

DOH 320-038

Environmental Radiation Program

*Hanford Environmental Oversight Program
2003 Data Summary Report*

June 2005



Environmental Health Division

Environmental Radiation Program

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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 2003.

The Oversight Program's objectives are met through collection and analysis 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 2003, samples of air, groundwater, surface water, riverbank seep water, drinking water, discharge water, sediment, food and farm products, and fish and wildlife were collected. In addition, ambient external radiation levels were measured using radiation dosimeters.

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

The DOH and DOE contractor data are not expected to be in exact agreement for every sample because of the statistical nature of radioactive decay and the fact that samples collected from the field are not homogenous. In addition to a few samples where the concentrations are similar but do not exactly match, there are a few categories of samples with a systematic disagreement, and one sample that shows an unexpectedly large disagreement between DOH and DOE results.

Systematic bias was observed for gross beta and uranium activity in air samples, gross alpha and gross beta activity in water samples, and uranium activity in sediment samples. In the case of uranium, the discrepancy is due to a difference in laboratory analytical methods. For the other cases, the systematic bias indicates a probable difference in laboratory procedures. Lastly, for gross beta in air, the difference in sampling intervals may contribute to the bias.

There were significant differences between DOH and DOE results for one Columbia River sediment sample. DOH detected Cs-137 and Am-241 in this sample, while the DOE analysis of the split sample did not show elevated results. In particular, DOE did not detect Am-241.

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), uranium isotopes (U-234, 238), and tritium (H-3) were detected above background levels in some Hanford Site groundwater wells and riverbank seep water in 2003. Tritium and uranium isotopes were detected at concentrations greater than background in some Columbia River surface water samples.

Strontium 90 was detected in off-site alfalfa, which is consistent with historical results. Cesium 137 was detected in a Hanford Site rabbit. While DOH has not analyzed many rabbit samples, Cs-137 has been found in other wildlife both on and off the Hanford Site. Tritium is commonly detected in Hanford Site groundwater wells; however, it appears to be increasing in the 100K Area.

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.

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Acronyms

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

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 2003.

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 analysis of environmental samples and interpretation of results. DOH samples are either split or co-located with samples collected by the DOE contractors. In 2003, 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/m^3); radioactivity in liquids such as water and milk is expressed as picocuries per liter (pCi/L); and radioactivity in solid material such as soil, vegetation, and food is expressed as picocuries per gram (pCi/g). Ambient gamma radiation is expressed as radiation exposure, measured in 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 and Scatter Plots

In addition to qualitative assessment, linear regression analysis is used to compare DOH and DOE data when appropriate. In this report, regression analysis is carried out when a) there 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, and discharge water (Section 3.2); dosimeters measuring external gamma radiation (Section 3.3); 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/PNNL and DOH/Duratek co-located bi-weekly gross beta results are in fair agreement. The data follow the same trends, but there is a small systematic discrepancy between the DOH and DOE contractor data sets.
- The DOH/PNNL and DOH/Duratek co-located quarterly and semi-annual composite air sample results are in good agreement for all radionuclides, except for isotopes of uranium. The discrepancy in uranium concentrations originates from a difference in DOH and DOE contractor laboratory analytical methods.
- The gross beta results are consistent with background air concentrations.
- The DOH quarterly and semi-annual composite air concentrations were below detection limits for most radionuclides. However, uranium was consistently detected in composite air samples, and Pu-239/240 was detected in one sample. In all cases, the concentrations were small, being less than three times greater than detection limits.

3.1.1 Purpose and General Discussion

Atmospheric releases of radioactive material from the Hanford Site are a potential source of human exposure. DOH 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. In addition to oversight of the DOE monitoring program, DOH evaluates Hanford impacts 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 such as beryllium-7 and tritium that are generated in the atmosphere by interactions with cosmic radiation.

3.1.2 Monitoring Locations

In 2003, DOH collected air samples co-located with PNNL at five locations. These locations include Wye Barricade, Prosser Barricade, Battelle Complex, and Station 8 that are located in the prevailing downwind direction of most Hanford Site operating and contaminated facilities; and Yakima Barricade that is in the prevailing upwind direction of operating and contaminated facilities.

DOH also collected air samples co-located with Duratek at four locations, three of which are 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-SE), and the K Area fuel storage basins (KE Basin). The fourth co-located site is at the Yakima Barricade. All the DOH co-located air sampling sites are shown in Figure 3.1.1.

3.1.3 Monitoring Procedures

Airborne particles are sampled by continuously drawing air through a filter. 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	Co-60; Cs-134, 137
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 concentrations in bi-weekly co-located air samples are in fair agreement, as the data follow the same trend at each of the monitoring locations. As an example, the DOH and PNNL data at Station 8, which is located downwind across the Columbia River, is shown in Figure 3.1.2.

The scatter plots for 2003 and historical DOH and PNNL gross beta concentrations are shown in Figures 3.1.3 and 3.1.4. The scatter plots show the data from all sites that are co-located with PNNL. Again, it is clear the data follow the same general trend. However, there is significant scatter in the data, with differences up to a factor of two

between the DOH and PNNL concentrations being common. In addition, there is a small systematic bias between the DOH and PNNL results. The regression analysis indicates that PNNL on average reports slightly higher concentrations at the lower range of results, while DOH on average reports slightly higher concentrations at the upper range.

The DOH and Duratek gross beta concentrations in bi-weekly co-located air samples are in fair agreement, as the data follow the same trend at each of the monitoring locations. As an example, DOH and Duratek data at C Farm are shown in Figure 3.1.5. The scatter plots and regression analyses for 2003 and historical data (Figures 3.1.6 and 3.1.7) show that differences up to a factor of two between DOH and Duratek concentrations are common, and that there appears to be a small systematic bias similar to that seen with the DOH and PNNL data.

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.

DOH and PNNL analyzed co-located quarterly composite air samples for Co-60, Cs-134, and Cs-137 at Battelle Complex, Prosser Barricade, Station 8, Wye Barricade, and Yakima Barricade. Co-located quarterly composite air samples were analyzed for isotopes of uranium at Station 8 and Wye Barricade.

The DOH and PNNL Co-60, Cs-134, and Cs-137 quarterly composite concentrations are in good agreement (all results are below detection limits). The agreement is only fair for isotopes of uranium due to a systematic discrepancy between the two data sets. The U-238 concentrations are shown in Figure 3.1.8. The PNNL uranium concentrations are systematically less than those reported by DOH. The results for U-234 are similar. The agreement is good for U-235; however, all concentrations are below detection limits.

The discrepancy between DOH and PNNL uranium concentrations in air exists historically, and originates from different laboratory procedures. DOH completely dissolves samples prior to analysis and reports uranium present in the entire sample, whereas the contractor laboratory reports only the uranium that can be leached from the sample surface.

The historical DOH and PNNL quarterly composite U-238 concentrations for the years 1999 through 2003 is shown in Figure 3.1.9, and the corresponding scatter plot is shown in Figure 3.1.10. The discrepancy appears for samples in which DOH measures U-238 concentrations greater than the detection limit of 2.5E-5 pCi/m³. In these cases, the corresponding PNNL data do not confirm the elevated DOH results.

DOH and Duratek analyzed co-located quarterly composite air samples for Co-60, Cs-134, and Cs-137 at the Yakima Barricade. All reported concentrations are in good agreement (all results are below detection limits).

DOH and Duratek analyzed co-located semi-annual composite air samples at C Farm, ERDF-SE, and KE Basin. The DOH and Duratek airborne concentrations are in good agreement for Co-60; Cs-134, Cs-137; U-235, Pu-238, and Pu-239/240 (most results are

below detection limits). However, the U-234 and U-238 concentrations are only in fair agreement, as the Duratek concentrations are systematically less than those reported by DOH. As with the DOH and PNNL composite data, the bias originates from different laboratory procedures. The DOH and Duratek U-238 data are shown in Figure 3.1.11. The U-234 data are similar.

3.1.5 Discussion of DOH 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 3.1.12, which shows gross beta activity at Wye Barricade from 1993 through 2003.

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, Prosser Barricade, Battelle Complex, 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 (C Farm, ERDF-SE, and KE Basin).

The average air concentrations 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. In addition, the average air concentration at the locations near operating facilities is also not significantly different from the upwind site. For the year 2003, all of the weekly DOH gross beta results ranged between 0.0025 and 0.053 pCi/m³, with an annual average of 0.013 pCi/m³.

Site	DOH (pCi/m ³)			Contractor (pCi/m ³)			
	Min	Max	Average	Name	Min	Max	Average
Battelle Complex	0.0027	0.053	0.016	PNNL	0.0071	0.038	0.015
C Farm	0.0026	0.052	0.014	Duratek	0.0053	0.038	0.017
ERDF-SE	0.0027	0.043	0.012	Duratek	0.0054	0.037	0.014
KE Basin	0.0025	0.049	0.013	Duratek	0.0054	0.033	0.014
Prosser B.	0.0028	0.044	0.012	PNNL	0.0018	0.034	0.015
Station 8	0.0031	0.052	0.013	PNNL	0.0060	0.028	0.014
Wye B.	0.0032	0.047	0.013	PNNL	0.0058	0.037	0.015
Yakima B.	0.0034	0.051	0.013	PNNL	0.0061	0.031	0.014

Table 3.1.2 Summary Statistics for Gross Beta Concentrations in Air

In addition to the co-located results discussed above, DOH also analyzed quarterly composite air samples for U-238 at the Yakima Barricade. Most of the DOH results for Co-60, Cs-134, Cs-137, Pu-238, and U-235 concentrations in composite air samples are below laboratory detection limits (see Appendix B). Cesium 137 was detected in a few of the samples at concentrations near the detection limit. Uranium-234 and U-238 were detected in several samples, as shown in Figure 3.1.13, with concentrations ranging from the detection limit of approximately 0.000025 pCi/m^3 to 0.00008 pCi/m^3 . A Pu-239/240 concentration of 0.000006 pCi/m^3 was detected at ERDF-SE. Plutonium-239/240 has been detected just above the detection limit of 0.000005 pCi/m^3 at this location for the past several years, as shown in Figure 3.1.14.

These uranium and plutonium concentrations are very small, and are only at most a few times greater than the detection limits. Continuous breathing of air with a Pu-239/240 concentration of 0.000005 pCi/m^3 would result in an annual radiation dose of approximately 0.02 mrem/yr. Both the U.S. Environmental Protection Agency (40 CFR Part 61) and Washington State (Chapter 246-247 WAC) limit radiation dose to the public from air emissions to 10 mrem/year. The maximum radionuclide concentrations detected in DOH composite air samples are all several orders of magnitude less than EPA Concentration Levels for Environmental Compliance (as listed in 40 CFR Part 61, Appendix E, Table 2).

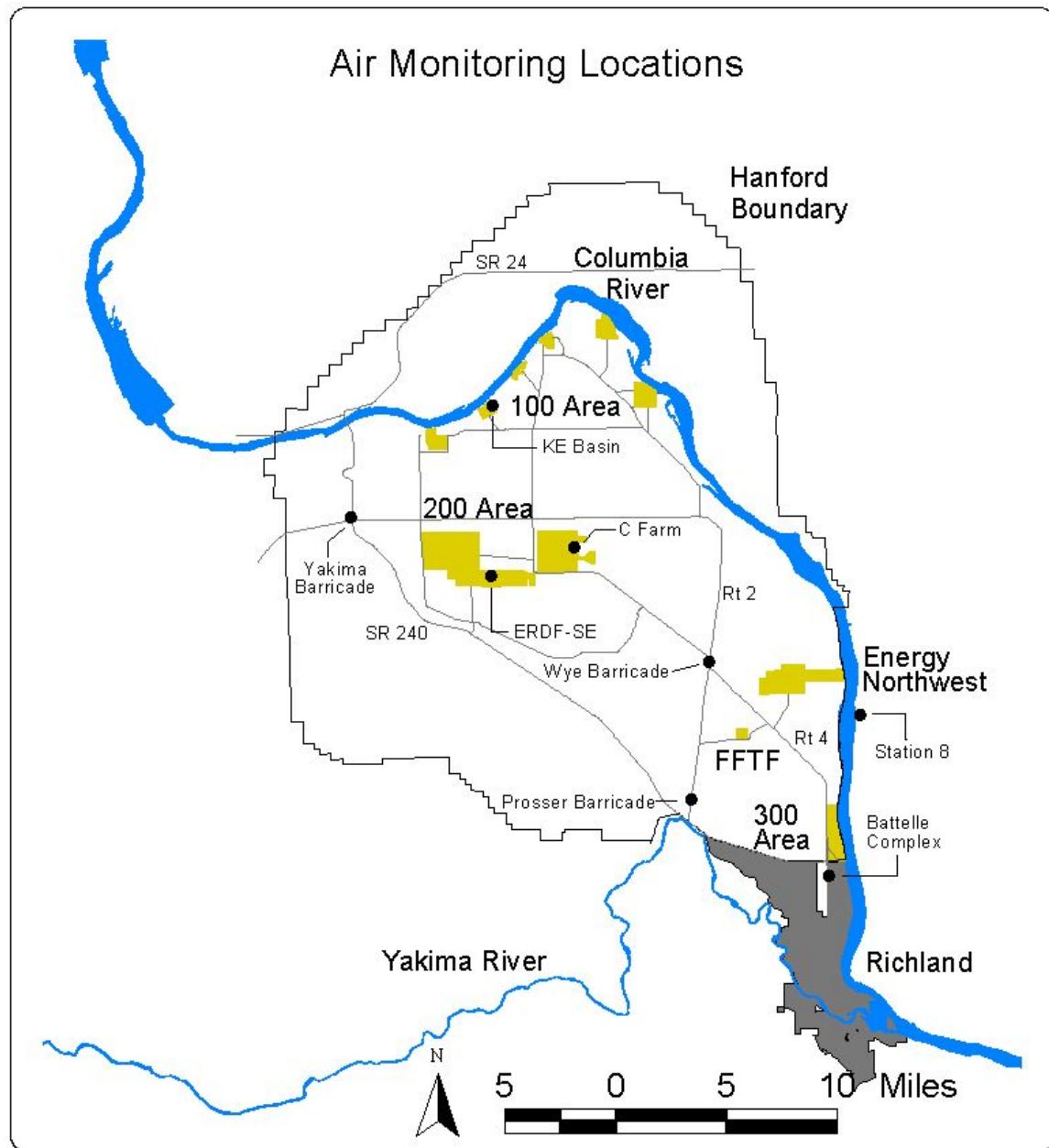


Figure 3.1.1 Air Monitoring Locations

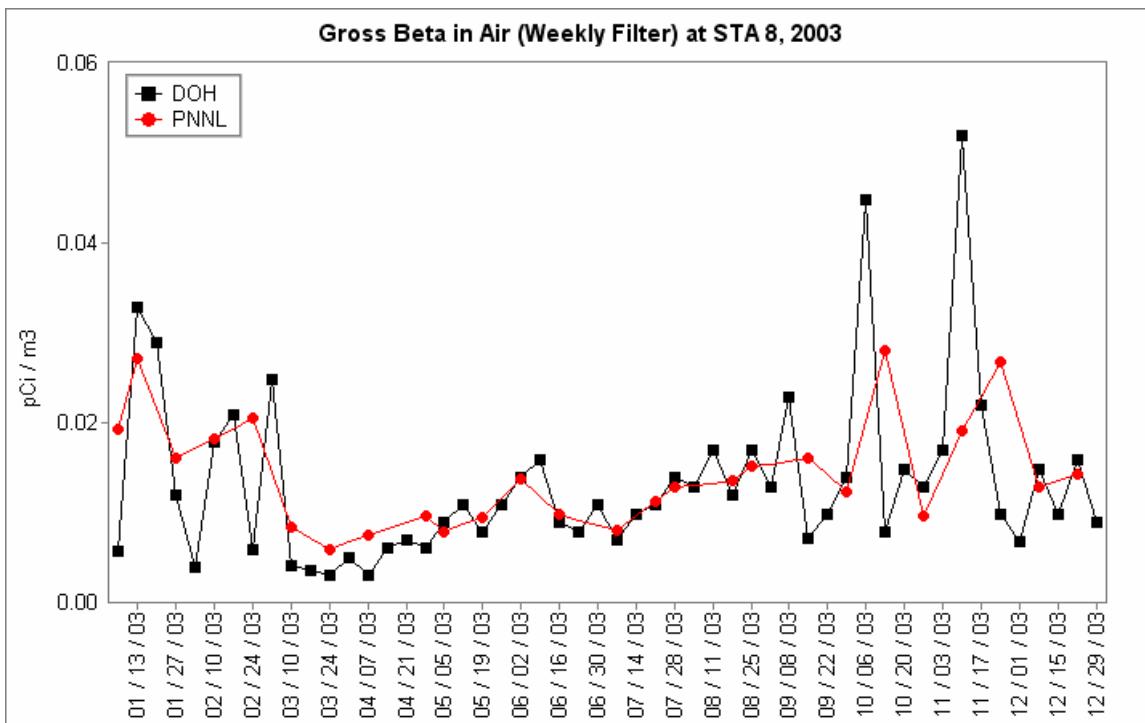


Figure 3.1.2 DOH and PNNL Gross Beta Concentrations in Air at Station 8

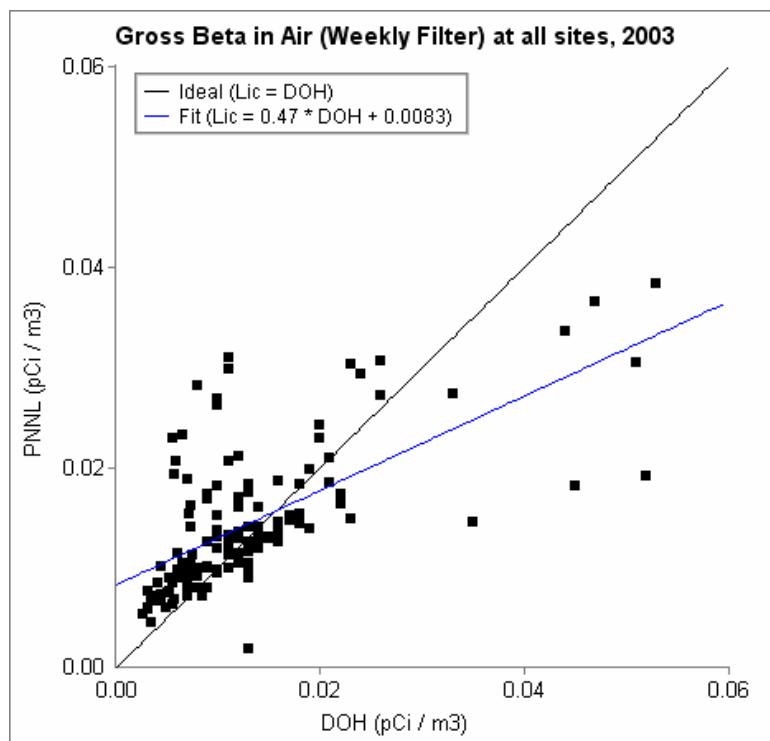


Figure 3.1.3 DOH and PNNL Scatter Plot for Gross Beta Concentrations in Air (2003)

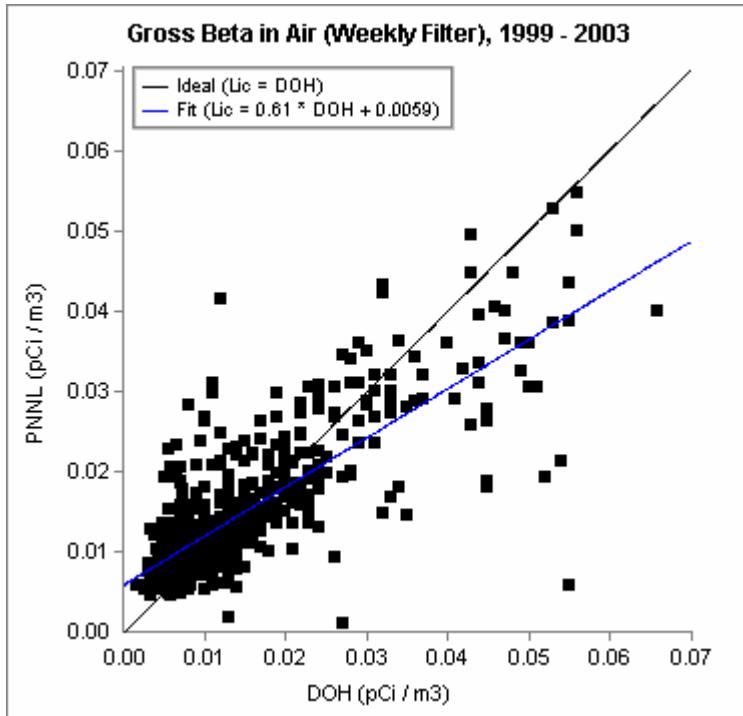


Figure 3.1.4 DOH and PNNL Scatter Plot for Historical Gross Beta Concentrations in Air

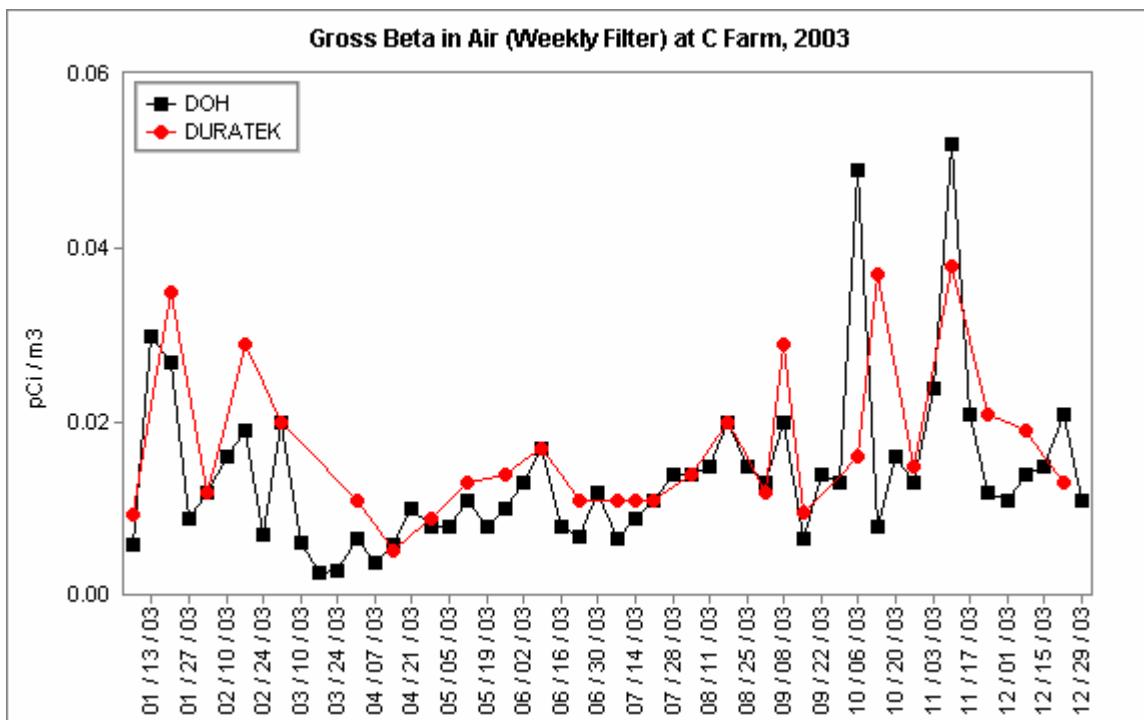


Figure 3.1.5 DOH and Duratek Gross Beta Concentrations in Air at C Farm

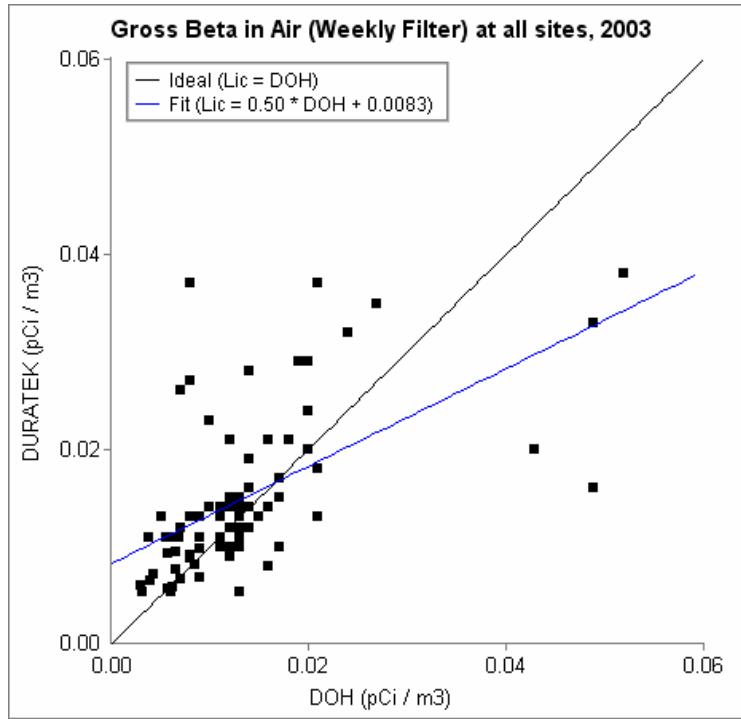


Figure 3.1.6 DOH and Duratek Scatter Plot for Gross Beta Concentrations in Air (2003)

