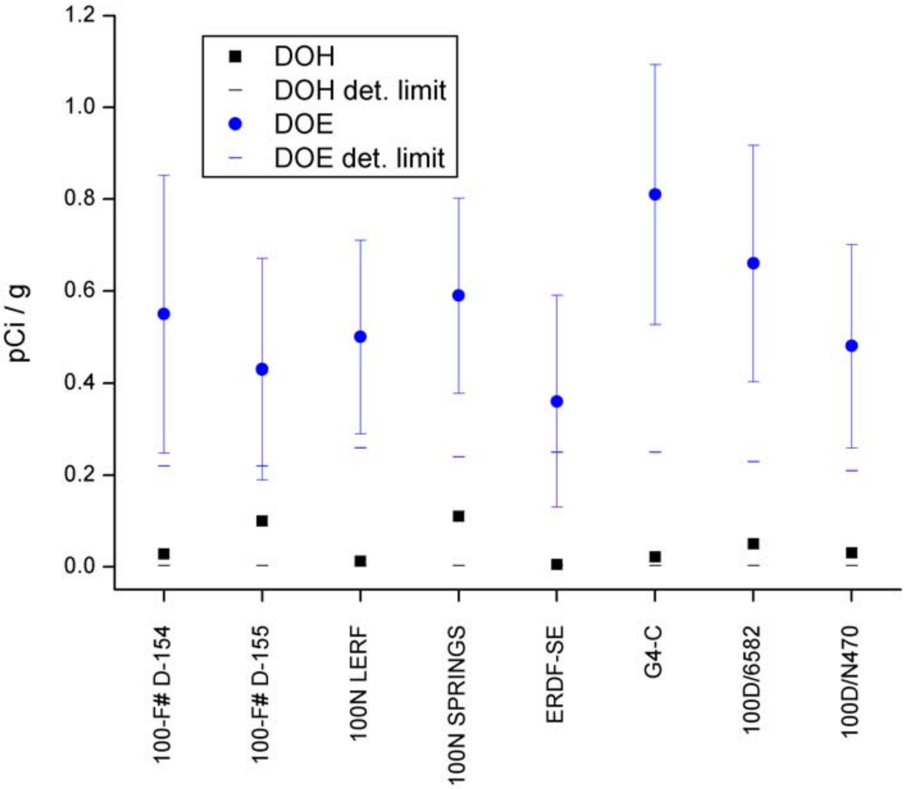

Figure 4.1 DOH and Duratek Sr-90 Concentrations in Soil for Year 2000

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 phenomena 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 include the use of radioactive materials in 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. Elements are delineated by their chemical names followed by their 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 therefore a radioisotope of carbon.

All radioisotopes will eventually decay, by emitting radiation, to 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 this 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 below 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 at 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 on 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, high dose rate health effects data all the way down 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/aßCntr	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 = $e^{-(\ln 2/T1/2)(t)}$

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 $(\text{BKG}/T_2)^{1/2}$)

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 component measured in a radiochemical analysis. For example, tritium, Sr-90, and U-238 are analytes.
Background (Background Radiation)	Radiation that occurs naturally in the environment. Background radiation consists of cosmic radiation from outer space, radiation from the radioactive elements in rocks and soil, and radiation from radon and its decay products in the air we breathe.
Baseline Samples	Environmental samples taken in areas unlikely to be affected by any facilities handling radioactive materials.
Becquerel	A unit, in the International System of Units (SI), of measurement of radioactivity equal to one transformation per second.
Beta Particle	A high-speed particle emitted from the nucleus, which is identical to an electron. They can have a –1 or +1 charge and are effectively shielded by thin layers of metal or plastic. Beta particles are generally only hazardous when they are internally deposited.
CFR	Code of Federal Regulations

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

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 in the human.
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 in 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 is 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 2 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
Sb-125	Antimony
Sr-90	Strontium-90
Tc-99	Technetium-99
Total U	Total Uranium
U-234	Uranium-234
U-235	Uranium-235
U-236	Uranium-236
U-238	Uranium-238