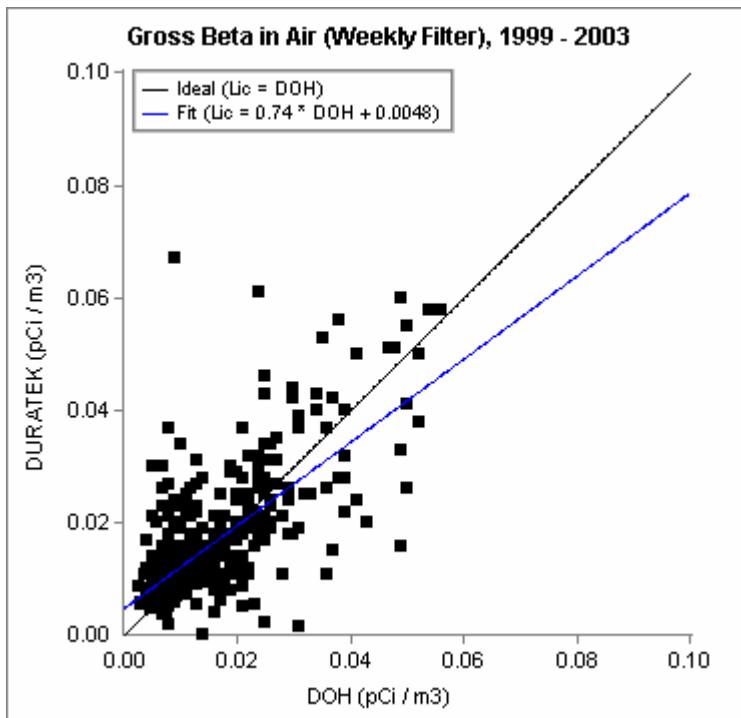


Figure 3.1.7 DOH and Duratek Scatter Plot for Historical Gross Beta Concentrations in Air

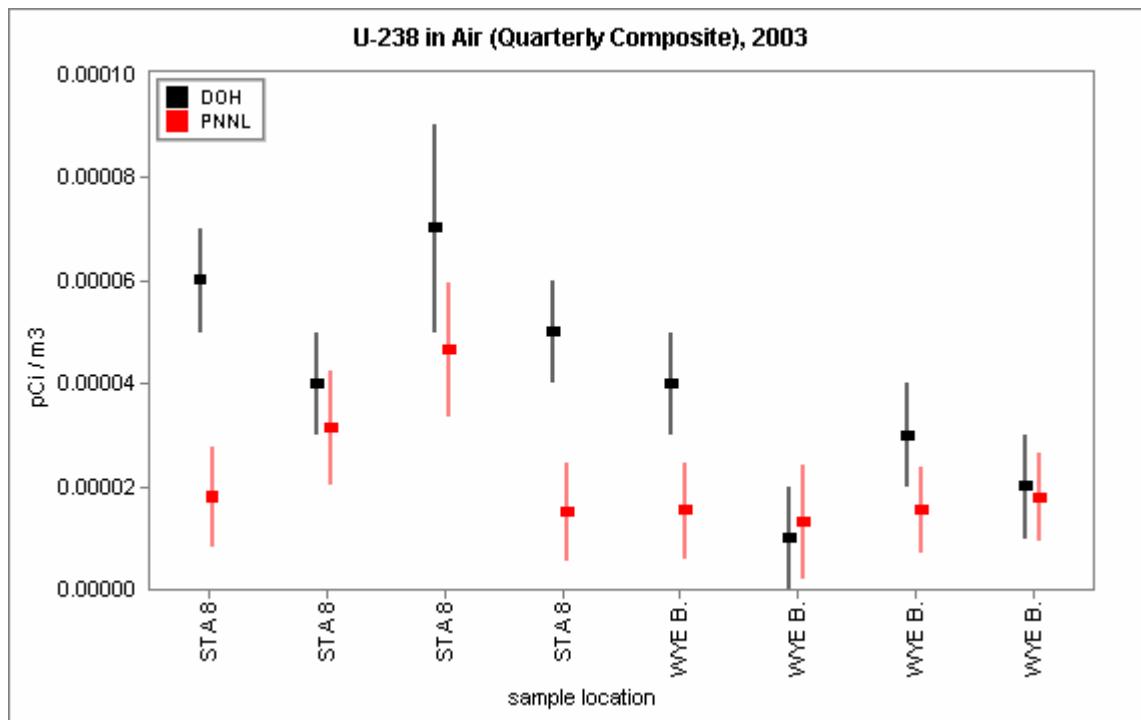


Figure 3.1.8 DOH and PNNL U-238 Concentrations in Quarterly Composite Air Samples

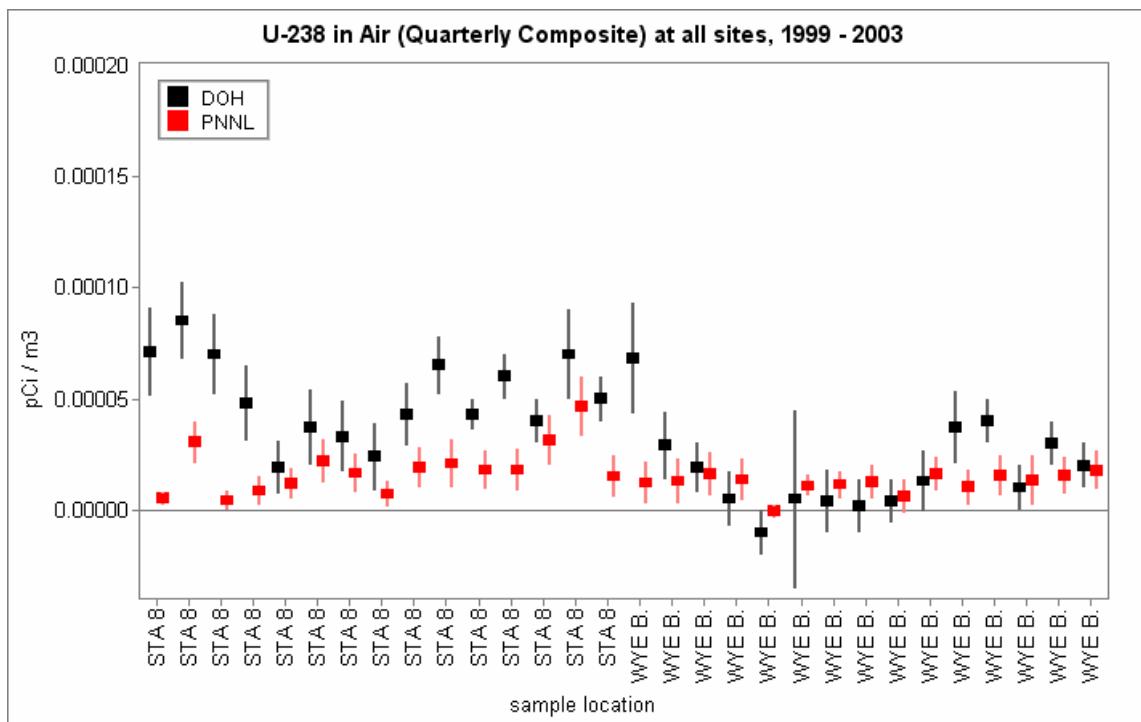


Figure 3.1.9 Historical DOH and PNNL U-238 Concentrations in Quarterly Composite Air

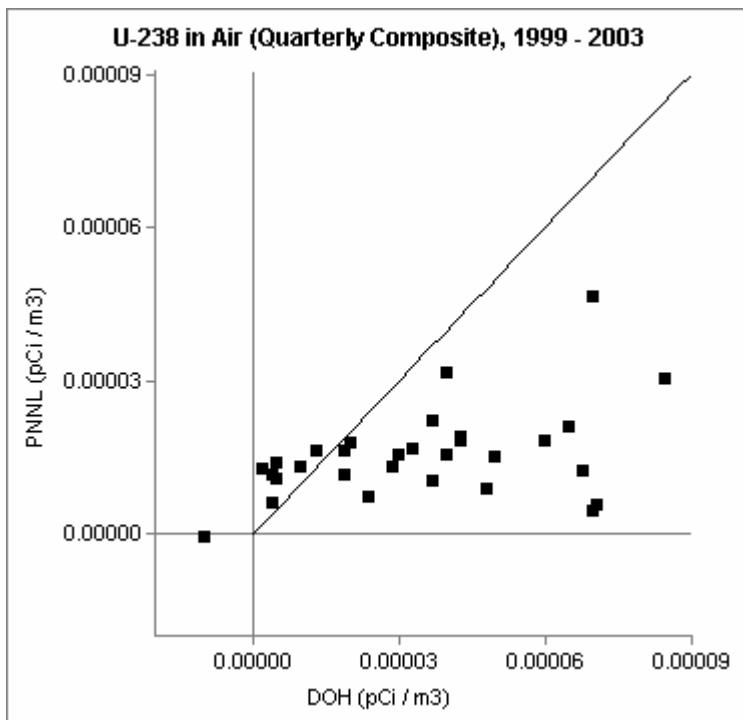


Figure 3.1.10 DOH and PNNL Scatter Plot for Historical U-238 Concentrations in Air

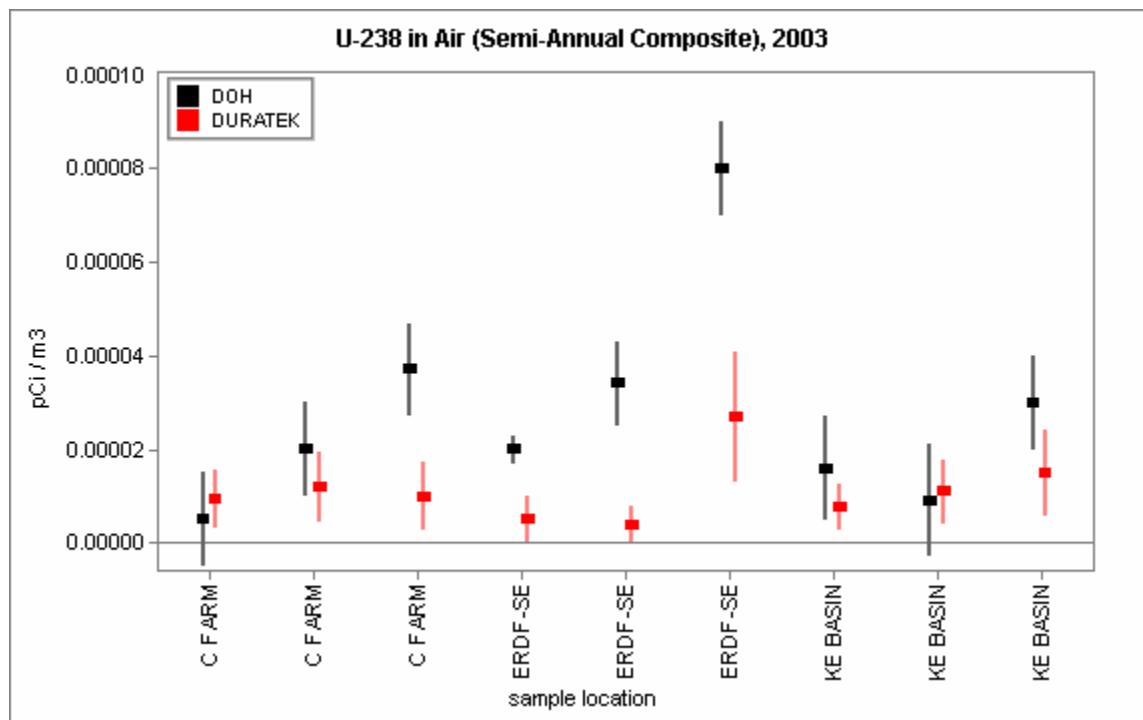


Figure 3.1.11 DOH and Duratek U-238 Concentrations in Semi-Annual Composite Air

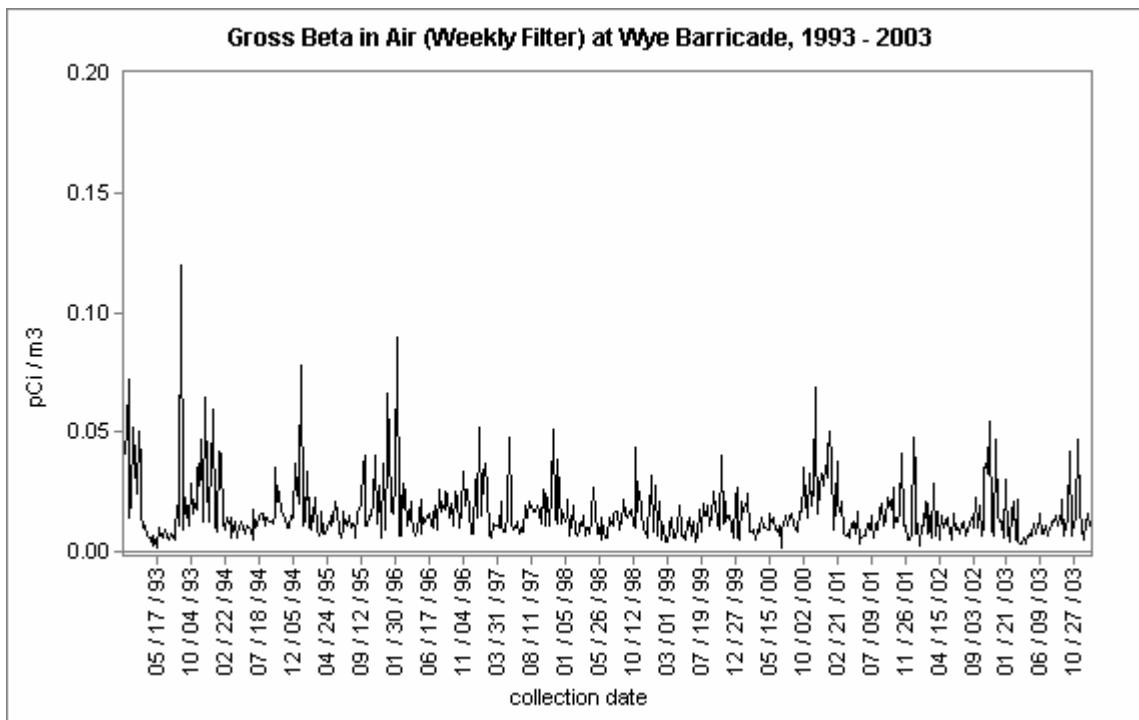


Figure 3.1.12 DOH Historical Gross Beta Concentrations in Air at Wye Barricade

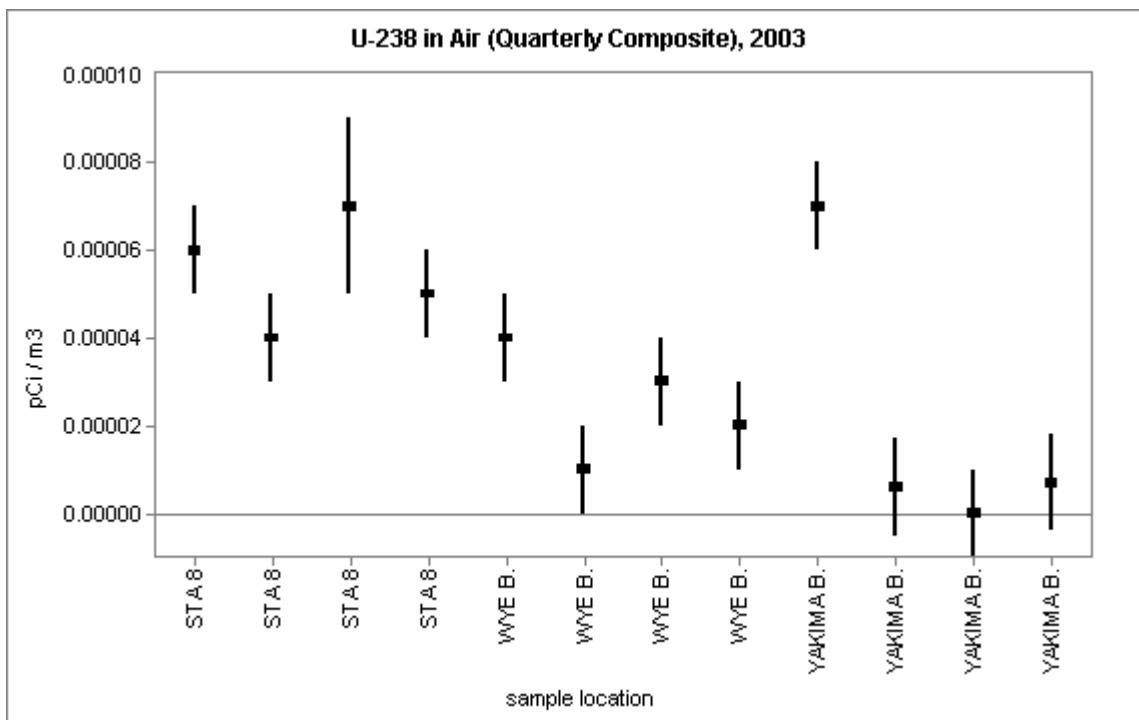


Figure 3.1.13 DOH U-238 Concentrations in Quarterly Composite Air Samples

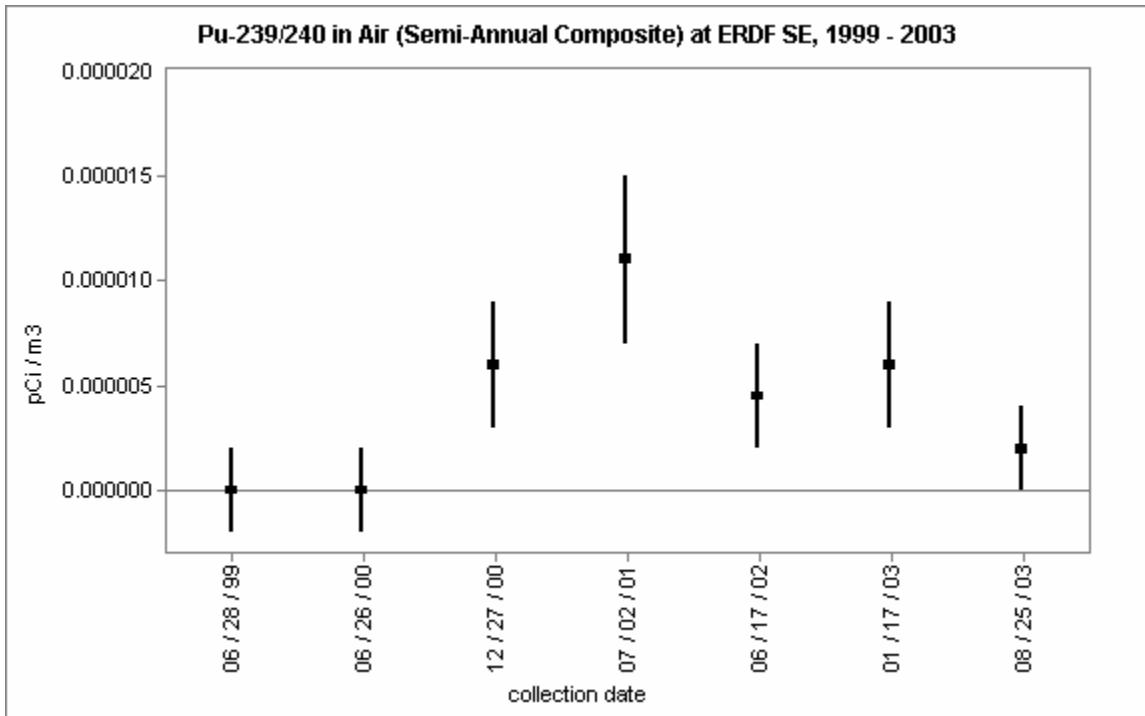


Figure 3.1.14 DOH Pu-239/240 Concentrations in Air Samples at ERDF-SE

3.2 Groundwater, Riverbank Seep, and Surface Water Monitoring

Major Findings:

- The DOH and PNNL split water results are in good agreement for most radionuclides analyzed in water samples. A small systematic bias exists in the gross alpha and gross beta results, and this bias has existed historically. The historical agreement for I-129 results is poor; however, all I-129 concentrations in 2003 were below detection limits. The DOH and WMFS split TEDF discharge water results are in good agreement.
- Water results in 2003 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.
- DOH detected H-3, Sr-90, Tc-99, and isotopes of uranium in Hanford water samples. Most results in 2003 samples were consistent with historical results, with the exception of increasing H-3 concentrations in 100K Area groundwater wells.
- Radionuclide concentrations measured by DOH in Ligo Facility drinking water are all below detection limits.
- 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 enters the Columbia River through riverbank seeps.

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

DOH 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 are 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 and PNNL split 21 groundwater samples from 17 groundwater wells in 2003. 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 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 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 reactors in the 100 Area, the Old Hanford Townsite, and the 300 Area.

DOH and PNNL split ten Columbia River riverbank seep samples in 2003. Sample locations included the 100B, 100F, 100H, 100K, and 100N reactor areas; the Old Hanford Townsite (Spring 28.2); and the 300 Area. Figure 3.2.1 shows the locations of the riverbank seep sampling sites.

Surface and Discharge Water

DOH and PNNL split 24 surface water samples in 2003. Twenty two of the samples were collected from the Columbia River - two from near Priest Rapids Dam located upstream of Hanford, ten from the 100N Area, and ten from the 300 Area. Two of the samples were collected from irrigation canals, one located across the Columbia River at Riverview, and the other at the southern boundary of the Hanford Site at the Horn Rapids irrigation pumping station. Figure 3.2.1 shows the locations of the surface water sampling sites.

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

DOH conducts discharge effluent monitoring at the 310 Treated Effluent Disposal Facility (TEDF) as acknowledged in the Aquatic Lands Sewer Outfall Lease No. 20-013357. This agreement between the Department of Natural Resources (DNR) and DOE requires DOH to provide oversight of the discharge effluent monitoring program by splitting approximately 15% of the 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. DOH and WMFS split 2 discharge samples in 2003.

Drinking Water

Drinking water for the 400 Area (the Fast Flux Test Facility [FFTF]) comes from groundwater wells in the area. Drinking water for the 100N Area comes from the 100B Area pumphouse. Typically, DOH and PNNL split one or more drinking water samples each year. However, no drinking water samples were split in 2003. DOH collected and analyzed a drinking water sample from the LIGO Facility, and those results will be reported here, even though there are no DOE contractor split results.

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 Sr-90, I-129, Tc-99, and isotopes of 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, and H-3. Specific analyses for Sr-90, Tc-99, and isotopes of uranium were added where appropriate.

Surface and Discharge Water

Columbia River surface water is monitored by collecting samples at several points spanning the width of the river. This technique is known as transect sampling. Columbia River 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 H-3. Analyses for gross alpha, gross beta, gamma-emitting radionuclides, Sr-90, 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 H-3.

Drinking Water

Drinking water is monitored by sampling tap water. The samples were analyzed for gross alpha, gross beta, gamma-emitting radionuclides, and H-3.

Summary

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

Water Matrix	DOE Contractor	Analytes	Number of Sample Sites	Number of Samples
Groundwater	PNNL	Co-60, Cs-134, Cs-137, gross alpha, gross beta, H-3, I-129, Sb-125, Sr-90, Tc-99, Total U, U-234, U-235, U-238	17	21
Riverbank Seep	PNNL	Co-60, Cs-137, gross alpha, gross beta, H-3, Sr-90, Tc-99, U-234, U-235, U-238	10	10
Surface Water	PNNL	Co-60, Cs-137, gross alpha, gross beta, H-3, Sr-90, Tc-99, U-234, U-235, U-238	23	24
Discharge Water	WMFS	gross alpha, H-3	1	2

Table 3.2.1 Summary of Split Water Samples

3.2.4 Comparison of DOH and Contractor Data

In 2003, DOH split groundwater, surface water, and riverbank seep water samples with PNNL. There were no split drinking water samples in 2003. In addition, DOH split discharge water samples with WMFS. The analysis of the split water sample results is discussed below. See section 2.2.4.2 for a discussion of scatter plots and regression analyses that are used to assess these data.

The DOH and PNNL concentrations of gamma emitting radionuclides in water samples are in good agreement. Results are reported for Co-60, Cs-134, Cs-137, I-129, and Sb-125. However, all DOH and PNNL results are below detection limits, and therefore a regression analysis was not carried out. Historically, DOH and PNNL split water results are in good agreement for all gamma emitting radionuclides except for I-129. In cases where I-129 concentrations are above the detection limit, the agreement is poor.

The DOH and PNNL gross alpha concentrations in water samples are in fair agreement. For example, the split gross alpha results in groundwater are shown in Figure 3.2.2, where it can be seen that the DOH and PNNL data follow the same trend. However, a small systematic bias is revealed upon close inspection of the data. Figure 3.2.3 shows a scatter plot for historical DOH and PNNL gross alpha data. This scatter plot, and all others in this section, show data for all water samples, which includes groundwater, surface water, and riverbank seep water. The slope of the best-fit straight line to the data in the regression analysis indicates that PNNL on average reports concentrations that are only 80% of the results reported by DOH.

The DOH and PNNL gross beta concentrations in water samples are in fair agreement. For example, the split gross beta results in riverbank seep water are shown in Figure 3.2.4, where it can be seen that the DOH and PNNL data follow the same trend. However, a small systematic bias is revealed upon close inspection of the data.

Figure 3.2.5 shows a scatter plot for historical DOH and PNNL gross beta data with concentrations below 10 pCi/L. Figure 3.2.6 shows a scatter plot for historical data with concentrations between 10 and 100 pCi/L. Finally, Figure 3.2.7 shows a scatter plot for historical data with concentrations above 100 pCi/L. The regression analyses in these figures indicate that when gross beta concentrations are below 10 pCi/L, DOH and PNNL on average report similar results. However, when concentrations are above 10 pCi/L, there is a systematic bias in the results. For concentrations between 10 and 100 pCi/L, PNNL on average reports concentrations that are 50% less than those reported by DOH. For concentrations above 100 pCi/L, PNNL reports concentrations that are 30% greater than those reported by DOH. This discrepancy is currently under investigation.

The DOH and PNNL tritium (H-3) concentrations in water samples are in good agreement. For example, the split H-3 results in riverbank seep water are shown in Figure 3.2.8, where it can be seen that the DOH and PNNL data follow the same trend. Figure 3.2.9 shows a scatter plot for historical DOH and PNNL H-3 data. The slope of the best-fit straight line to the data in the regression analysis indicates that on average, DOH and PNNL report similar H-3 concentrations. Historically, the DOH and PNNL split H-3 results in water are in good agreement.

The DOH and PNNL Sr-90 concentrations in water samples are in good agreement. For example, the split Sr-90 results in groundwater are shown in Figure 3.2.10, where it can be seen that the DOH and PNNL data follow the same trend. Figure 3.2.11 shows a scatter plot for historical DOH and PNNL Sr-90 data. The slope of the best-fit straight line to the data in the regression analysis indicates that on average, DOH and PNNL report similar Sr-90 concentrations. Historically, the DOH and PNNL split Sr-90 results in water are in good agreement.

The DOH and PNNL Tc-99 concentrations in water samples are in good agreement. For example, the split Tc-99 results in all water samples are shown in Figure 3.2.12, where it can be seen that the DOH and PNNL data follow the same trend. Figure 3.2.13 shows a scatter plot for historical DOH and PNNL Tc-99 data. The slope of the best-fit straight line to the data in the regression analysis indicates that on average, DOH and PNNL report similar Tc-99 concentrations. Historically, the DOH and PNNL split Tc-99 results in water are in good agreement.

The DOH and PNNL isotopic uranium concentrations in water samples are in good agreement. For example, the split U-238 results in surface water samples are shown in Figure 3.2.14, where it can be seen that the DOH and PNNL data follow the same trend. The results for U-234 are similar, and most of the U-235 results are below detection limits.

Figure 3.2.15 shows a scatter plot for historical DOH and PNNL U-238 data with concentrations less than 50 pCi/L. The slope of the best-fit straight line to the data in the regression analysis indicates that on average, DOH and PNNL report similar U-238 concentrations. The results for U-234 are similar. There are three results from samples collected in 1999 where the concentrations exceeded 50 pCi/L, and in that case, PNNL reported results approximately twice the concentrations reported by DOH. Otherwise, the DOH and PNNL historical uranium results are in good agreement.

The DOH and WMFS gross alpha and H-3 concentrations for the two discharge water samples collected at TEDF are in good agreement. Historically, the DOH and WMFS reported discharge water concentrations are in good agreement. Figure 3.2.16 shows the historical gross alpha concentrations.

3.2.5 Discussion of DOH Results

All concentrations of gamma emitting radionuclides in water samples reported by DOH were below detection limits. The gamma emitting radionuclides reported by DOH include Co-60, Cs-134, Cs-137, I-129, and Sb-125. Detection limits are listed in Appendix B. DOH typically detects I-129 in groundwater well 699-35-70; however, this well was not sampled by DOH in 2003. The 2003 results for gamma emitting radionuclides are similar to historical data.

DOH typically reports results for C-14, Pu-238, and Pu-239/240 at groundwater well 199-K-109A; and for Pu-238 and Pu-239/240 at well 399-1-17A. PNNL does not report

corresponding results. The concentrations of these radionuclides from samples collected in 2003 are all below the detection limits listed in Appendix B, which is consistent with historical DOH results.

DOH routinely detects H-3, Sr-90, Tc-99, isotopes of uranium, gross alpha, and gross beta in Hanford water samples. These radionuclides are detected in areas of known groundwater plumes or in areas where groundwater plumes are known to be entering the Columbia River. In 2003, most concentrations reported by DOH for these radionuclides were consistent with historical results.

DOH detected H-3 in groundwater wells at concentrations ranging from below the detection limit to 104,000 pCi/L. Concentrations above 20,000 pCi/L were detected in wells 199-K-109A, 199-K-27, 199-N-14, 699-26-33, 699-41-1A and 699-60-60. Tritium (H-3) concentrations in most well samples were consistent with historical results, with the exception of wells 199-K-109A and 199-K-27, where concentrations increased in 2003 compared to historical results (see Figures 3.2.16 and 3.2.17). DOH will continue to monitor these wells in the future to determine if H-3 concentrations are increasing in 100K Area groundwater.

DOH detected H-3 in riverbank seep water at the 100B, 100F, 100H, 100K, 100N, and 300 Areas, and at the Old Hanford Townsite. Concentrations ranged from 300 to 14,000 pCi/L, with the highest concentrations found at the Old Hanford Townsite. These results are consistent with historical DOH riverbank seep results. Tritium (H-3) was also detected in Columbia River surface water samples. Most results were below the detection limit. However, concentrations from samples collected near the 300 Area shoreline ranged from 100 to 1,800 pCi/L. Tritium (H-3) was also detected in TEDF discharge water at 440 pCi/L.

DOH detected Sr-90 in groundwater wells at concentrations ranging from below the detection limit to 2000 pCi/L. The highest concentrations were detected at wells 199-K-109A and 199-N-14, where the 2003 results are consistent with historical concentrations at these locations. Concentrations of Sr-90 in riverbank seep water ranged from below the detection limit to 4 pCi/L at a seep in the 100B Area. Strontium-90 is typically detected in seep water from the 100N Area; however, DOH did not collect samples from that area in 2003. Concentrations of Sr-90 in Columbia River surface water samples were all below the detection limit.

DOH detected Tc-99 in groundwater wells at concentrations ranging from below the detection limit to 150 pCi/L. The highest concentrations were detected at wells 699-60-60, 699-41-1A, and 699-26-33, where the 2003 results are consistent with historical concentrations at these locations. Concentrations of Tc-99 in riverbank seep water ranged from 4 to 14 pCi/L, with the highest concentrations found at the Old Hanford Townsite and the 300 Area. PNNL did not report a Tc-99 concentration from the 300 Area riverbank spring. Concentrations of Tc-99 in Columbia River surface water samples were all below the detection limit.

DOH detected total uranium (the sum of U-234, U-235, and U-238) concentrations in groundwater ranging from below the detection limit to 43 pCi/L. The highest

concentrations were detected at groundwater well 399-1-17A. This well is in the vicinity of a known uranium plume in the 300 Area. The uranium concentrations from samples collected in 2003 are consistent with historical DOH results.

Total uranium concentrations of 100 pCi/L were detected in riverbank seep water from the 300 Area. These concentrations are also consistent with historical results. The total uranium concentrations in most Columbia River surface water samples were similar to background values of approximately 0.3 to 0.7 pCi/L. Near-shore samples from the 300 Area were elevated compared to background, with a maximum concentration of 12 pCi/L. Again, concentrations in Columbia River surface water samples collected in 2003 are similar to historical results.

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

Summary

Radionuclides detected in groundwater wells include H-3, Sr-90, Tc-99, and isotopes of uranium. Radionuclide concentrations in 2003 were similar to historical data, and were detected in the vicinity of known groundwater plumes.

Radionuclides detected in riverbank seep water include H-3, Sr-90, Tc-99, and isotopes of uranium. Uranium from 300 Area seep water samples was the only radionuclide to exceed U.S. Environmental Protection Agency (EPA) drinking water standards.

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. Elevated H-3 and uranium concentrations were detected in near-shore Columbia River surface water from the 300 Area. However, all concentrations were below EPA drinking water standards.

DOH and PNNL did not split drinking water samples in 2003. However, DOH collected a drinking water sample from the LIGO Facility on the Hanford Site, and results for gamma emitting radionuclides, gross alpha, gross beta, and H-3 were all below detection limits.

Concentrations of gamma emitting radionuclides, gross alpha, and gross beta were below detection limits in 300 Area TEDF discharge water samples. Tritium (H-3) was detected at 440 pCi/L. 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 H-3.

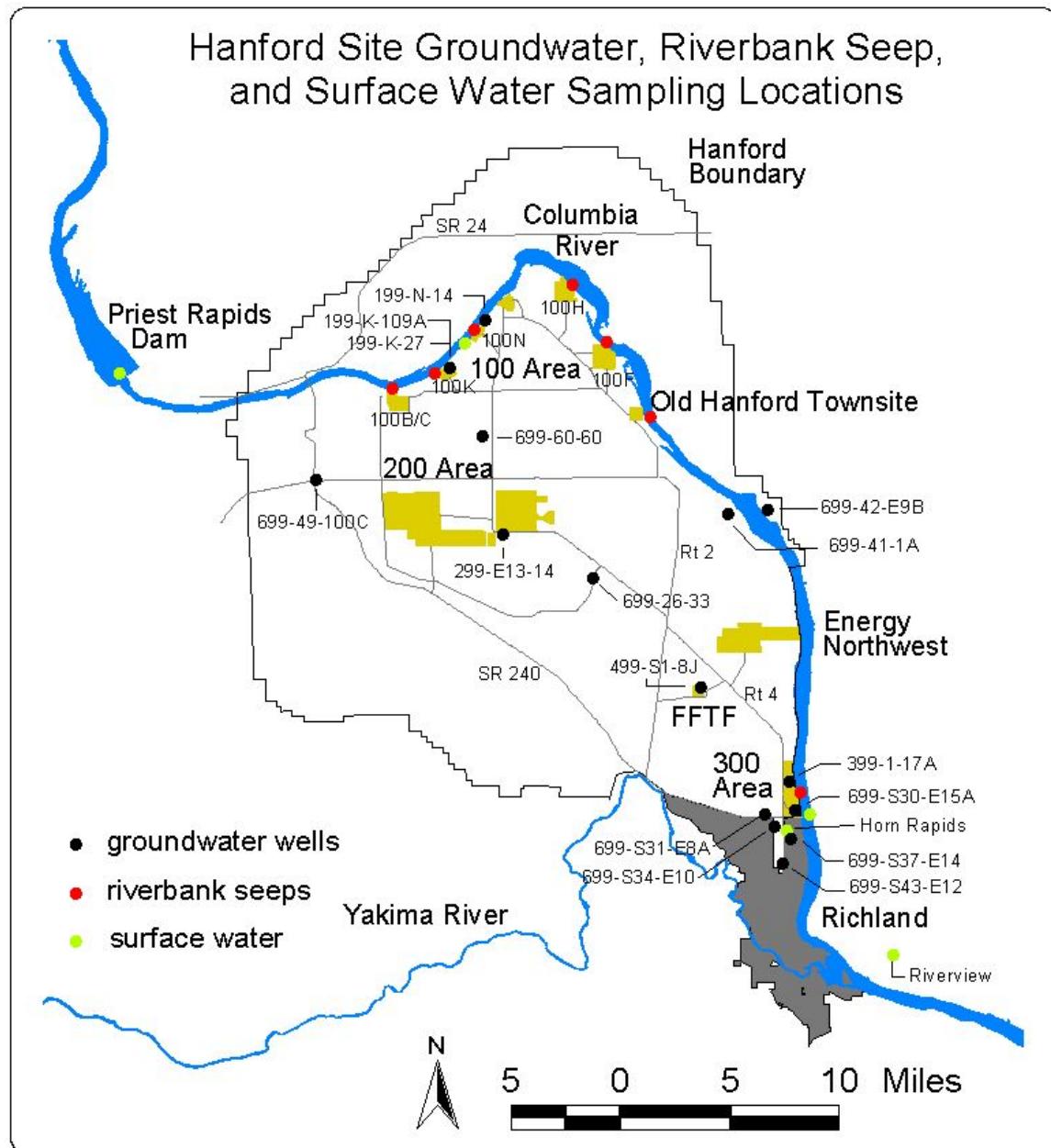


Figure 3.2.1 Water Monitoring Locations

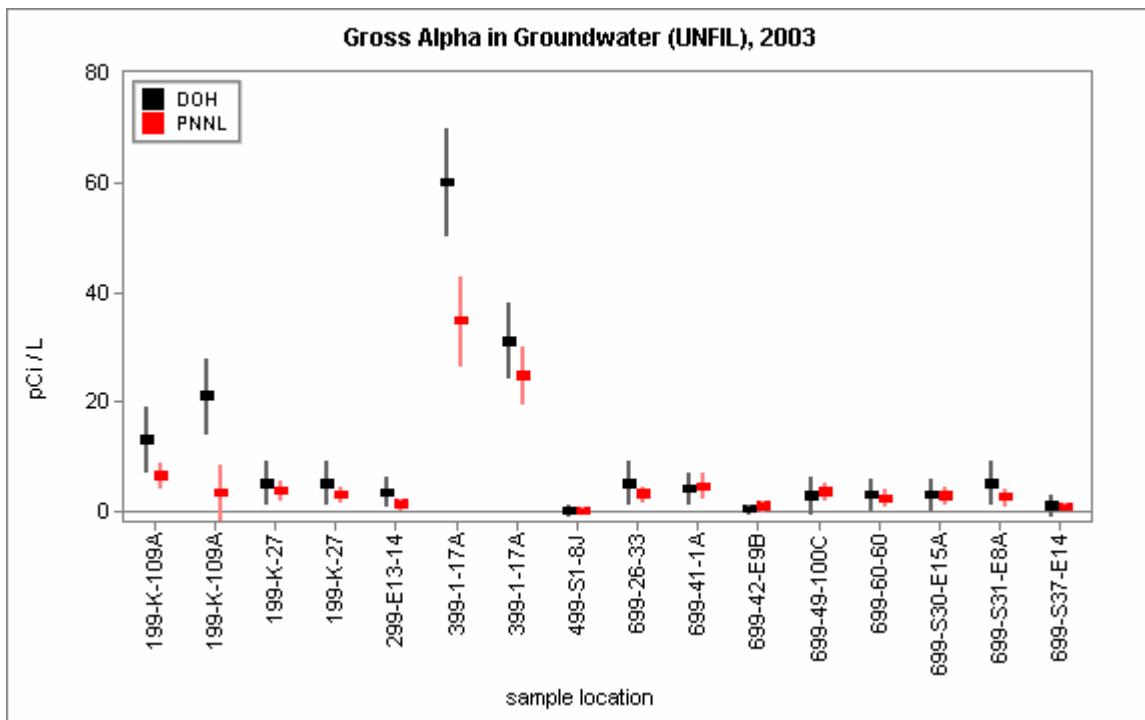


Figure 3.2.2 DOH and PNNL Gross Alpha Concentrations in Groundwater

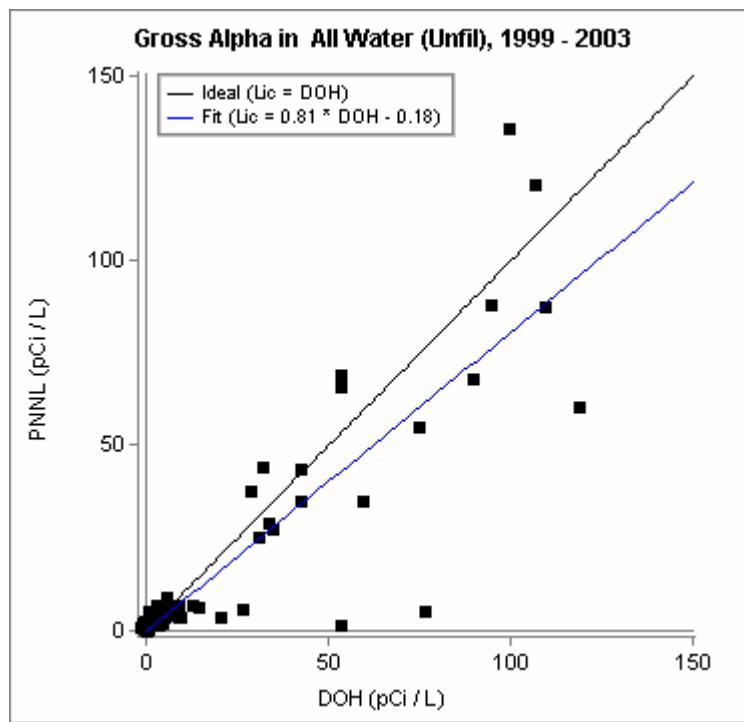


Figure 3.2.3 DOH / PNNL Scatter Plot for Historical Gross Alpha Concentrations in Water

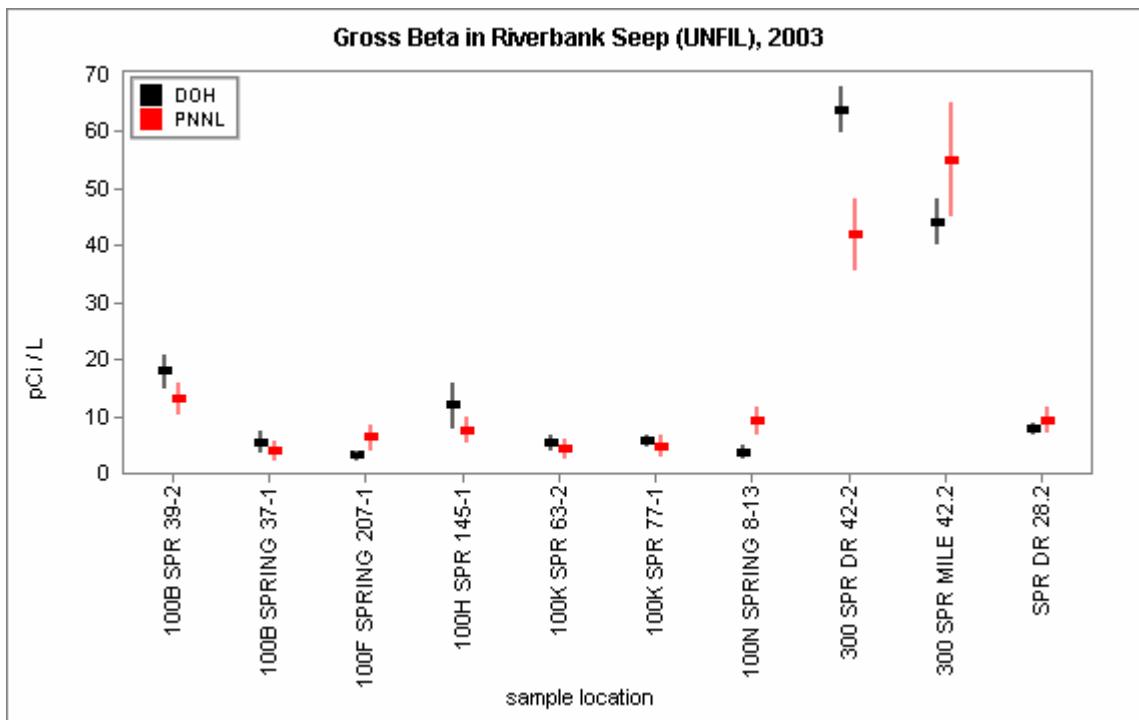


Figure 3.2.4 DOH and PNNL Gross Beta Concentrations in Riverbank Seep Water

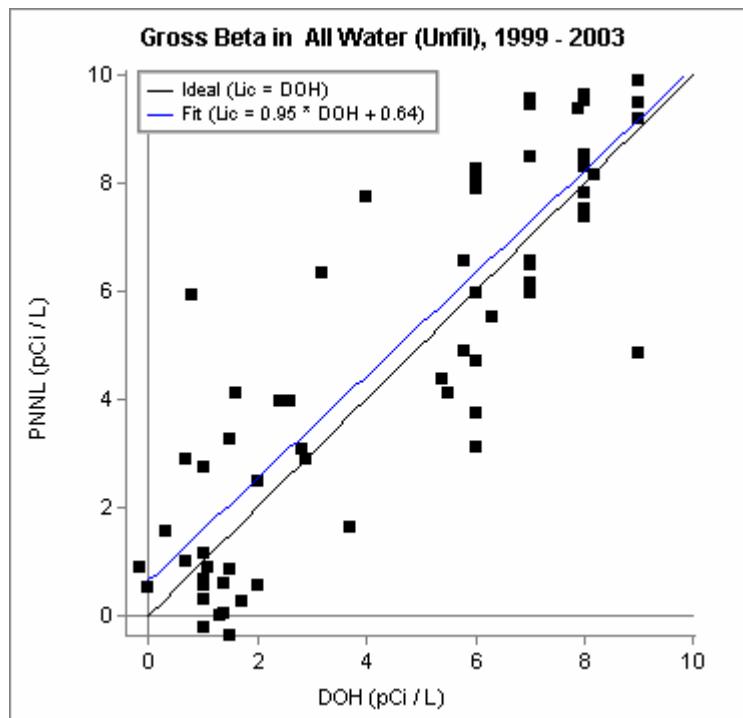


Figure 3.2.5 DOH / PNNL Scatter Plot for Historical Gross Beta Concentrations between 0 and 10 pCi/L in All Water Samples

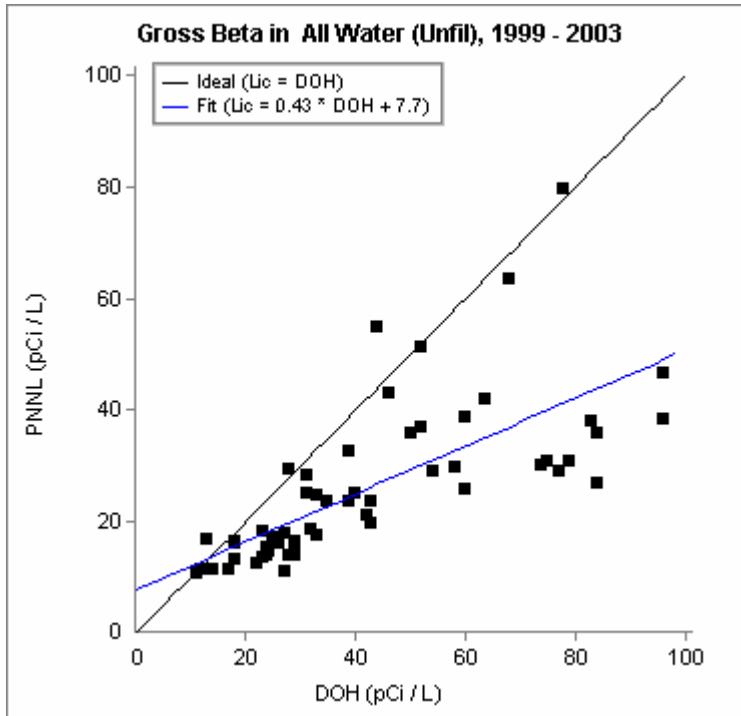


Figure 3.2.6 DOH / PNNL Scatter Plot for Historical Gross Beta Concentrations between 10 and 100 pCi/L in All Water Samples

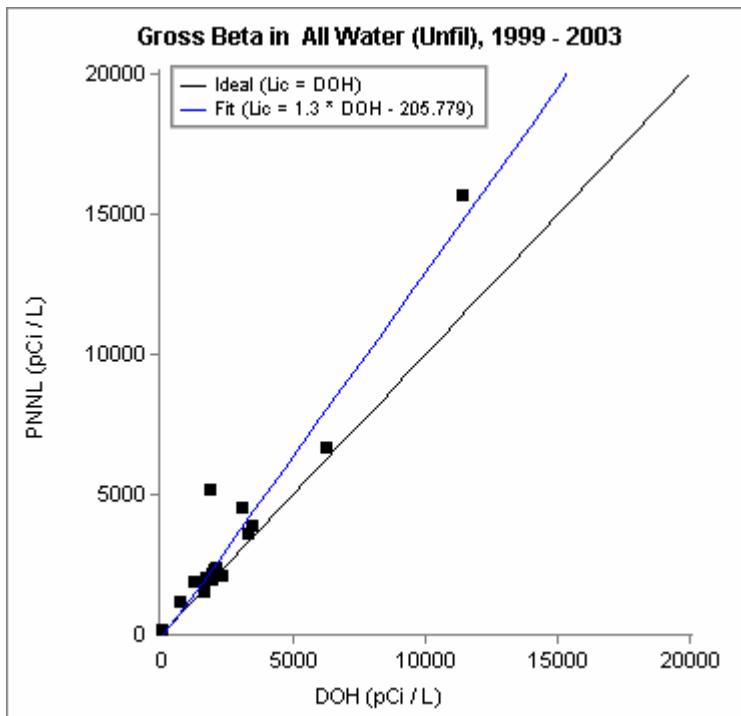


Figure 3.2.7 DOH / PNNL Scatter Plot for Historical Gross Beta Concentrations above 100 pCi/L in All Water Samples

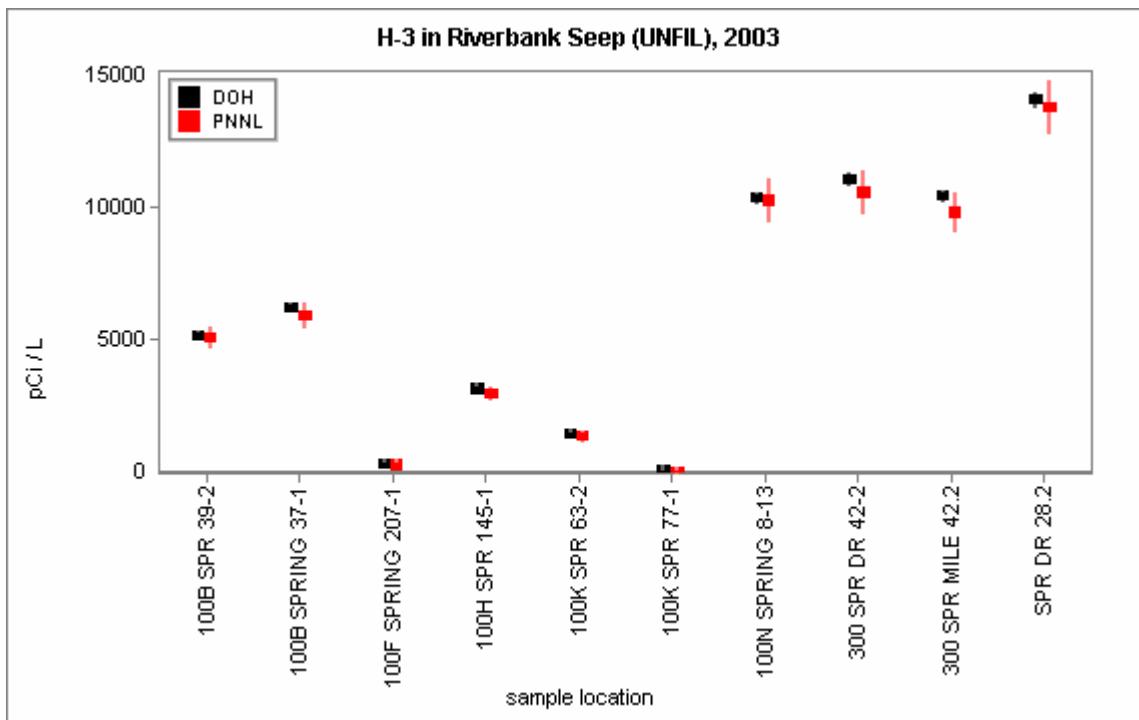


Figure 3.2.8 DOH and PNNL H-3 Concentrations in Riverbank Seep Water

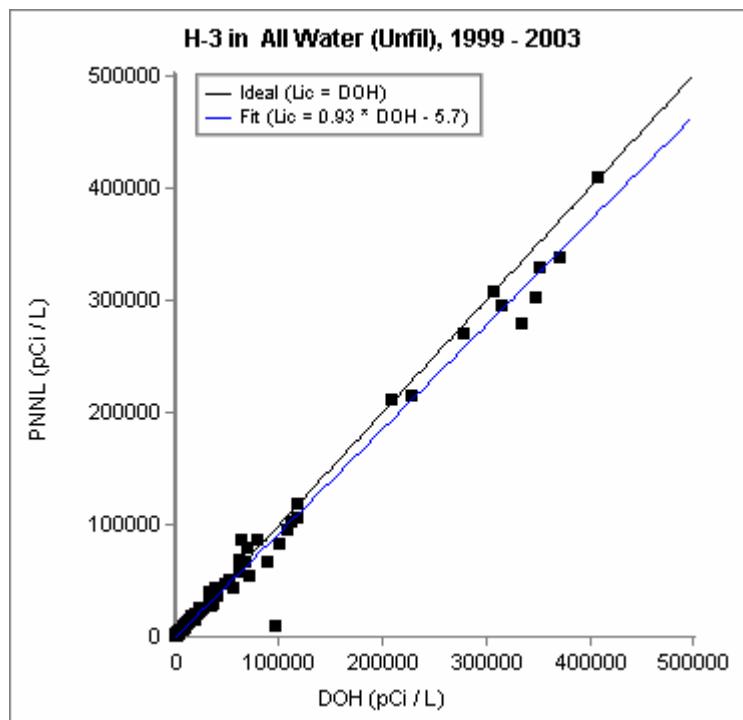


Figure 3.2.9 DOH and PNNL Scatter Plot for Historical H-3 Concentrations in Water

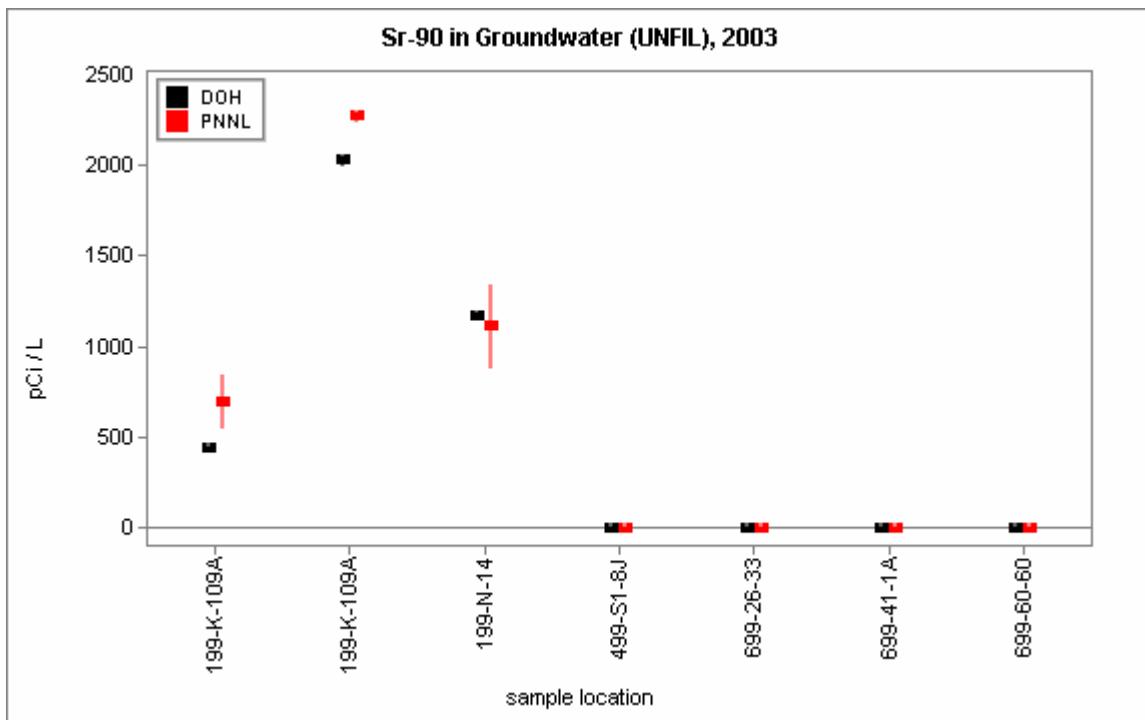


Figure 3.2.10 DOH and PNNL Sr-90 Concentrations in Groundwater

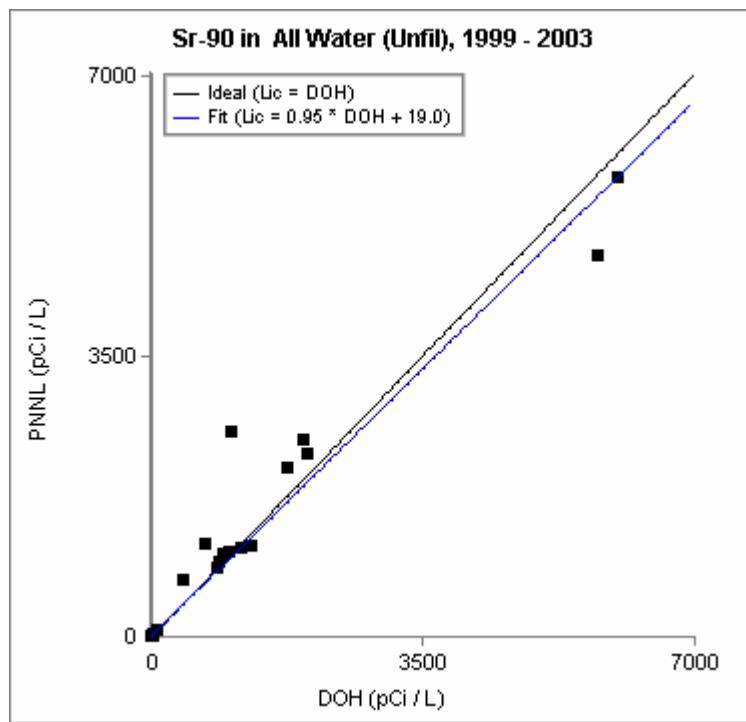


Figure 3.2.11 DOH and PNNL Scatter Plot for Historical Sr-90 Concentrations in Water

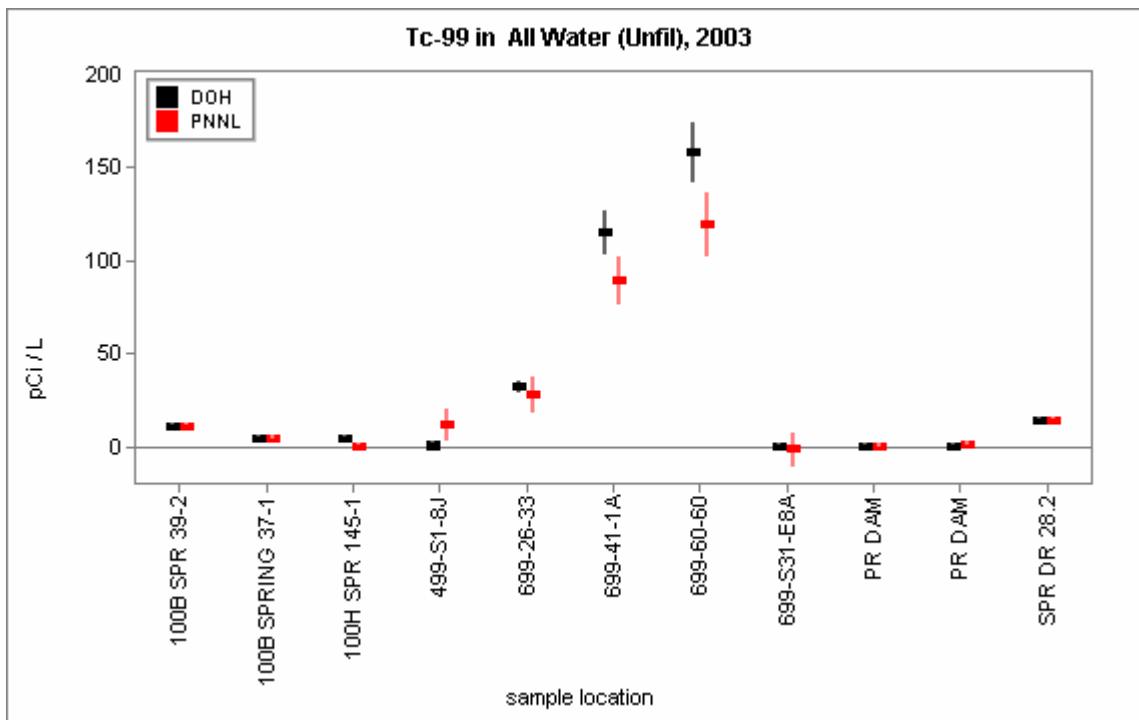


Figure 3.2.12 DOH and PNNL Tc-99 Concentrations in All Water Samples

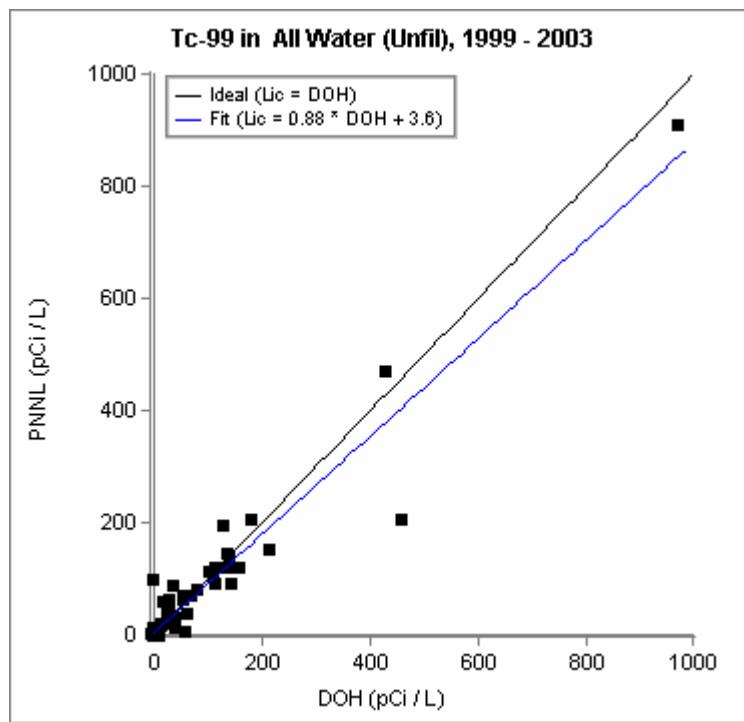


Figure 3.2.13 DOH and PNNL Scatter Plot for Historical Tc-99 Concentrations in Water

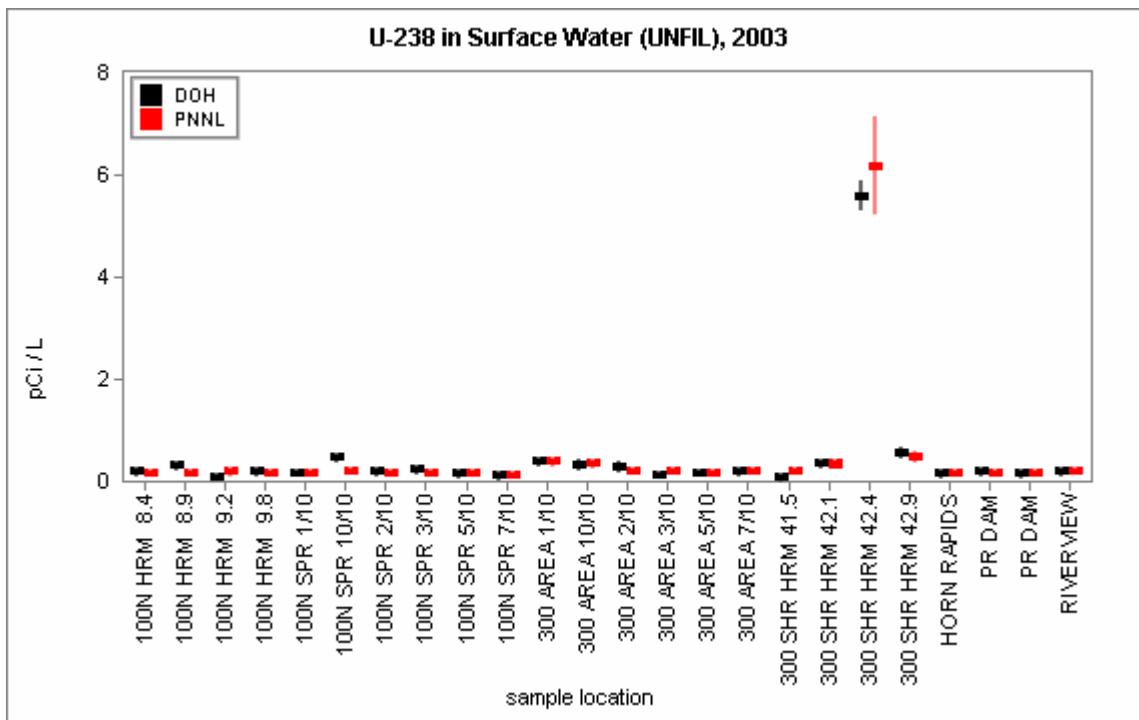


Figure 3.2.14 DOH and PNNL U-238 Concentrations in Surface Water

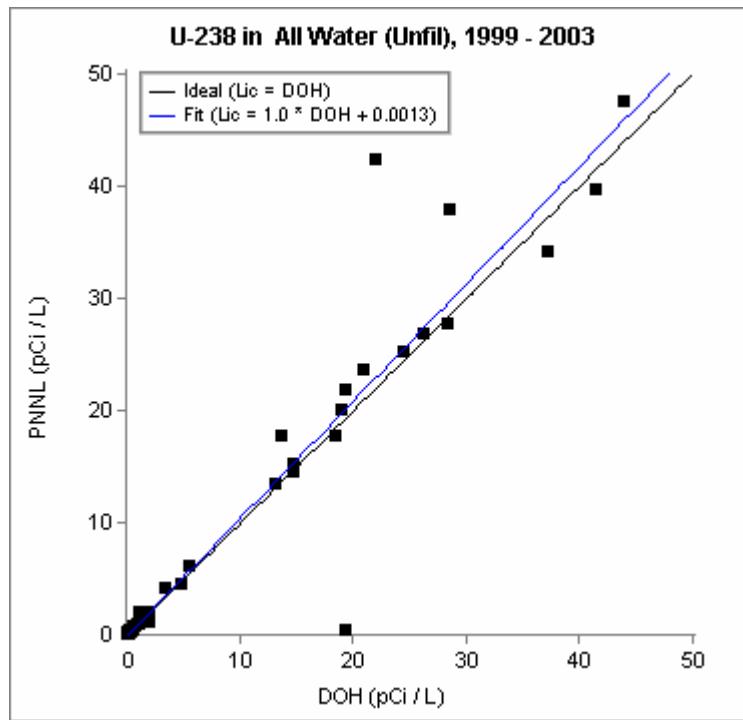


Figure 3.2.15 DOH and PNNL Scatter Plot for Historical U-238 Concentrations in Water

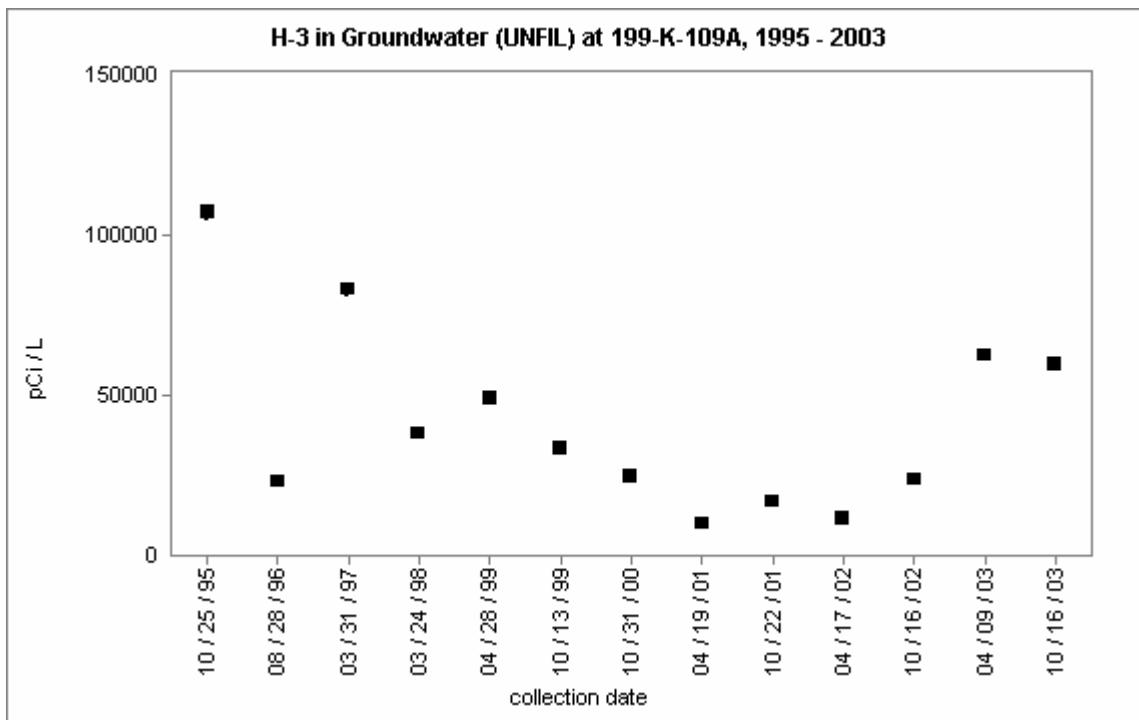


Figure 3.2.16 DOH Historical H-3 Concentrations at Groundwater Well 199-K-109A

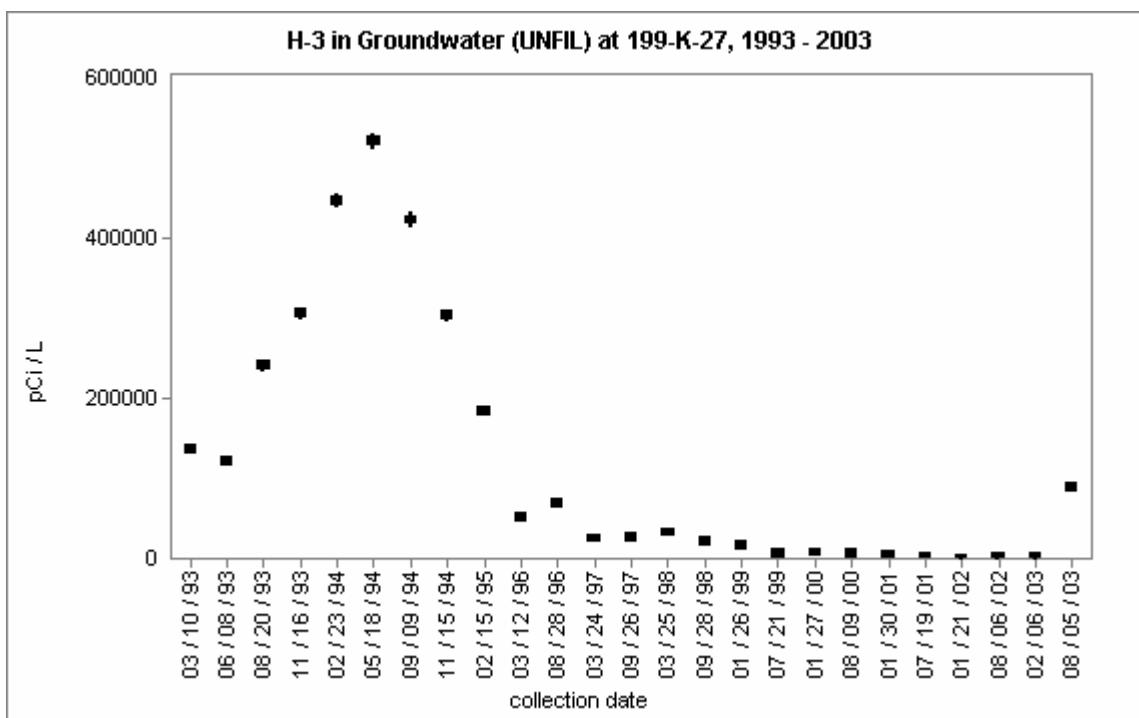


Figure 3.2.17 DOH Historical H-3 Concentrations at Groundwater Well 199-K-27

3.3 External Gamma Radiation Monitoring

Major Findings:

- The DOH and DOE contractor results are in good agreement.
- Radiation exposure rates at DOH TLD locations on the Hanford Site range from background to 1.5 times higher than exposure rates at perimeter and distant locations.
- The portion of exposure rate that is above background is below regulatory limits at all DOH TLD locations.

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 may contribute to man-made sources of gamma radiation. In addition to oversight of the DOE monitoring program, DOH compares onsite and offsite TLD results to determine if Hanford is impacting workers or the public.

3.3.2 Monitoring Locations

In 2003, DOH operated 24 ambient gamma radiation monitoring sites under the Hanford Environmental Oversight Program, five of which are co-located with Duratek, and 19 of which are co-located with PNNL. The site locations are shown in Figure 3.3.1. Thirteen of the TLD sites are located near Hanford operational or contaminated facilities. Three sites (Yakima and Wye Barricades, and Ligo Facility) are located on the Hanford Site, but away from contaminated areas. Five of the sites (Stations 4, 6, and 8; Byers Landing; and Benton County Shops) are located just outside the Hanford Site perimeter. The remaining three sites (Othello, Toppenish, and Yakima Airport) are significantly 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 five co-located sites are shown in Figure 3.3.2, and the DOH and PNNL TLD results for the 19 co-located sites are shown in Figures 3.3.3 through 3.3.5. Each of these figures show the first, second, third, and fourth quarter results for each site. As can be seen, there is good agreement between the DOH and DOE contractor results, as the two data sets follow the same trends. However, close inspection of the figures indicates that the Duratek and PNNL dose rates are typically slightly higher than those reported by DOH.

Historical (1999-2003) DOH vs. Duratek and DOH vs. PNNL TLD scatter plots for the combined co-located sites are shown in Figures 3.3.6 and 3.3.7, respectively. 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). The scatter plots indicate good agreement between the DOH and DOE contractor data, although these plots also show that the contractor results are slightly higher (about 10%) than those reported by DOH. This discrepancy is small, and is not considered significant.

3.3.5 Discussion of DOH Results

The average of the quarterly external radiation exposure rates at each location on the Hanford Site near contaminated or impacted areas ranged from 0.19 to 0.29 mR/day. The average of the quarterly exposure rates for all the perimeter locations was 0.23 mR/day, and for all the distant locations was 0.19 mR/day. The exposure rates at the distant locations are slightly lower than the perimeter locations, most likely due to different concentrations of naturally occurring radioactivity at the distant locations.

The highest exposure rate of 0.3 mR/day, measured at 100N-1, is slightly higher than the average perimeter exposure rate of 0.23 mR/day. A person spending 365 days at one of these locations would receive 26 mR greater than the annual exposure at the Site perimeter. An exposure rate of 26 mR/year, or approximately 26 mrem/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. There is no public access to these locations on the Hanford Site.

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 3.3.8. Exposure rates at this site have decreased over the past decade, in part due to the decay of Co-60 (half life = 5 years) surface contamination at 100N Area.

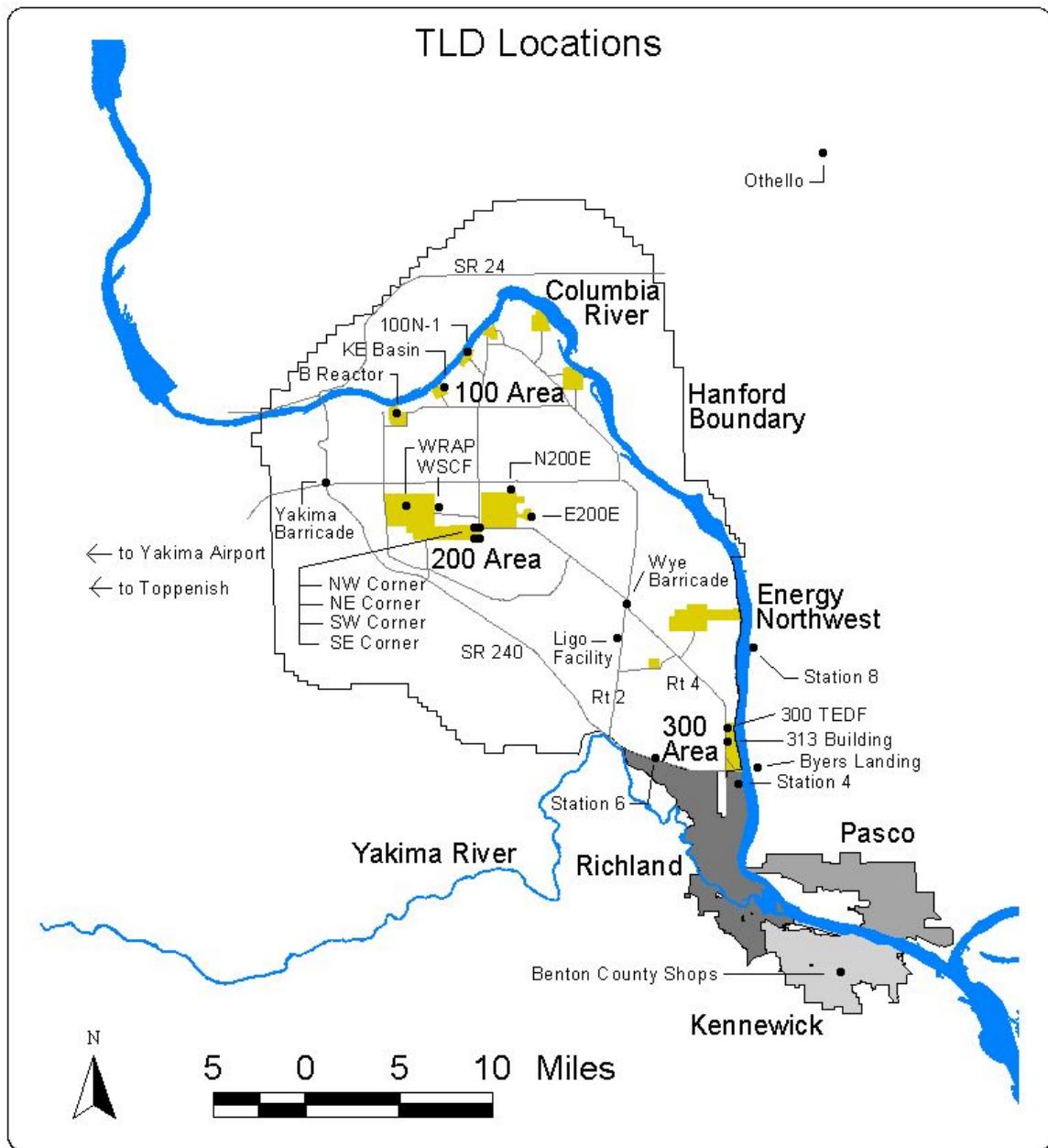


Figure 3.3.1 External Radiation Monitoring (TLD) Locations

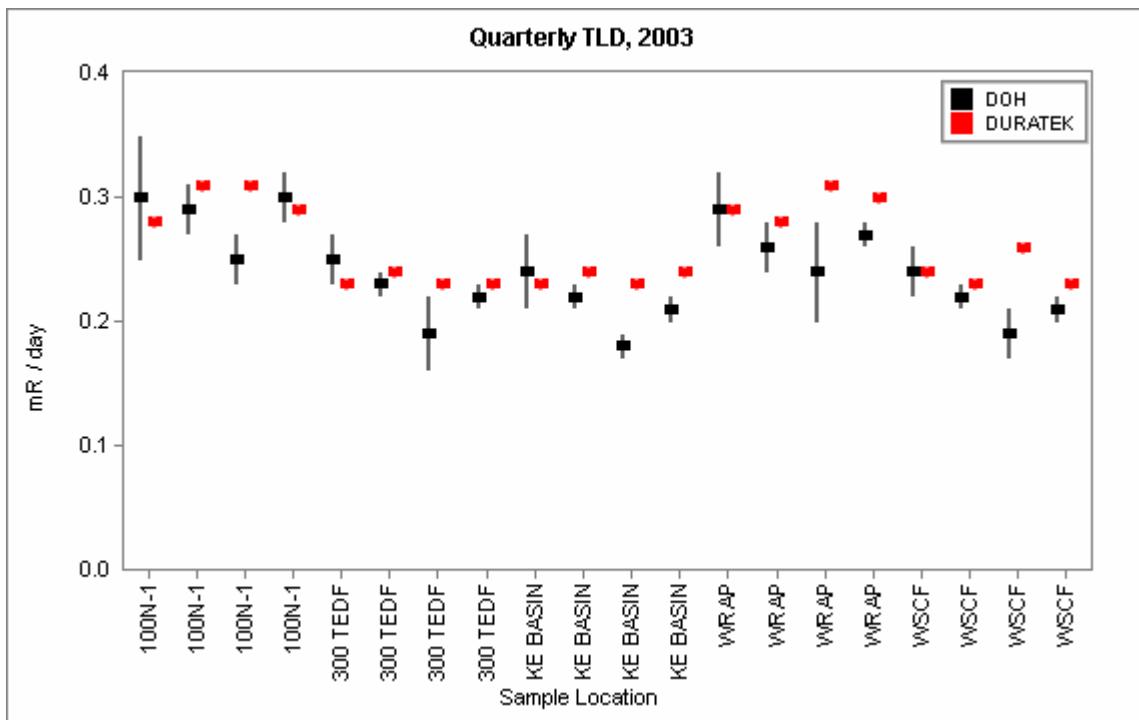


Figure 3.3.2 DOH and Duratek Quarterly TLD Results

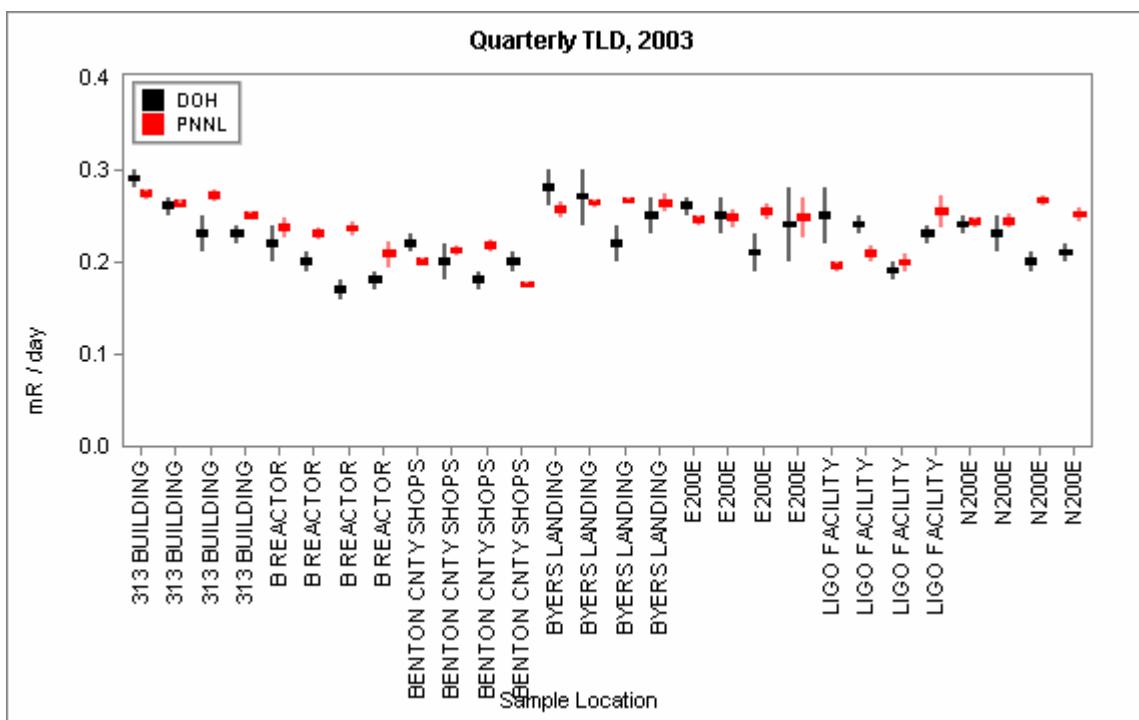


Figure 3.3.3 DOH and PNNL Quarterly TLD Results (Chart 1)

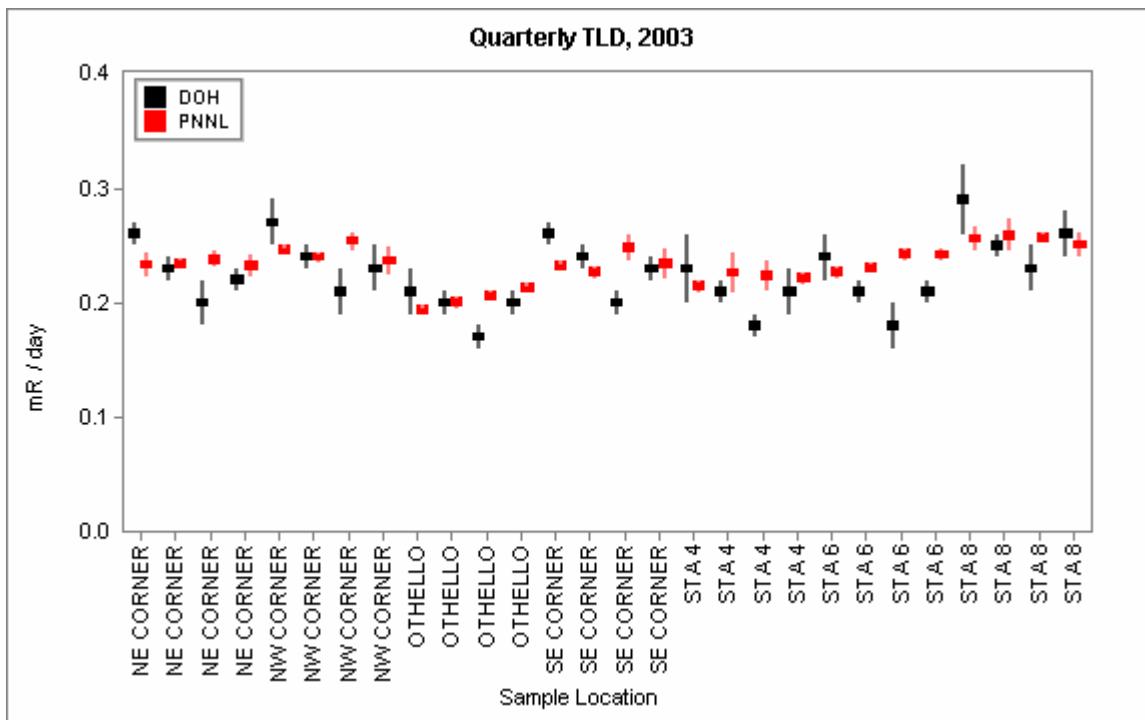


Figure 3.3.4 DOH and PNNL Quarterly TLD Results (Chart 2)

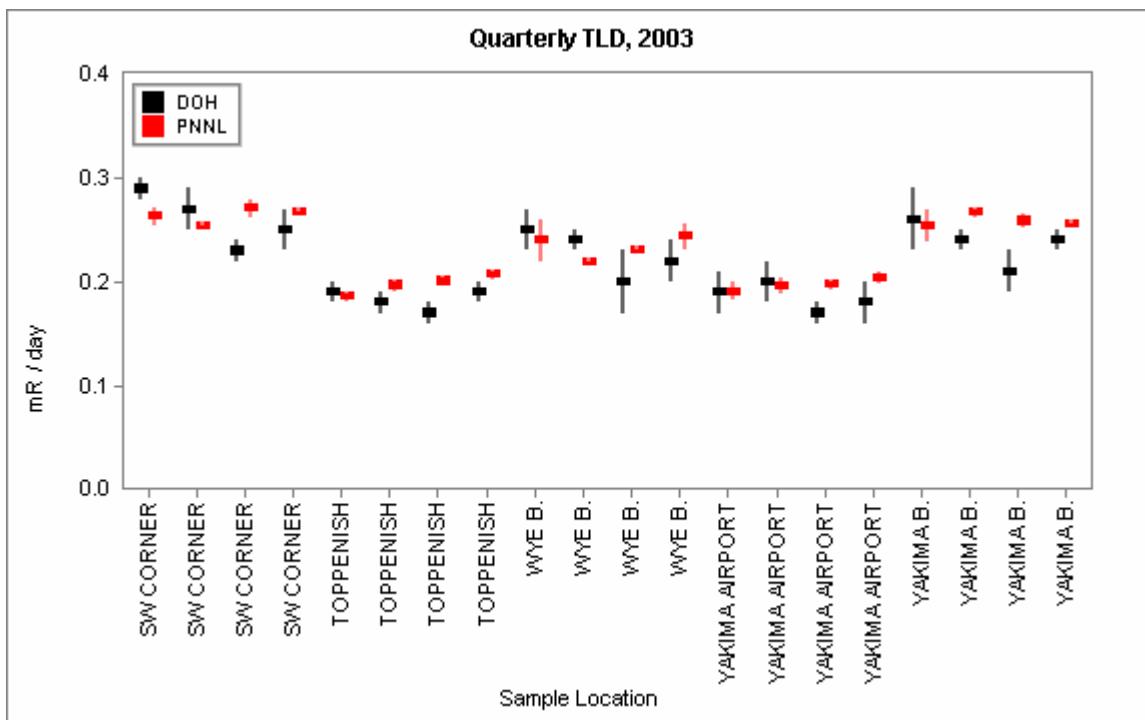


Figure 3.3.5 DOH and PNNL Quarterly TLD Results (Chart 3)

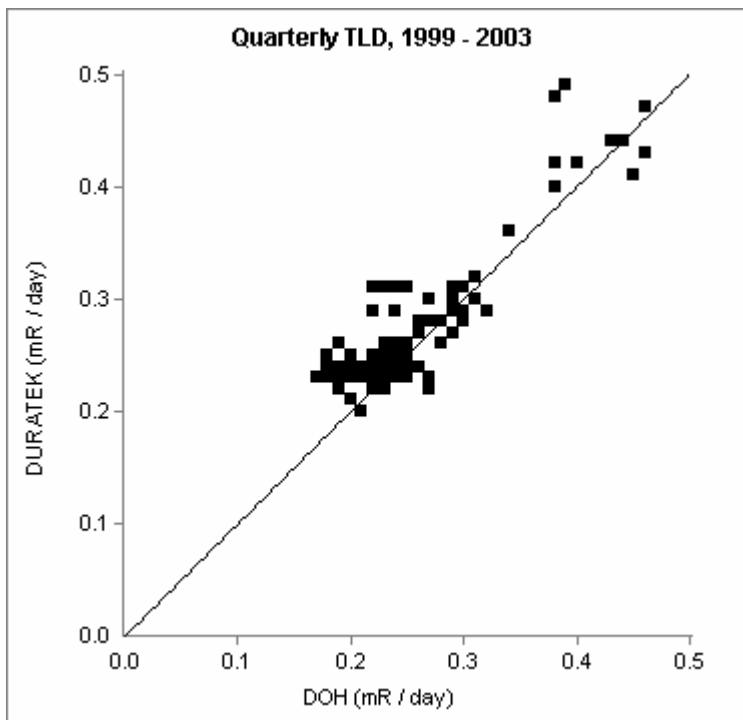


Figure 3.3.6 DOH vs. Duratek Scatter Plot for Historical TLD Results

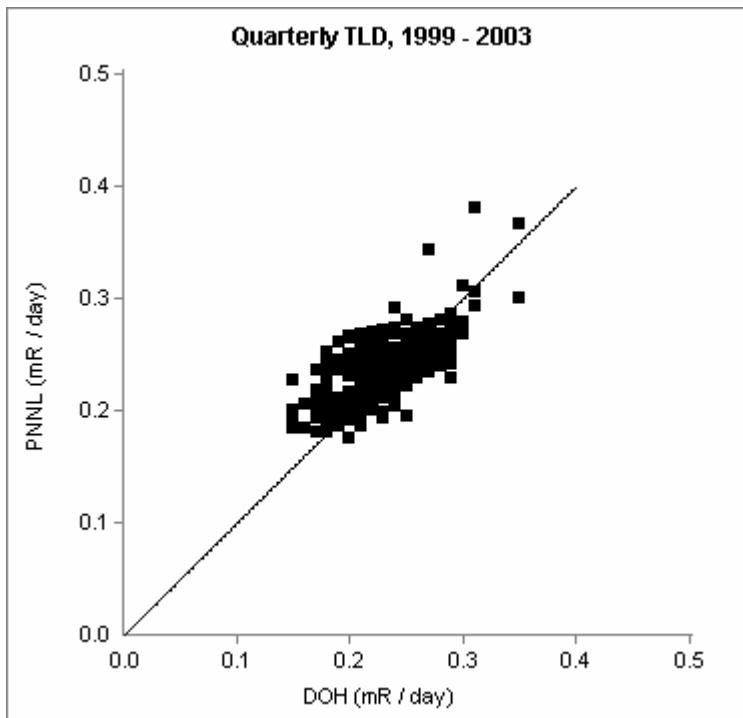


Figure 3.3.7 DOH vs. PNNL Scatter Plot for Historical TLD Results

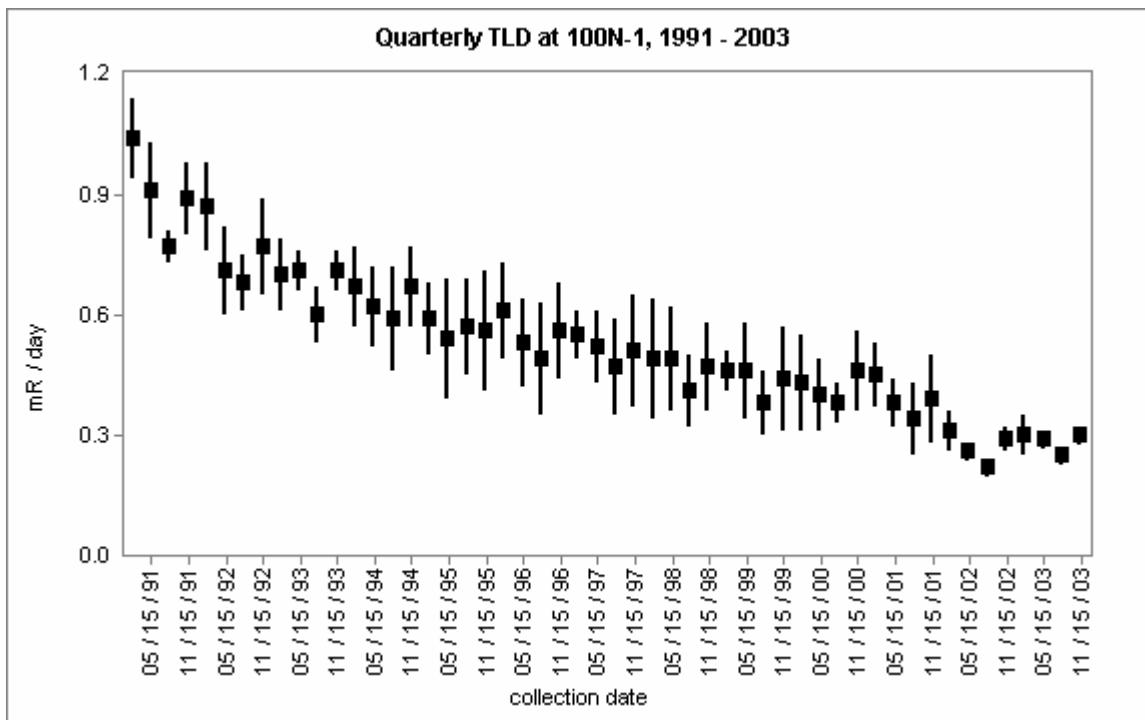


Figure 3.3.8 Historical DOH TLD Results at Location 100N-1 in the 100N Area

3.4 Sediment Monitoring

Major Findings:

- DOH and PNNL results in 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 in most sediment samples are either consistent with those at the upstream background location or are in the range of activity that is typically observed at Hanford.
- A sediment sample from Hanford's 100H Area contained an anomalously high Cs-137 result as well as an unexpected positive result for Am-241.

3.4.1 Purpose and General Discussion

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

Radionuclides in soil and sediment originate from many sources including natural terrestrial sources, atmospheric fallout from nuclear weapons tests, and contaminated liquid and gaseous effluents. In addition, contaminants can reach Columbia River sediments from erosion of contaminated soil and flow of contaminated groundwater. Cesium-137, Sr-90, and plutonium isotopes are radionuclides consistently seen in soil or sediments 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.

In 2003, DOH split Columbia River sediment samples with PNNL. No split soil samples were collected in 2003. PNNL monitors Columbia River sediments to evaluate Hanford's impact on the environment. DOH splits sediment samples with PNNL to provide oversight of the DOE monitoring program.

3.4.2 Monitoring Locations

A total of 24 Columbia River sediment samples were split with PNNL. These samples were collected from seven general areas, which include Priest Rapids Dam located upstream of the Hanford Site; the 100 Area and 300 Area along the Hanford Reach; and McNary Dam, John Day Dam, The Dalles Dam, and Bonneville Dam, all located downstream of the Hanford Site.

Priest Rapids Dam, being upstream from Hanford, is considered a background location. McNary Dam is the first dam downstream from Hanford, and therefore is expected to have the highest radionuclide concentrations. Sediment locations within the Hanford boundary change from year to year and are chosen to monitor areas where contaminants may be discharged into the river, areas where deposits could accumulate, or areas where the public may gain access to the shoreline. In 2003, sediment samples were collected from the 100B, 100F, 100H, 100K, and 300 Areas. Sediment sample site locations are shown in Figure 3.4.1.

3.4.3 Monitoring Procedures

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 Contractor Data

Most of the DOH and PNNL split sediment results for Co-60, Cs-137, Eu-152, Pu-238, Pu-239/240, and Sr-90 are in good agreement. One of the Cs-137 results, from the sample collected at 100H Area, is in disagreement. The DOH result is five times higher than the concentration reported by PNNL (Figure 3.4.2). A few of the Pu-239/240 results show a small disagreement, as can be seen in Figure 3.4.3. In addition, DOH detected Am-241 in the sediment sample from the 100H Area, while PNNL did not report a concentration for this radionuclide.

The DOH and PNNL split sediment results for isotopes of uranium are in poor agreement. The U-238 results for 2003 are shown in Figure 3.4.4. In addition, the historical U-238 results (1999 through 2003) are shown in a scatter plot in Figure 3.4.5. 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). The slope of the best-fit straight line to the data indicates that on average, the PNNL U-238 concentrations are approximately one-half the concentration reported by DOH.

This discrepancy in uranium results for sediment originates from different laboratory procedures. DOH completely dissolves soil and sediment samples prior to analysis and reports uranium present in the entire sample, whereas the contractor laboratory reports only the uranium that can be leached from the surface of the soil or sediment granules. A similar discrepancy is seen in the U-235 and U-234 soil results (not shown).

3.4.5 Discussion of DOH Results

DOH collected several additional sediment samples beyond those split with PNNL. The results from these additional samples, along with the DOH results from the split samples, are discussed in this section.

Radionuclides consistently identified by DOH in sediment samples collected in 2003 include Cs-137, U-234, U-235, and U-238. Uranium-233 (lower limit of detection approximately 0.1 pCi/g), was not detected in any of the sediment samples. The Cs-137 results are attributed to world-wide fallout as a result of nuclear weapons testing, and most of the uranium results are attributed to natural background.

Most of the Cs-137 results ranged from 0.1 to 0.5 pCi/g. These concentrations are similar to those measured at the background location at Priest Rapids Dam and are similar to historical results. An anomalous Cs-137 concentration of 1.1 pCi/g was measured from a sample collected at the 100H Area. DOH will collect and analyze a sample from the same location in 2005 to confirm this result.

Concentrations of U-234 and U-238 ranged from 0.5 to 2.3 pCi/g. Most of the concentrations are similar to those measured at the Priest Rapids Dam background location (approximately 1 pCi/g) and are similar to historical results. Uranium concentrations from Hanford's 300 Area sediment samples are slightly higher than background, most likely due to uranium contamination in that area.

Other radionuclides identified in some of the sediment samples include Co-60, Eu-152, Pu-238, Pu-239/240, and Sr-90. Co-60 was detected at the F-Slough near Hanford's 100F Area, and at McNary Dam, John Day Dam, and Dalles Dam. All other results, including those at the Priest Rapids background location, were below the detection limit of 0.02 pCi/g. The DOH Co-60 results in sediment are shown in Figure 3.4.6. The highest concentration of 0.05 pCi/g was measured in a sample from John Day Dam. Cobalt-60 has been historically detected by DOH at F-Slough and McNary Dam. The concentrations measured in 2003 are consistent with historical results at these locations, as seen in Figures 3.4.7 and 3.4.8.

DOH detected Eu-152 in ten sediment samples in 2003, with concentrations ranging from 0.05 to 0.25 pCi/g (see Figure 3.4.9). The concentrations measured in 2003 are similar to historical results. DOH has no data at the Priest Rapids Dam background location. Europium-152 has been historically detected at F-Slough and McNary Dam. The historical results at one of the McNary Dam sample collection locations are shown in Figure 3.4.10.

Plutonium-238 is rarely detected by DOH in sediment samples. However, positive results were detected in 2003 at Dalles and McNary Dams. The highest result, at the Dalles Dam, was 0.02 pCi/g. All other results, including those at the Priest Rapids Dam background location, are below the detection limit of 0.005 pCi/g. The Pu-238 results are shown in Figure 3.4.11. The figure includes the minimum detectable activity (MDA) for each sample. Samples with results below the MDA are considered not detected.

The DOH Pu-239/240 results, including MDAs, are shown in Figure 3.4.12, with concentrations ranging from below the detection limit of 0.004 pCi/g to 0.05 pCi/g at Dalles Dam. Most of the concentrations measured in 2003 are similar to historical results at the Priest Rapids Dam background location and historical results at other common sediment sampling locations. Plutonium-239/240, which is found in the environment from world-wide fallout of nuclear weapons testing, is typically detected at Priest Rapids Dam (upstream of Hanford) and McNary Dam (downstream of Hanford). Historical results at these dams are shown in Figures 3.4.13 and 3.4.14.

The DOH results for Sr-90 in sediment samples are shown in Figure 3.4.15. Strontium-90 was detected in sediments from all of the dams located downstream of Hanford, as well as from the background site at Priest Rapids Dam located upstream of Hanford. The results at the downstream dams are similar to historical results at the upstream dam (average historical Sr-90 concentrations at Priest Rapids Dam of 0.015 pCi/g). Strontium-90, which is found in the environment from world-wide fallout of nuclear weapons testing, is typically detected by DOH at Priest Rapids Dam (upstream of Hanford) and McNary Dam (downstream of Hanford). Concentrations at all other locations were close to the detection limit of 0.005 pCi/g.

The sediment sample from Hanford's 100H Area had an unexpected positive result for Am-241, with a concentration of 0.47 pCi/g. This radionuclide has not been previously detected by DOH in sediment samples. PNNL did not report a concentration for this radionuclide from the split sample.

DOH detected U-236 at a concentration of 0.04 pCi/g in one of the sediment samples collected from the 300 Area, at site 300 SPR DR 42-2. Uranium-236 was also detected in 1995 from a 300 Area sediment sample. Typically, this radionuclide is not detected in Hanford sediment samples.

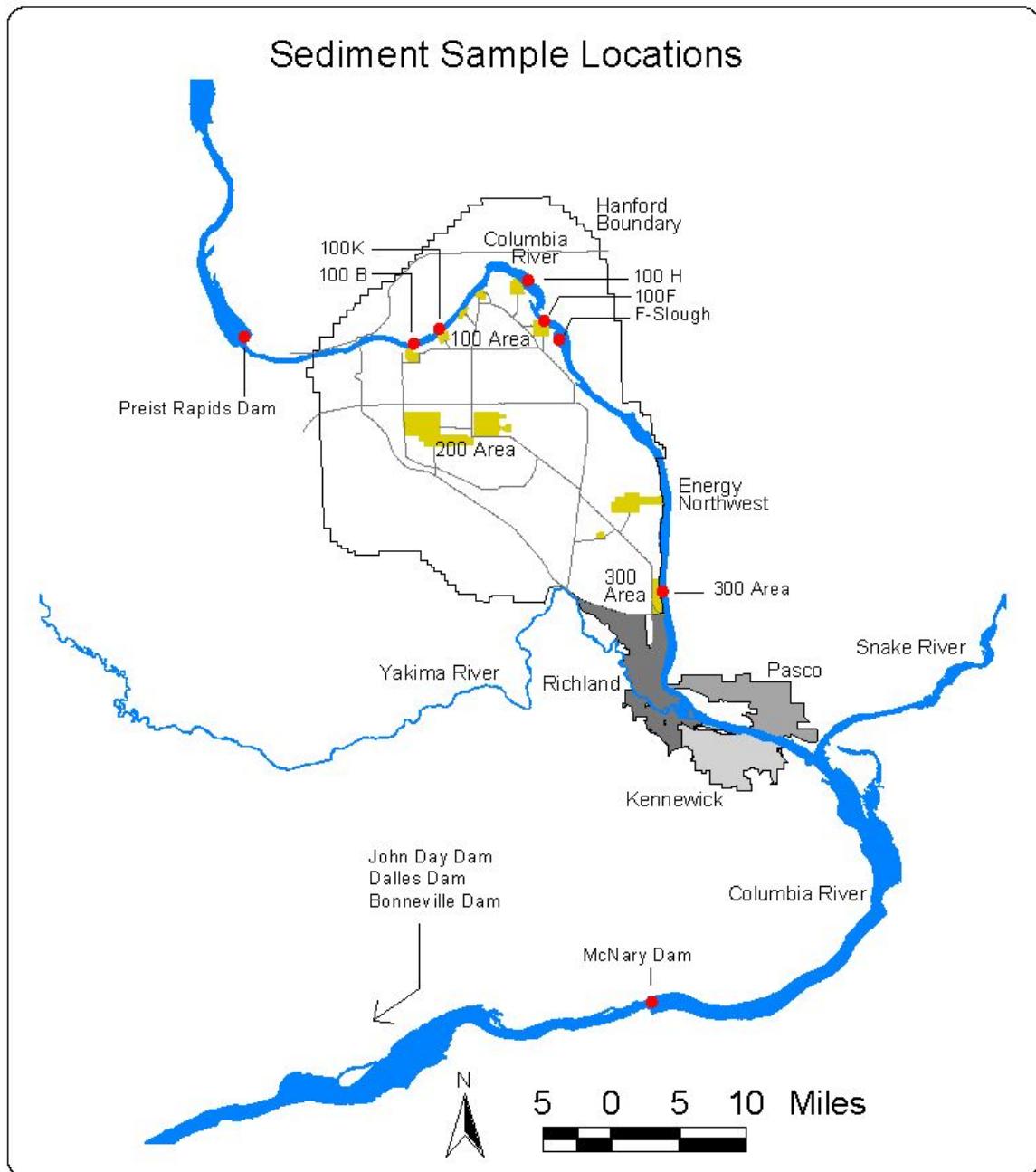


Figure 3.4.1 Sediment Monitoring Locations

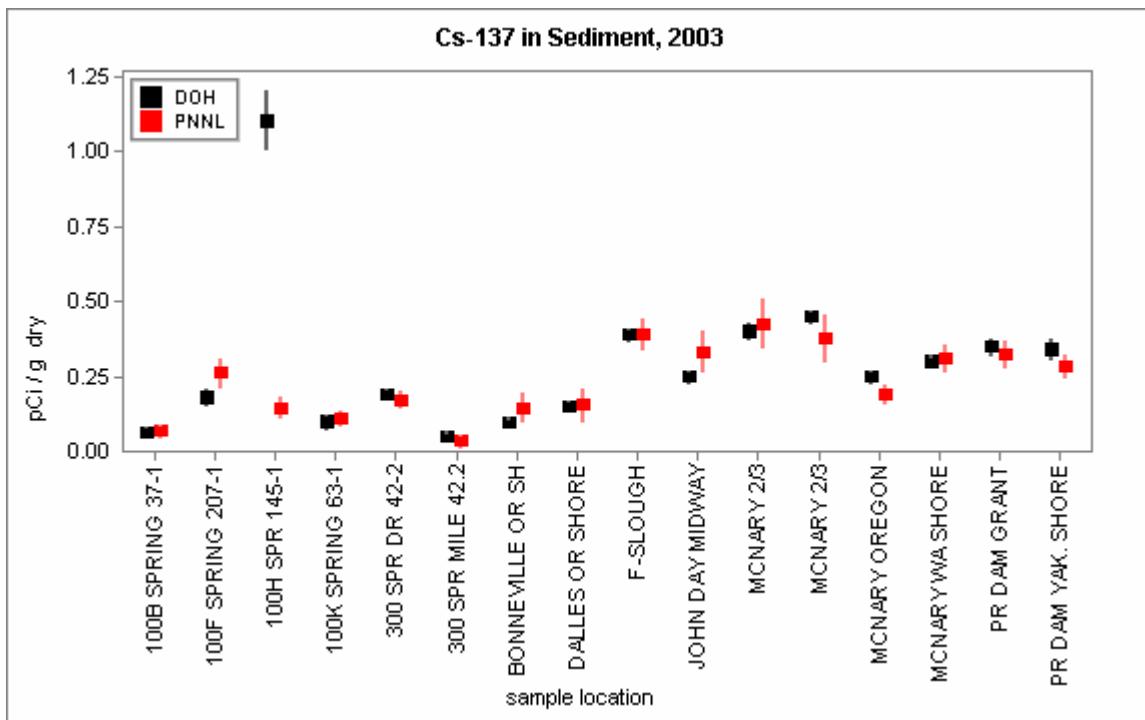


Figure 3.4.2 DOH and PNNL Cs-137 Concentrations in Sediment

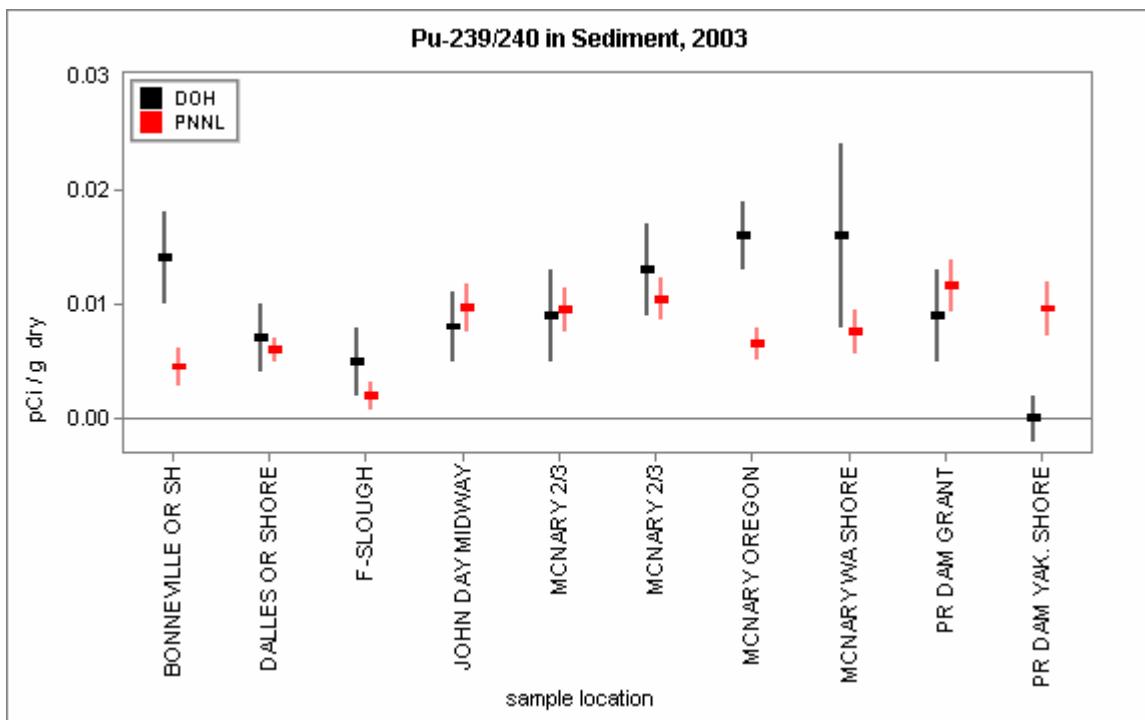


Figure 3.4.3 DOH and PNNL Pu-239/240 Concentrations in Sediment

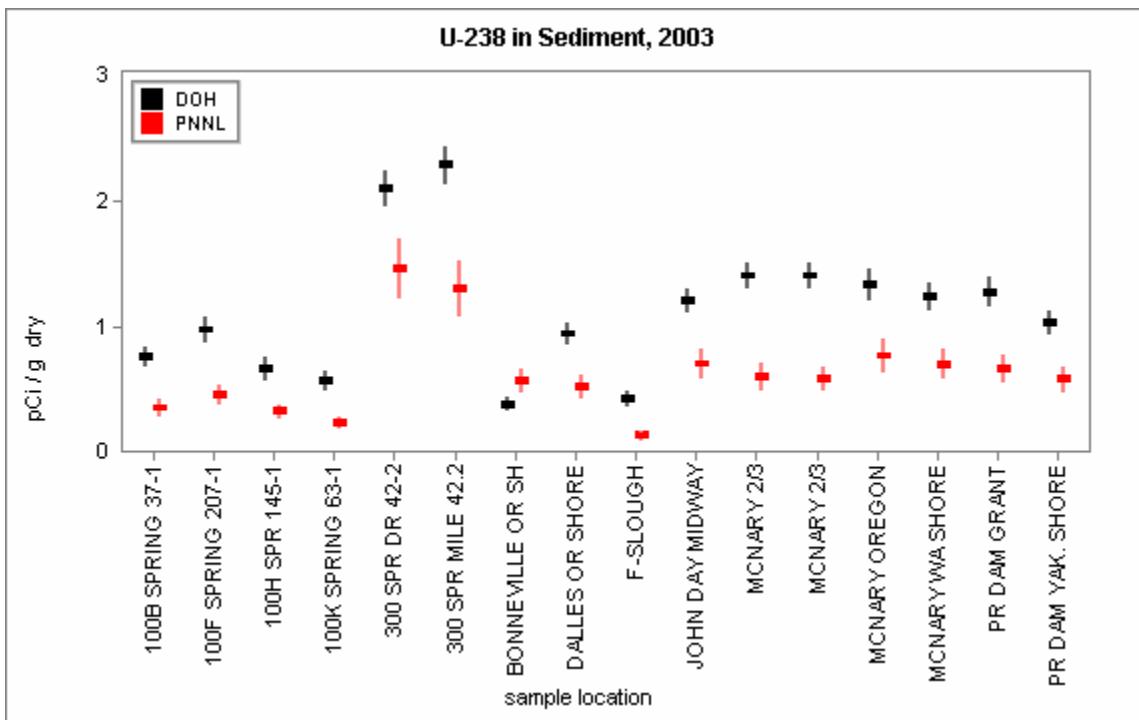


Figure 3.4.4 DOH and PNNL U-238 Concentrations in Sediment

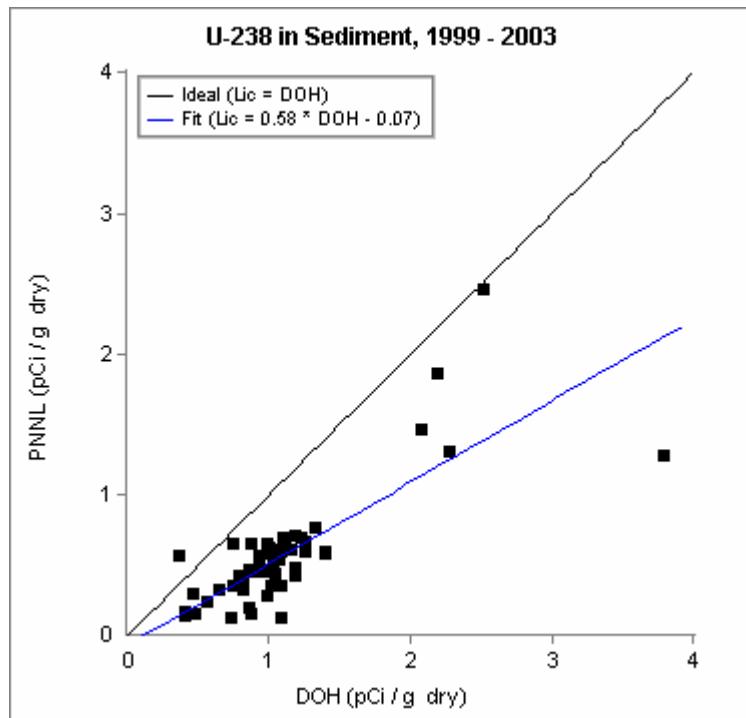


Figure 3.4.5 DOH and PNNL Scatter Plot for Historical U-238 Concentrations in Sediment

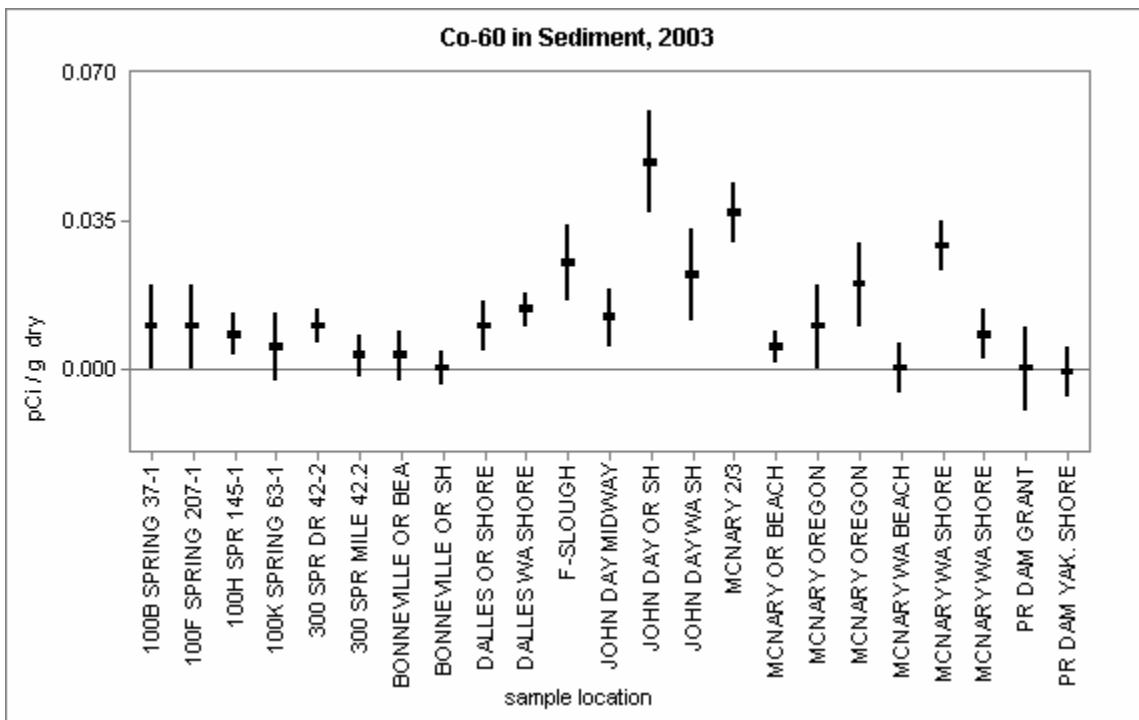


Figure 3.4.6 DOH Co-60 Concentrations in Sediment

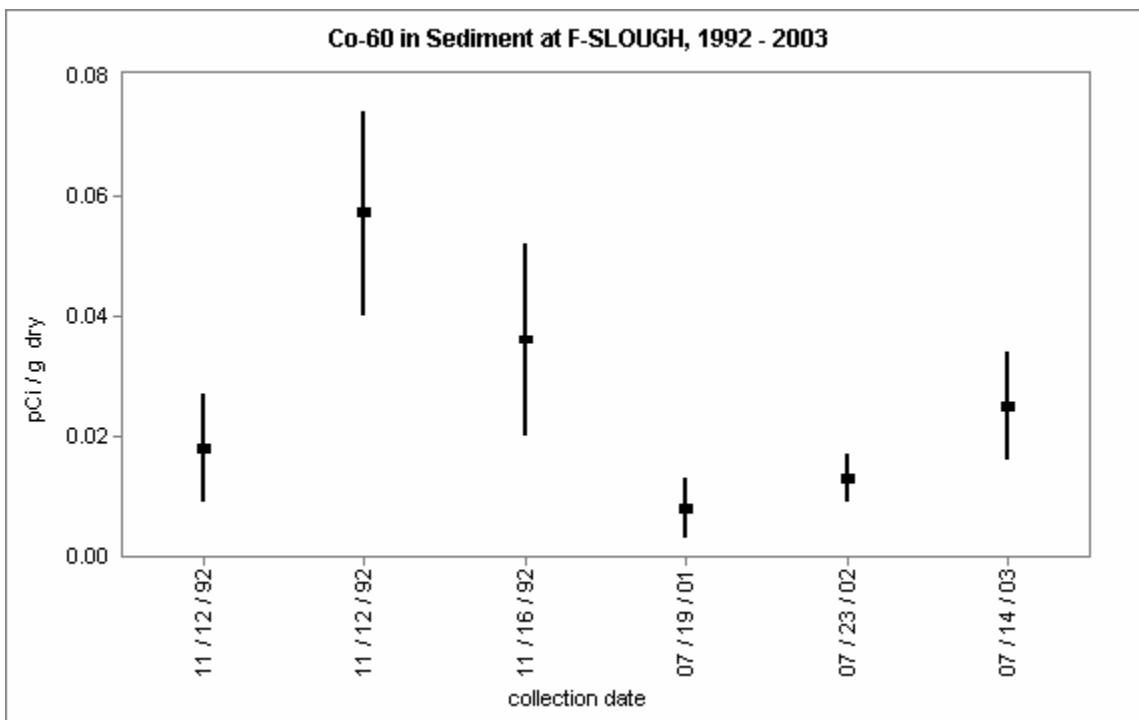


Figure 3.4.7 Historical DOH Co-60 Concentrations in Sediment at F-Slough

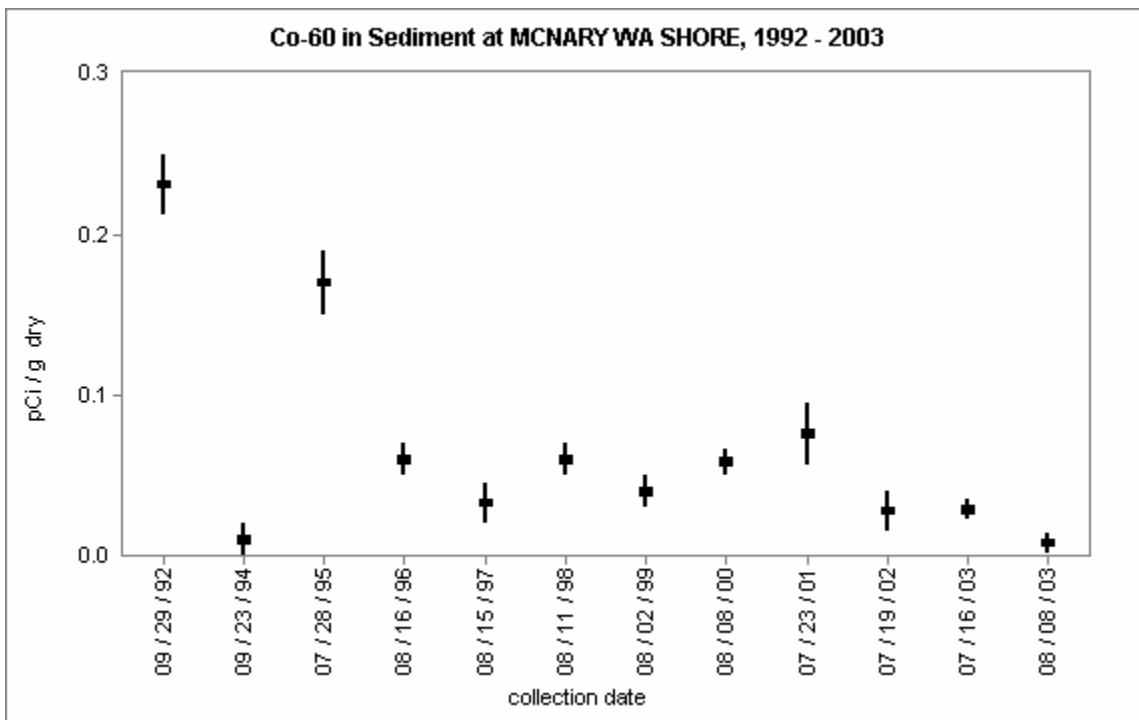


Figure 3.4.8 Historical DOH Co-60 Concentrations in Sediment at McNary Dam

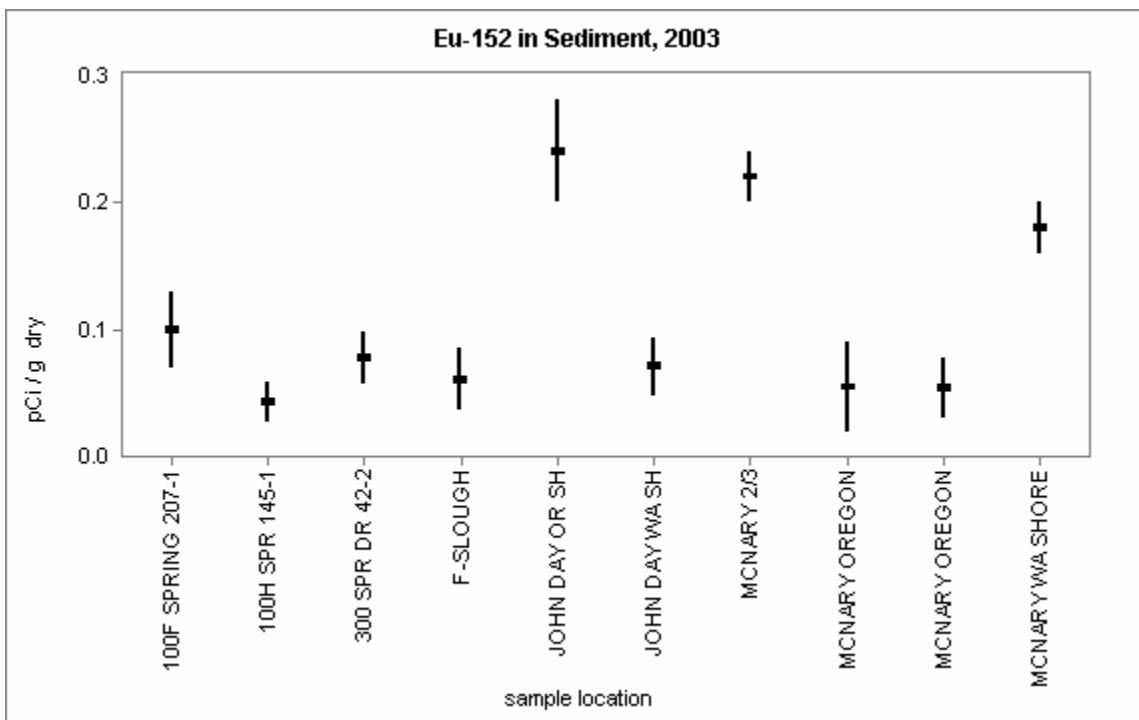


Figure 3.4.9 DOH Eu-152 Concentrations in Sediment

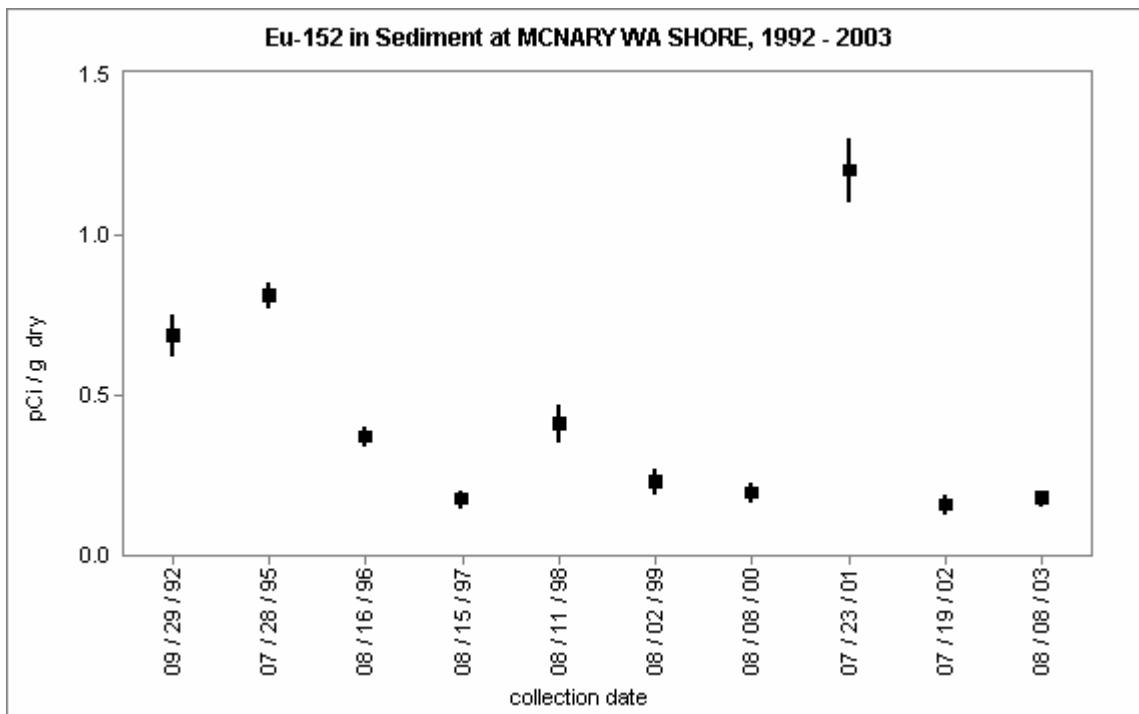


Figure 3.4.10 Historical DOH Eu-152 Concentrations in Sediment at McNary Dam

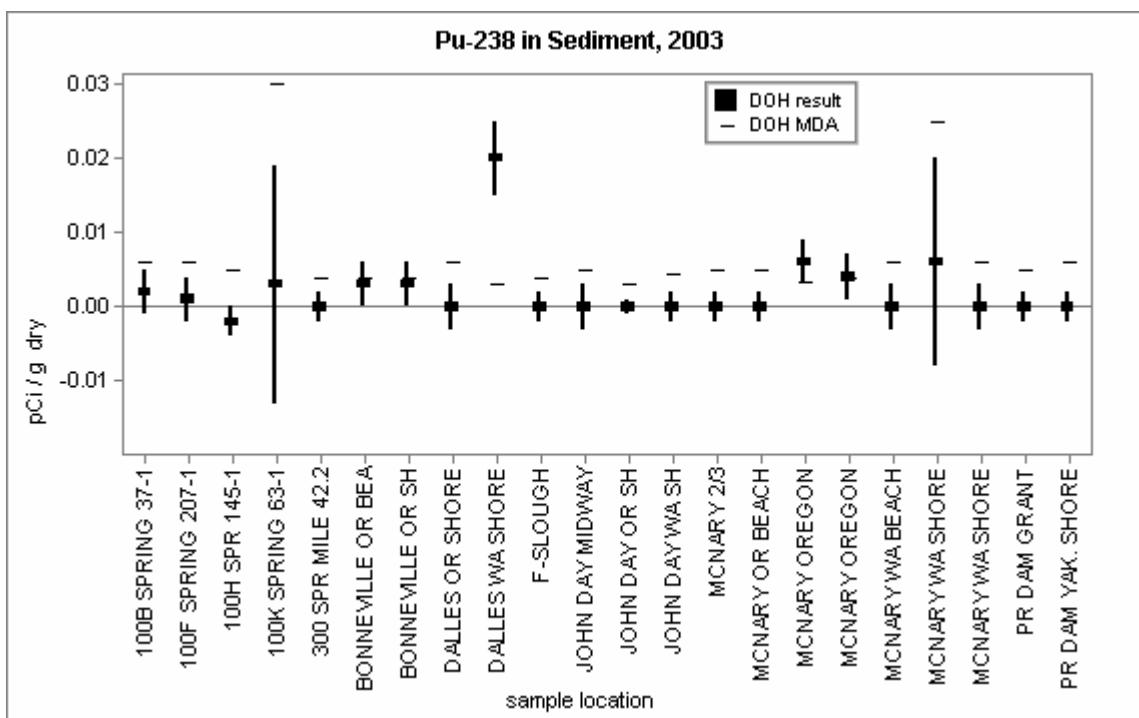


Figure 3.4.11 DOH Pu-238 Concentrations in Sediment

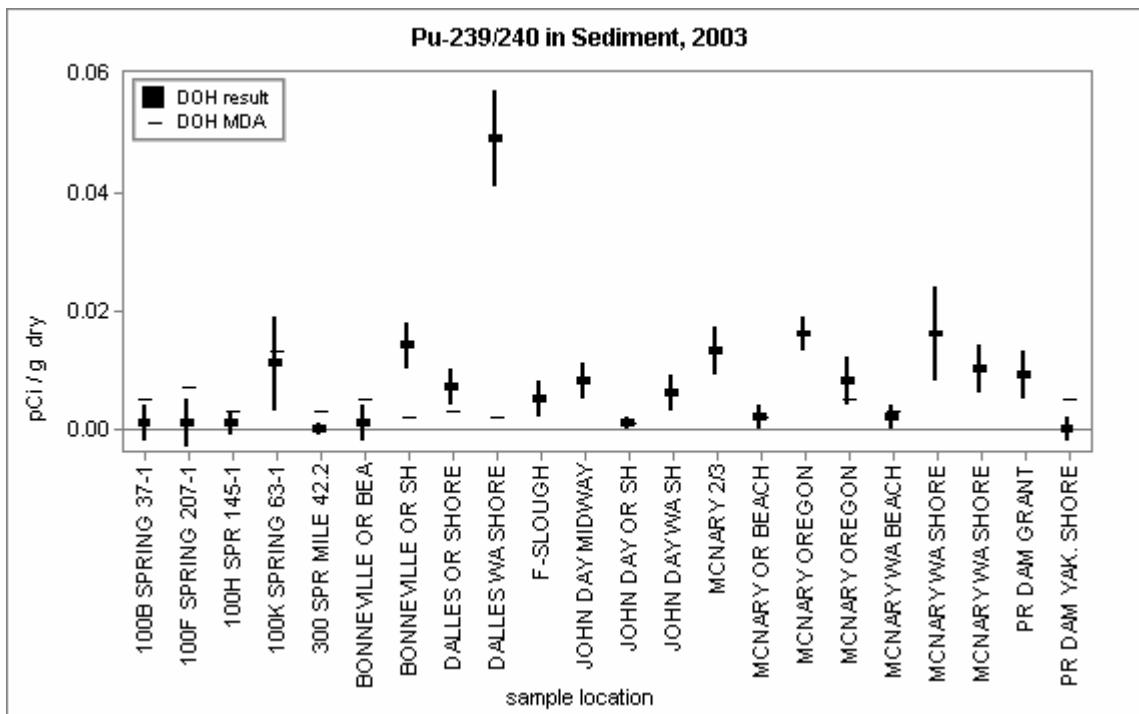


Figure 3.4.12 DOH Pu-239/240 Concentrations in Sediment

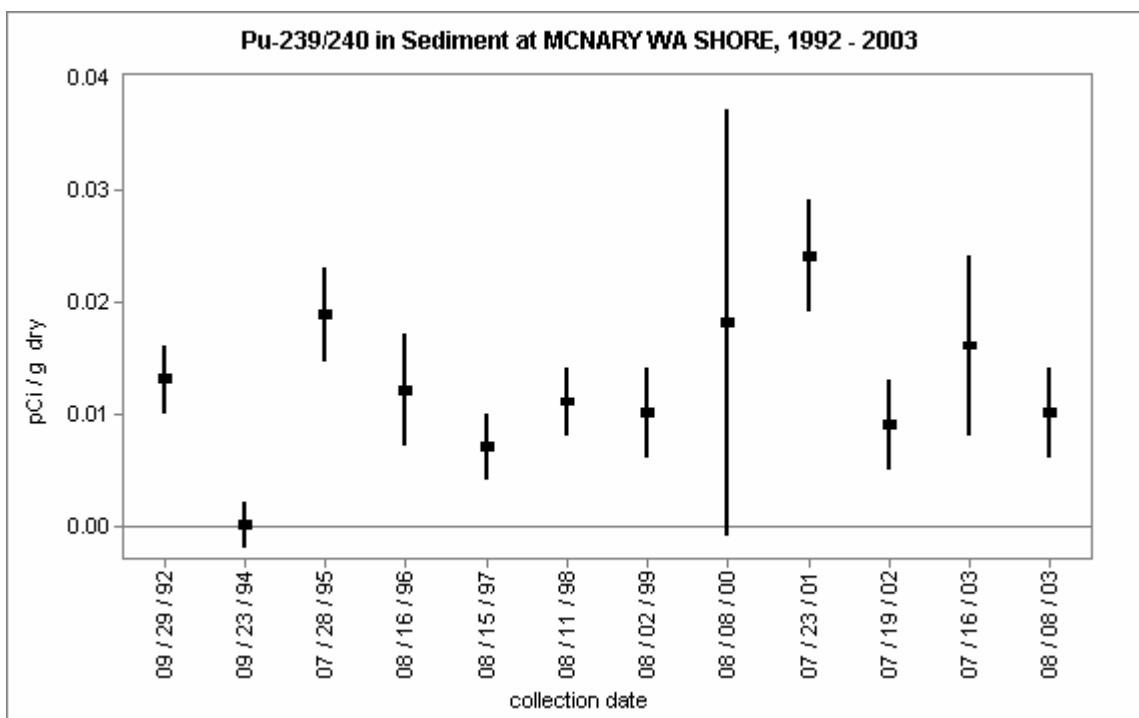


Figure 3.4.13 Historical DOH Pu-239/240 Concentrations in Sediment at McNary Dam

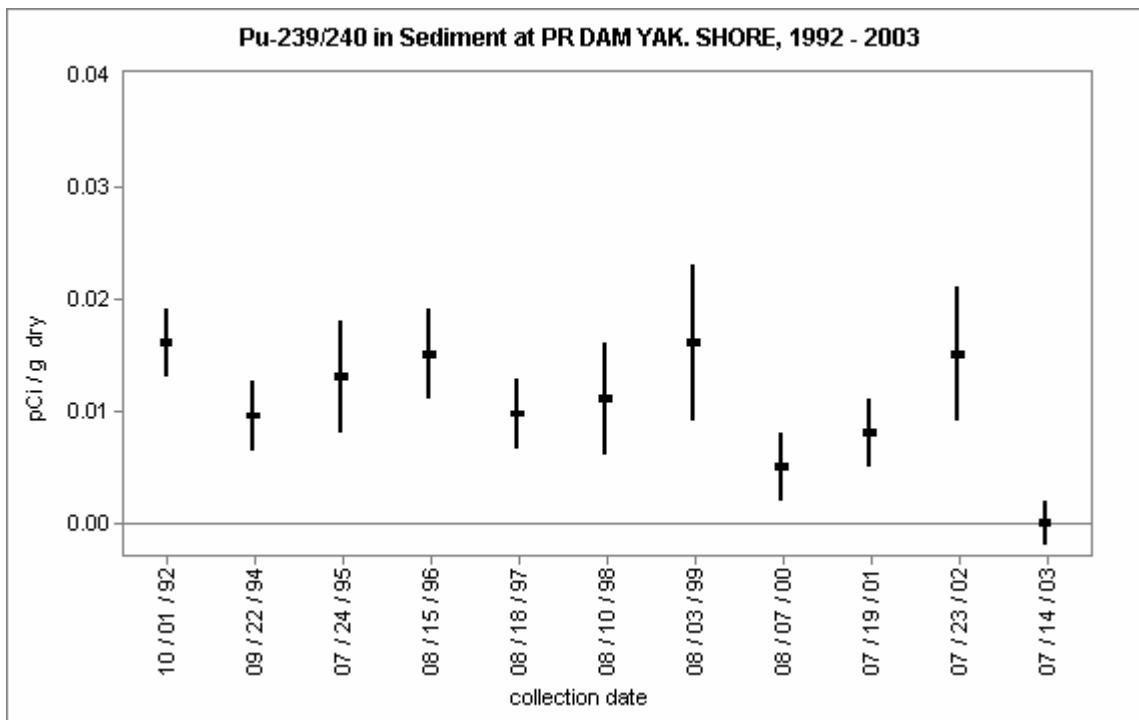


Figure 3.4.14 Historical DOH Pu-239/240 Concentrations in Sediment at Priest Rapids Dam

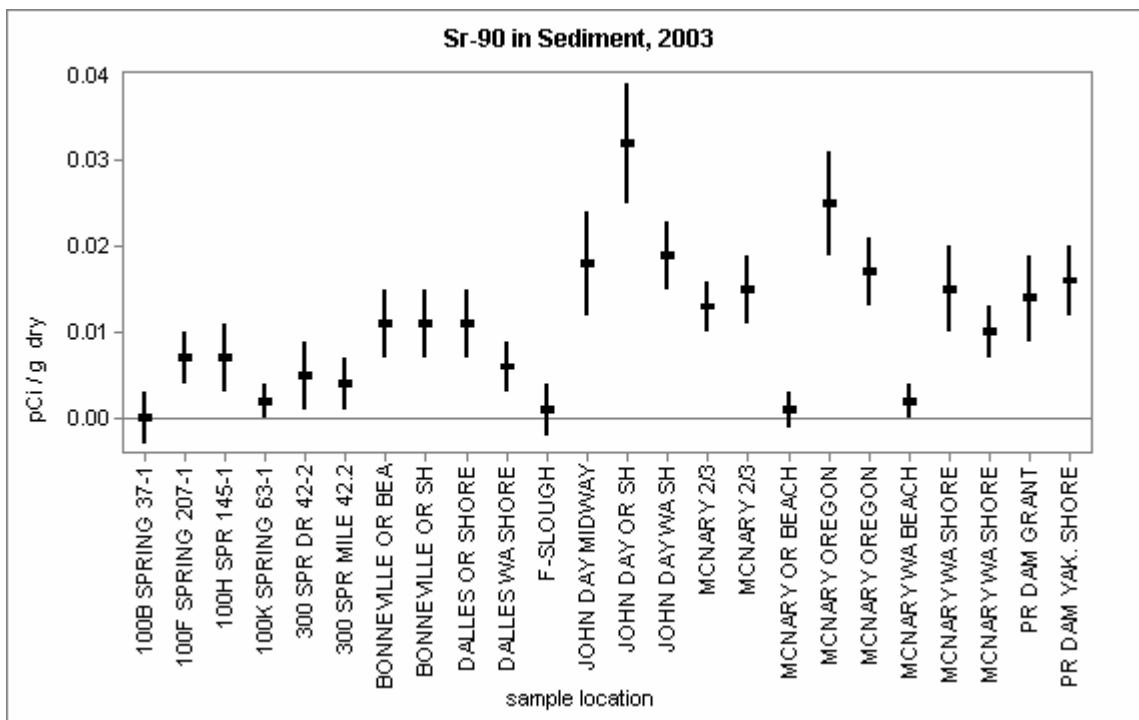


Figure 3.4.15 DOH Sr-90 Concentrations in Sediment

3.5 Farm Products Monitoring

Major Findings:

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

3.5.1 Purpose and General Discussion

The Department of Health and DOE contractors monitor farm products; i.e., food and wine, to determine if airborne contamination has deposited on plants that may be consumed by people. The food products, radionuclides analyzed, and number of samples are listed in Table 3.5.1.

Farm Product	Analyte	Number of Samples
Honey	Co-60, Cs-137, Pu-238, Pu-239/240, Sr-90, uranium	2
Apples	Co-60, Cs-137, Sr-90	4
Asparagus	Co-60, Cs-137, Sr-90, U-234, U-235, U-238	2
Potatoes	Co-60, Cs-137, Sr-90	1
Tomatoes	Co-60, Cs-137, H-3, Sr-90	1
Red Wine	Co-60, Cs-137	2
White Wine	Co-60, Cs-137	2

Table 3.5.1 Radionuclides Analyzed in Food and Farm Products

3.5.2 Monitoring Locations

All of the farm products were collected at locations which are nearby, but offsite of the Hanford Site. Samples were collected from farms located in the areas of Riverview, Sagemoor, Horse Heaven Hills, Richland, Pasco, Zillah, and Sunnyside. Most sample locations were in the prevailing downwind direction (to the southeast) from the Site.

3.5.3 Monitoring Procedures

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 H-3, are reported in pCi/g wet weight. Water extracted from the tomato sample was analyzed for H-3, and the results are reported in pCi/L.

3.5.4 Comparison of DOH and Contractor Data

Most of the 50 DOH and PNNL radionuclide concentrations reported for split food and wine samples are in good agreement. The only exceptions are the Sr-90 and total uranium results in one of the honey samples. In each of these two cases, PNNL detected small concentrations of radioactivity while the DOH results are below their detection limit (0.005 pCi/g for Sr-90 and 0.002 pCi/g for total uranium). The Sr-90 and total uranium (the sum of all uranium isotopes) concentrations for food samples collected in 2003 are shown in Figures 3.5.1 and 3.5.2, respectively.

3.5.5 Discussion of DOH Results

All of the radioactivity concentrations reported by DOH for farm product samples collected in 2003 are below the detection limits listed for food in Appendix B. DOH occasionally detects small concentrations of Sr-90 in farm products around the Hanford Site; however, this was not the case in 2003. The food and farm product results for all radionuclides analyzed in 2003 are consistent with historical DOH results.

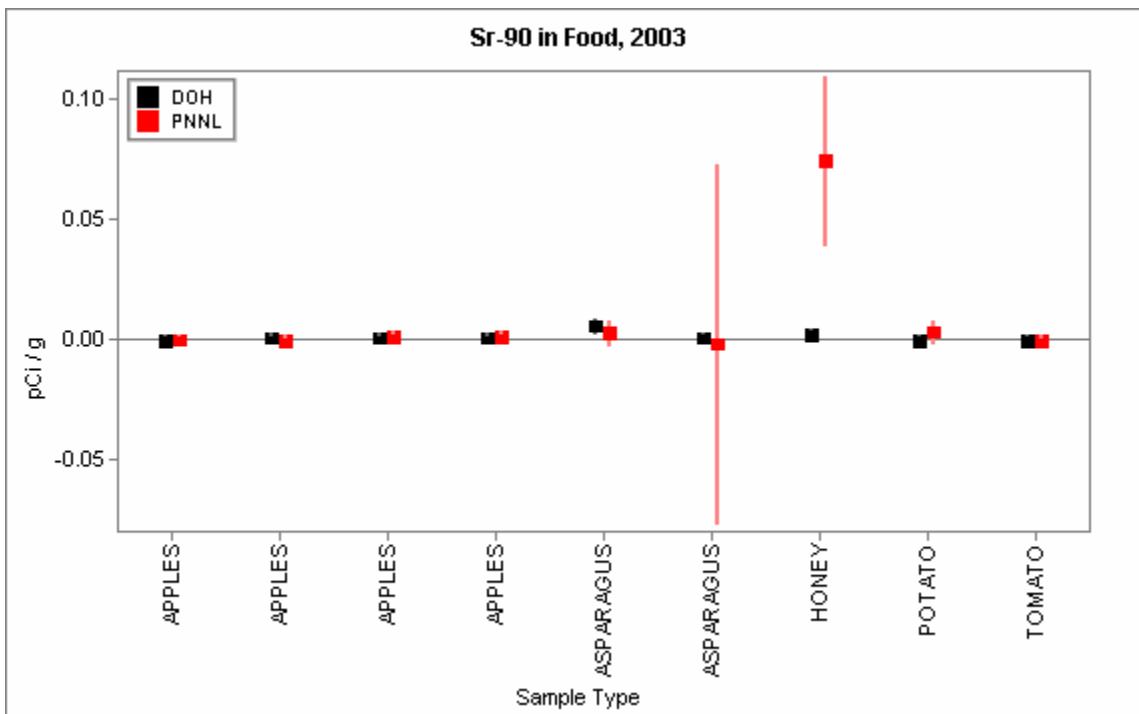


Figure 3.5.1 DOH and PNNL Sr-90 Concentrations in Food

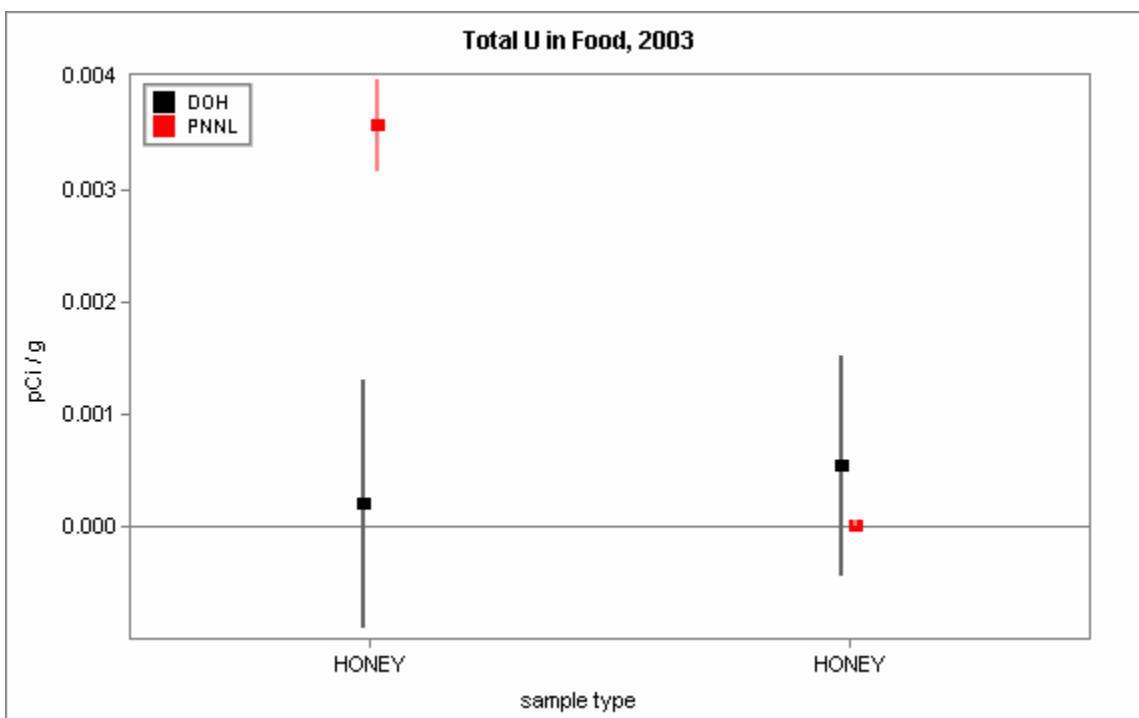


Figure 3.5.2 DOH and PNNL Total Uranium Concentrations in Food

3.6 Fish and Wildlife Monitoring

Major Findings:

- DOH and PNNL results are in good agreement.
- Most of the DOH results are below detection limits. Cs-137 was detected at 0.08 pCi/g in meat from a rabbit collected at the 100N Area.

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, vegetation, or water. In 2003, DOH split two wildlife samples and one fish sample. The type of samples, radionuclides analyzed, and number of samples are listed in Table 3.6.1.

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

Table 3.6.1 Radionuclides Analyzed in Fish and Wildlife

3.6.2 Monitoring Locations

The Canadian goose and rabbit samples were collected from the 100N Area, and the fish sample was collected from the Columbia River adjacent to the 100 Area. No background fish or game bird samples were collected in 2003.

3.6.3 Monitoring Procedures

Fish and wildlife samples were collected by PNNL and given to DOH for analysis. 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

The DOH and PNNL radionuclide concentrations reported for split fish and wildlife samples are in good agreement. Historically, DOH and PNNL Co-60 and Cs-137 results

in fish and wildlife are in good agreement, while Sr-90 results range from good to fair to poor agreement. Figures 3.6.1 and 3.6.2 show historical Cs-137 and Sr-90 concentrations in split wildlife samples collected from 1999 to 2003.

3.6.5 Discussion of DOH Results

All but one of the DOH Co-60 and Cs-137 fish and wildlife results are below the detection limit of 0.008 pCi/g. Cesium-137 was detected at 0.08 pCi/g in the meat of the rabbit sample from the 100N Area (Figure 3.6.1). This result is plausable, as Cs-137 is a world-wide fallout contaminant as well as a historical surface soil contaminant at the 100N Area. Sr-90 was not detected in the fish sample (detection limit of 0.2 pCi/g).

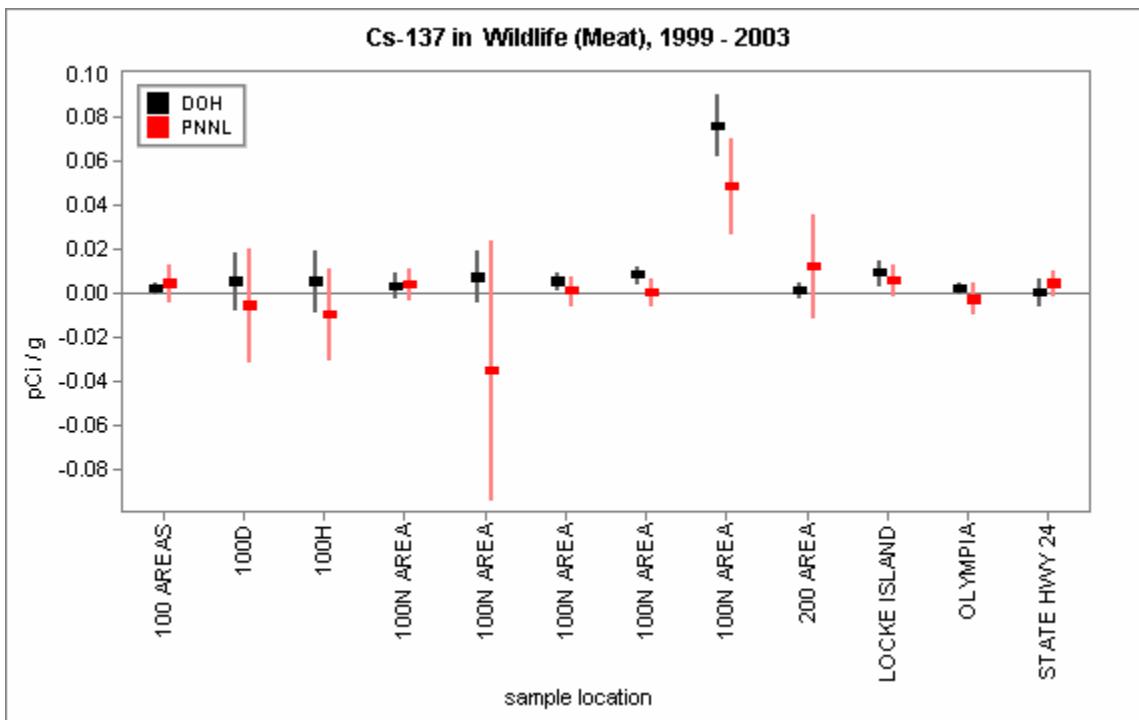


Figure 3.6.1 DOH and PNNL Historical Cs-137 Concentrations in Wildlife

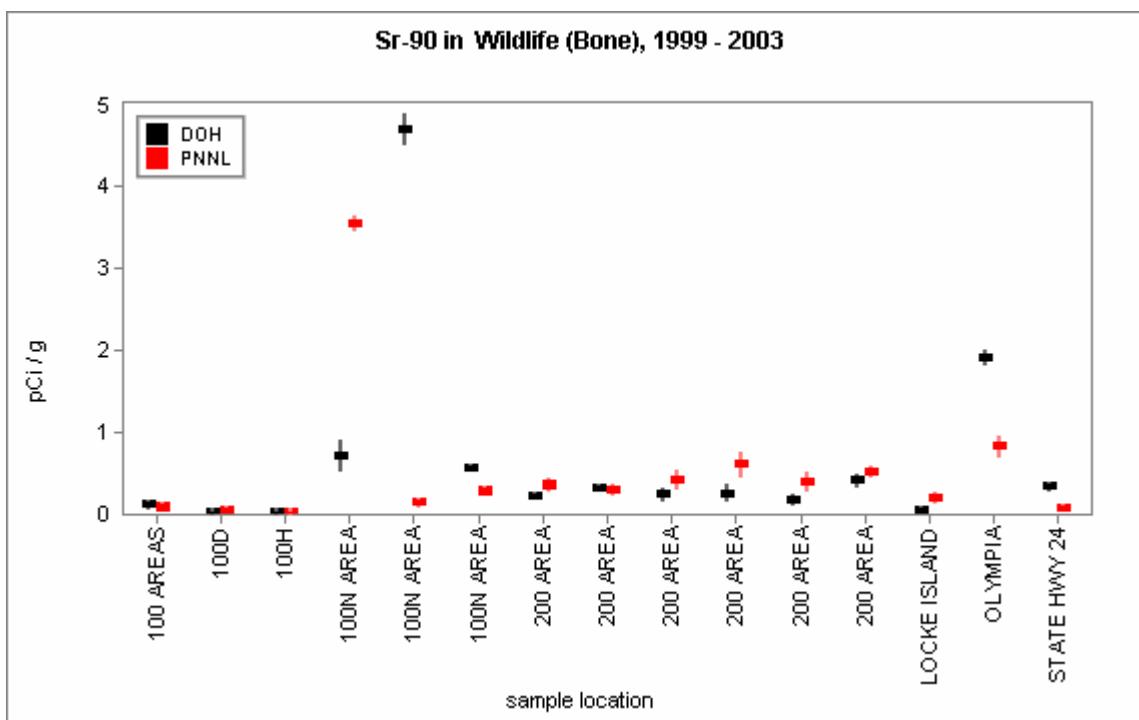


Figure 3.6.2 DOH and PNNL Historical Sr-90 Concentrations in Wildlife

3.7 Vegetation Monitoring

Major Findings:

- DOH and DOE contractor results are in good agreement.
- Concentrations of gamma emitting radionuclides are below detection limits.
- Low concentrations of Sr-90 were detected in offsite alfalfa samples. The concentrations are similar to historical offsite vegetation results.

3.7.1 Purpose and General Discussion

The Department of Health and DOE contractors monitor vegetation to evaluate contaminants that are incorporated into plants that, in turn, may be consumed by animals and potentially reach the public. Contaminants in vegetation arise from airborne deposition and from soil to plant transfer via root uptake. In 2003, DOH split two vegetation samples with PNNL. The type of vegetation, radionuclides analyzed, 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

Table 3.7.1 Radionuclides Analyzed in Vegetation

3.7.2 Monitoring Locations

The alfalfa samples were collected from two farms located off-site in the predominant downwind direction (to the southeast) of the Hanford Site.

3.7.3 Monitoring Procedures

The vegetation samples were collected in the fall of 2003 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

All of the DOH and PNNL split vegetation results are in good agreement. As an example, the DOH and PNNL Co-60 results in alfalfa are shown in Figure 3.7.1.

3.7.5 Discussion of DOH Results

The Co-60 and Cs-137 concentrations in vegetation samples are below the detection limit of 0.04 pCi/g. Strontium-90 was detected at both farm locations at concentrations of 0.1 pCi/g. The source of the Sr-90 is not known, since Sr-90 originates from world-wide fallout as well as Hanford operations. Historically, DOH has detected similar concentrations of Sr-90 in alfalfa at farms near the Hanford Site. Historical results for Sr-90 in alfalfa are shown in Figure 3.7.2.

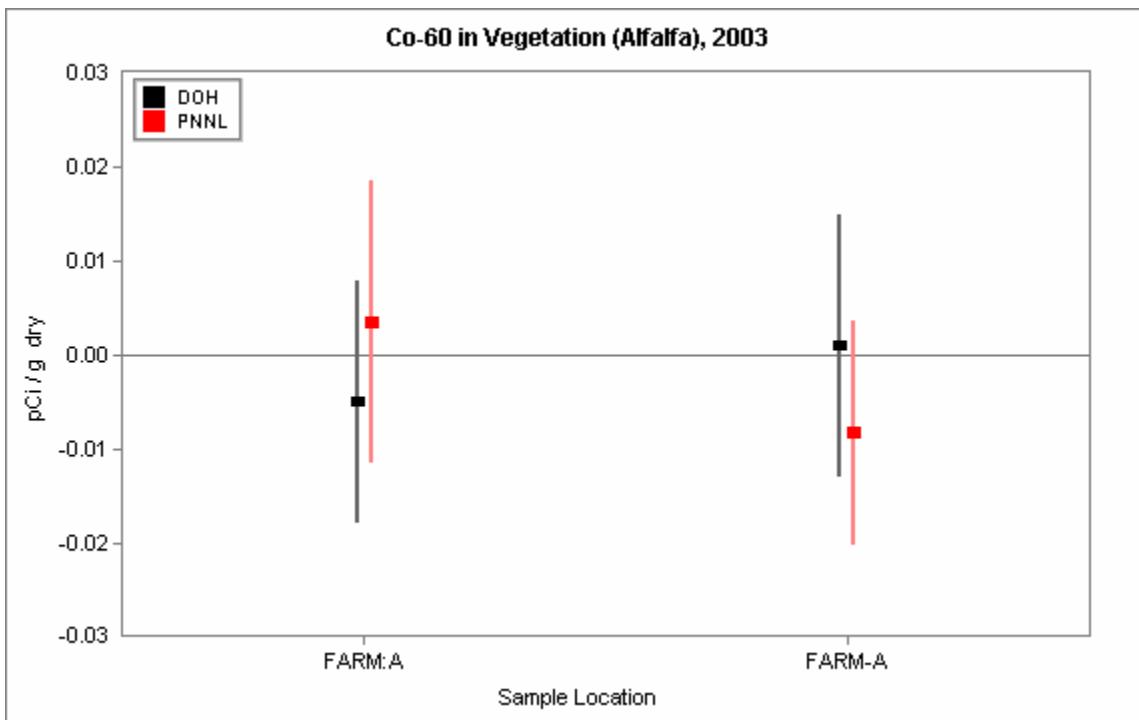


Figure 3.7.1 DOH and PNNL Co-60 Concentrations in Off-Site Alfalfa

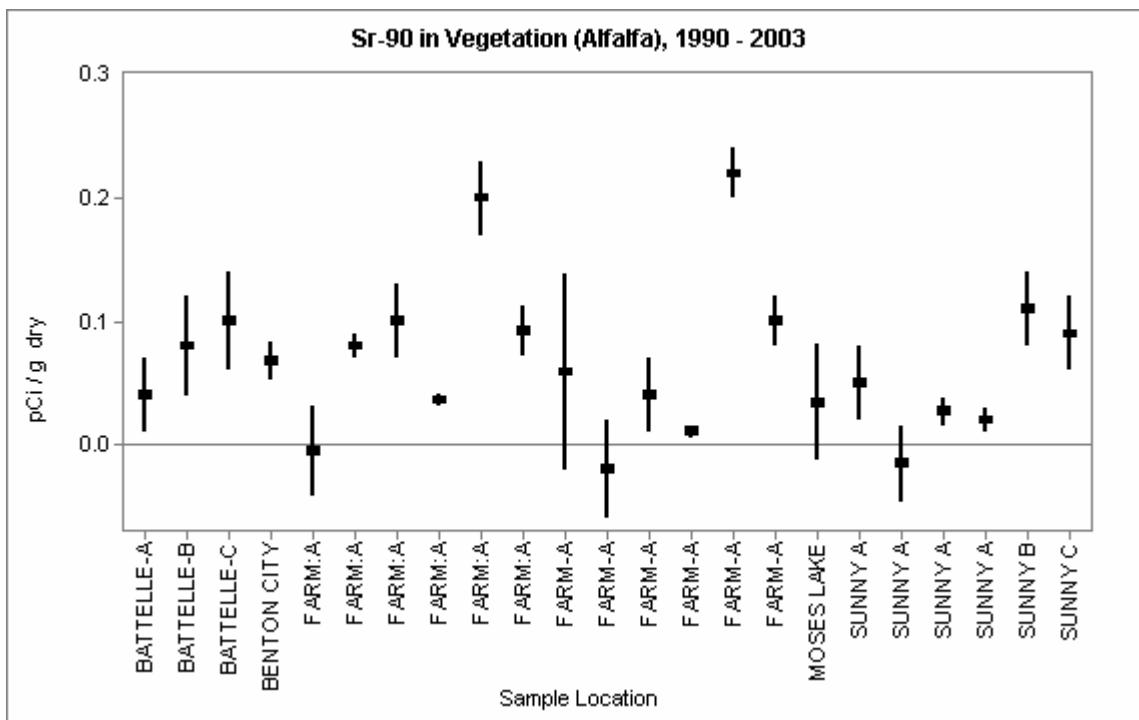


Figure 3.7.2 Historical DOH Sr-90 Concentrations in Alfalfa

4. Summary of Discrepancies Between DOH and DOE Contractor Results

The DOH and DOE Contractor co-located bi-weekly gross beta results in air samples are in fair agreement. The data follow the same trends, but there is a small systematic discrepancy between the two data sets. At the lower end of the range of reported concentrations, DOE consistently reports higher values than DOH. At the upper end of the range of concentrations, DOH consistently reports higher values than DOE. In most cases, the discrepancy is less than a factor of two. This discrepancy observed in 2003 is also evident in historical DOH and DOE results.

The DOH and DOE co-located composite uranium results in air samples are in poor agreement. DOE consistently reports concentrations that are significantly lower than the concentrations reported by DOH. This discrepancy, which is observed in historical data, results from different laboratory procedures.

The DOH and DOE split gross alpha and gross beta results in water samples are in fair agreement. A systematic discrepancy is observed between the two data sets. For about one-half of the samples analyzed, DOE reports gross alpha and gross beta concentrations that are less than values reported by DOH. The remaining results are in good agreement. This discrepancy observed in 2003 is also evident in historical DOH and PNNL results.

Historically, DOH and DOE split I-129 results in water samples are in poor agreement. However, all I-129 results for 2003 were below detection limits. Therefore, this discrepancy was not observed.

The DOH and DOE split uranium results in sediment samples are in poor agreement. A systematic discrepancy is observed between the two data sets. DOE typically reports uranium concentrations that are significantly lower than the values reported by DOH. This discrepancy, which is observed in historical data, results from different laboratory procedures.

Historically, DOH and DOE results for Sr-90 concentrations in fish and wildlife samples range from good to fair to poor agreement. However, in 2003, all Sr-90 results were below the detection limits. Therefore, this discrepancy was not observed.

There was an unexpectedly large discrepancy between DOH and DOE for one Columbia River sediment sample. DOH analysis detected Cs-137 and Am-241 in this sample while the DOE analysis of the split sample did not show elevated results. In particular, DOE did not detect Am-241.

The uranium discrepancies discussed above are understood, and originate from different laboratory procedures. All other discrepancies are under investigation, and the findings will be discussed in future annual reports.

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

of carbon are called isotopes of carbon. If an isotope is radioactive it is called a radioisotope. In the example given, carbon-12 and carbon-13 are non-radioactive isotopes of carbon. Carbon-14 is radioactive, and 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 severts. Since radiation doses are often small, units of millirem (mrem) or millisievert (mSv) are commonly used. A mrem is one-thousandth of a rem. Table A.1 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%
	Occupational Nuclear Fuel Cycle	0.9	< 0.01	< 0.3
Other	Fallout	< 1	< 0.01	< 0.03
	Miscellaneous	< 1	< 0.01	< 0.03
	Grand Total	363	3.63	100%

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

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

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

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

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

Appendix B - Laboratory a priori Lower Limits of Detection

Air Cartridge (pCi/m³)

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

Air Filter (pCi/m³)

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

Quarterly Composite Air Filter (pCi/m³)

	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.)

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

Semi-Annual Composite Air Filter (pCi/m³)

	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/m³) Continued

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

Food (pCi/g)

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

Milk (pCi/L)

	Nuclide	Volume (L)	Method	Standard LLD (400 min.)
Gamma	K-40	3	INGe	3.00E+01
	I-131	3	INGe	2.00E+00
	Cs-134	3	INGe	2.00E+00
	Cs-137	3	INGe	2.00E+00
	Ba-140	3	INGe	9.00E+00
				Standard LLD (1000 min.)
	I-131	4	IXR/INGe	7.00E-01
				Standard LLD (100 min.)
Beta	Sr-90	1	Nitric Acid/ $\alpha\beta$ Cntr	7.00E-01

Meat (pCi/g)

	Nuclide	Mass (g)	Method	Standard LLD (1000 min.)
Gamma	K-40	400	INGe	1.40E-01
	Mn-54	400	INGe	7.00E-03
	Co-58	400	INGe	7.00E-03
	Co-60	400	INGe	8.00E-03
	Cs-137	400	INGe	6.00E-03
	I-131	400	INGe	2.00E-02
	Ra-226(DA)	400	INGe	2.50E-01
	Am-241(GA)	400	INGe	2.00E-02
Alpha	Nat U	10	Alpha Spec	4.00E-03
	U-234	10	Alpha Spec	3.00E-03
	U-235	10	Alpha Spec	2.00E-03
	U-238	10	Alpha Spec	3.00E-03
	Pu-238	10	Alpha Spec	5.00E-03
	Pu-239	10	Alpha Spec	4.00E-03
	Am-241	10	Alpha Spec	4.00E-03
Beta	Sr-90 (bone)	5	Nitric Acid/ 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	$\alpha\beta$ Cntr	1.00E-01
Alpha	Ra-226(DA)	600	INGe	2.00E-02
				Standard (100 min.)
Alpha	Gross	0.1	$\alpha\beta$ Cntr	4.00E+01
Gamma				Standard LLD (1000 min.)
	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
Beta	Am-241(GA)	600	INGe	2.00E-02
	Tot U(GA)	600	INGe	2.00E-01
				Standard (100 min.)
Beta	Sr-90	150	Nitric Acid/	1.80E-03
	Tc-99	10	3M/LS	2.00E-01
	Gross beta	0.4	$\alpha\beta$ Cntr	1.50E+00

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

	Nuclide	Mass (g)	Method	Standard LLD (1000 min.)
Alpha	Nat U	10	Alpha Spec.	8.00E-03
	U-234	10	Alpha Spec.	6.00E-03
	U-238	10	Alpha Spec.	6.00E-03
	Pu-238	10	Alpha Spec.	5.00E-03
	Pu-239	10	Alpha Spec.	4.00E-03
	Am-241	10	Alpha Spec.	4.00E-03
Gamma	K-40	100	INGe	3.00E-01
	Mn-54	100	INGe	4.00E-02
	Co-60	100	INGe	4.00E-02
	Zn-65	100	INGe	1.50E-01
	Zr-95	100	INGe	2.00E-01
	Ru-106	100	INGe	4.00E-01
	Cs-137	100	INGe	4.00E-02
	I-131	100	INGe	4.00E-02
	Am-241(GA)	100	INGe	2.00E-01
Beta	Gross	0.4	$\alpha\beta$ Cntr	1.50E+00
	Sr-90	20	Nitric Acid/ $\alpha\beta$ Cntr	5.00E-02
	Tc-99	5	3M/LS	1.50E+00
				Standard LLD (100 min.)
	Nuclide	Volume (L)	Method	Standard LLD (200 min.)
	C-14	0.0002	Oxid/LS	3.00E+02
	H-3	0.002	LS	5.00E+02

Water (pCi/L)				Standard LLD (1000 min.)	Standard LLD (100 min.)
	Nuclide	Volume (L)	Method		
Alpha	Nat U	0.5	Alpha Spec	1.30E-01	
	U-234	0.5	Alpha Spec	8.00E-02	
	U-235	0.5	Alpha Spec	6.00E-02	
	U-238	0.5	Alpha Spec	8.00E-02	
	Ra-226	0.5	$\alpha\beta$ Cntr		2.00E-01
	Pu-238	0.5	Alpha Spec	8.00E-02	
	Pu-239	0.5	Alpha Spec	6.10E-02	
	Th-230	0.5	Alpha Spec	1.00E-01	
	Th-232	0.5	Alpha Spec	1.00E-01	
	Am-241	0.5	Alpha Spec	8.00E-02	
					Standard LLD (1000 min.)
Gamma	Am-241	3	INGe	1.00E+01	
	Ba-140	3	INGe	9.00E+00	
	Ce-144	3	INGe	1.30E+01	
	C0-58	3	INGe	1.50E+00	
	Co-60	3	INGe	2.00E+00	
	Cr-51	3	INGe	1.60E+01	
	Cs-134	3	INGe	2.00E+00	
	Cs-137	3	INGe	2.00E+00	
	Eu-152	3	INGe	5.00E+00	
	Eu-154	3	INGe	5.00E+00	
	Eu-155	3	INGe	8.00E+00	
	Fe-59	3	INGe	3.00E+00	
	I-129	3	IXR/LEP	8.00E-01	
	I-131	3	INGe	2.00E+00	
	K-40	3	INGe	3.00E+01	
	Mn-54	3	INGe	1.50E+00	
	Nb-95	3	INGe	2.00E+00	
	Ru-103	3	INGe	2.00E+00	
	Ru-106	3	INGe	1.50E+01	
	Sb-125	3	INGe	5.00E+00	
	Sn-113	3	INGe	2.00E+00	
	Zn-65	3	INGe	3.00E+00	
	Zr-95	3	INGe	2.00E+00	

Water (pCi/L) Continued

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

Appendix C - Glossary of Terms

Alpha Particle	A heavy particle emitted from the nucleus of an atom. It consists of two protons and two neutrons, which is identical to the nucleus of a helium atom without orbital electrons. These heavy charged particles lose their energy very rapidly in matter. Thus, they are easily shielded by paper or the surface layer of skin. Alpha particles are only hazardous when they are internally deposited.
Analyte	The specific 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	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 on humans.
Rad	The special unit of absorbed dose. It is a measure of the energy absorbed per mass of material. One rad is equal to an absorbed dose of 0.01 J kg^{-1} ($1 \text{ rad} = 0.01 \text{ gray}$).
Radioactivity	The process of undergoing spontaneous transformation of the nucleus, generally with the emission of alpha or beta particles, often accompanied by gamma rays. The term is also used to designate radioactive materials.
Radioisotope	A radioactive isotope; i.e. an unstable isotope that undergoes spontaneous transformation, emitting radiation. Approximately 2500 natural and artificial radioisotopes have been identified.
Radionuclide	A radioactive nuclide.
Rem	The special unit of dose equivalent. The dose equivalent in rem is equal to the absorbed dose in rad multiplied by a quality factor that accounts for the biological effect of the radiation. ($1 \text{ rem} = 0.01 \text{ sievert}$).
Replicate Sample	Two or more samples from one location that are analyzed by the same laboratory.
Roentgen	A unit of exposure to ionizing radiation. It is that amount of gamma or x-rays required to produce ions carrying 1 electrostatic unit of electrical charge in 1 cubic centimeter of dry air under standard conditions. Named after Wilhelm Roentgen, German scientist who discovered x-rays in 1895.
Split Sample	A sample from one location that is divided into two samples and analyzed by different laboratories.

TLD	Thermoluminescent Dosimeters
U.S. DOE	United States Department of Energy
WAC	Washington Administrative Code
X-ray	Electromagnetic waves or photons emitted from the outer shell of the atom instead of the nucleus. They have no charge and are best shielded by thick layers of lead or steel. X-ray energy may cause an external or internal radiation hazard.

Appendix D - List of Analytes

Am-241	Americium-241
Be-7	Beryllium-7
C-14	Carbon-14
Cm-244	Curium-244
Co-60	Cobalt-60
Cs-137	Cesium-137
Eu-152	Europium-152
Eu-154	Europium-154
Eu-155	Europium-155
H-3	Hydrogen-3
I-129	Iodine-129
K-40	Potassium
NO ₂ +NO ₃	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