DOH 320-047

Environmental Radiation Monitoring and Assessment Program

Hanford Environmental Oversight Program 2006 Data Summary Report

March 2008

Washington State Department of
Health
Division of Environmental Health

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Acronyms

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

Summary

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

Since 1985, the Washington State Department of Health's Hanford Environmental 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 2006.

The Oversight Program's objectives are met through collection and analysis of environmental samples and interpretation of results. DOH samples are either split or colocated with samples collected by DOE contractors, and the results are compared to verify the quality of the DOE monitoring programs at Hanford. In 2006, 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. Samples of soil or vegetation were not part of the 2006 Oversight Program.

This report uses the categories of *good*, *fair*, and *poo*r to describe the agreement between DOH and DOE contractor results. 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 the DOE environmental radiation data are valid.

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

The agreement between DOH and DOE contractor results for samples collected in 2006 is fair for gross beta and uranium activity in air samples, fair for gross alpha and gross beta activity in water samples, and fair for uranium activity in sediment samples. In the case of uranium in sediment samples, the discrepancy is due to a known difference in laboratory analytical methods. For the case of gross beta in air, the difference in sampling intervals and sampling equipment may contribute to the discrepancy. For the other cases, the discrepancies are under investigation, and are likely related to differences in laboratory procedures and sample collection protocol.

Most environmental samples analyzed by DOH have radioactivity concentrations either below detection limits or consistent with background. A few samples have concentrations elevated above background; however, in most cases the concentrations are very small and are consistent with historical trends.

For example, H-3 (tritium), Sr-90, Tc-99, and isotopes of uranium were detected above background levels in some Hanford Site and Hanford boundary water samples. A variety of radionuclides, including Cs-137, Eu-152, Pu-239/240, Sr-90, and isotopes of uranium, were found above background levels in some Columbia River sediment samples. Strontium-90 was found in small concentrations in some fish and wildlife samples. All elevated concentrations found in 2006 are consistent with historical trends.

Tritium concentrations in 100K Area groundwater wells have displayed large fluctuations over the last several years. This trend continued in 2006, although concentrations are currently decreasing. DOH will continue to monitor these wells in the future due to their proximity to the Columbia River.

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

1. Introduction

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

From 1943 until the mid-1980s, the primary mission of the U.S. Department of Energy's (DOE) Hanford Site was the production of plutonium for nuclear weapons. Operations resulted in releases of radioactivity to the environment. Today, weapons production operations have ceased, and the current mission of the Site includes cleanup of radioactive waste originating from the plutonium production era. DOE has extensive monitoring programs to characterize and track this contamination as it moves through the environment. The primary purpose of the DOH Hanford Environmental 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, colocated, and independent sampling at locations having the potential to release radionuclides to the environment or locations which may be impacted by such releases.

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

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

This report presents the results of environmental radiation measurements made by the Washington State Department of Health's Hanford Environmental Oversight Program for the calendar year 2006.

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 lower limits of detection are listed in Appendix B. Appendix C lists a glossary of radiation terms. Appendix D lists the full element names of the radionuclides discussed in this report, i.e. H-3 is Hydrogen-3.

2. The Hanford Environmental Oversight Program Description

The objectives of the Oversight Program (see Section 1, Introduction) are met through collection and analysis of environmental samples and interpretation of results. DOH samples are either split or colocated with samples collected by the DOE contractors. In 2006, samples were split with the Pacific Northwest National Laboratory (PNNL), Duratek, and Waste Management Federal Services (WMFS).

Split samples are prepared by dividing a sample into two parts. Colocated 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 milliroentgens per day (mR/day). Radiation exposure is discussed in Appendix A, and the units used to quantify radioactivity and exposure are defined in Appendix C.

2.2.1 Uncertainty in Radioactivity Measurements

All radioactivity measurements (i.e., counting the number of decays per unit time) have an associated uncertainty. Counting uncertainty is the dominant source of laboratory 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 the background radiation originating from sources outside of the sample. Background activity is measured by counting the radioactivity in a blank sample.

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

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

2.2.4 Techniques for Comparison of DOH and DOE Contractor Data

Since the primary purpose of the DOH Hanford Environmental Oversight Program is to verify DOE environmental monitoring programs, DOH either splits samples or collects colocated 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 colocated or split data are sorted by sample type and radionuclide. Then, for each sample type and radionuclide, all of the DOH and DOE contractor data for each sample location are plotted on a graph and visually inspected to qualitatively assess the agreement of the data. 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 colocated DOH and DOE results for a given sample type and radionuclide are formed into an (x, y) pair. The x-value represents the DOH result and the y-value represents the DOE result for a particular sample. The paired data for all samples of a given sample type and radionuclide are plotted on a two-dimensional scatter plot. The correlation coefficient R is then calculated for the set of (x, y) pairs. R can vary from -1 to +1. A value near ± 1 implies a strong correlation, while a value near 0 implies a weak or 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 colocated sample 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 and DOE contractor colocated biweekly gross beta results are in fair agreement. The data follow the same trends, but there is a small systematic discrepancy between the data sets. Different sampling frequencies and differences in sampling equipment between DOH and DOE contractors likely contribute to differences in results.
- The DOH and DOE contractor colocated quarterly and semiannual 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 semiannual composite air concentrations are below detection limits for most radionuclides. However, uranium was detected in composite air samples at concentrations consistent with historical results. Plutonium-239/240 was detected in a few samples, at concentrations slightly above 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 colocated 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 Hanford facilities and contaminated areas.

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

3.1.2 Monitoring Locations

DOH collected air samples colocated with PNNL at five locations. These locations include Wye Barricade, Prosser Barricade, Battelle Complex, and Station 8, that are all located in the prevailing downwind direction of most Hanford Site facilities and contaminated areas; and Yakima Barricade, that is in the prevailing upwind direction of potential sources of airborne radioactivity.

DOH also collected air samples colocated with Duratek at five locations, four of which are near facilities that have the potential to emit radionuclides to the air. These locations include a tank farm in the 200 Area (C Farm), the Environmental Restoration Disposal Facility (ERDF-SE), the K East Area fuel storage basins (100K East Basin), and the Integrated Disposal Facility in the 200 Area (IDF). The fifth colocated site is at the Wye Barricade. The DOH colocated 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 colocated filters every other week (biweekly). 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 biweekly) filter samples for a three or six-month period are dissolved and combined into quarterly or semiannual composite samples. The composite samples are analyzed for gamma emitting radionuclides and isotopes of uranium and plutonium. A summary of the 2006 colocated monitoring program is shown in Table 3.1.1.

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

Table 3.1.1 Radionuclides Monitored in Air Samples

3.1.4 Comparison of DOH and Contractor Data

Weekly/Biweekly Results

The DOH and PNNL gross beta concentrations in biweekly colocated 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 in the predominant downwind direction from Hanford on the opposite side of the Columbia River, are shown in Figure 3.1.2.

The scatter plots for 2006 and historical DOH and PNNL gross beta concentrations are shown in Figures 3.1.3 and 3.1.4. These plots show the data from all sites that are colocated with PNNL. The DOH and PNNL data follow the same general trend. However, there is significant scatter about the theoretical line where the DOH and PNNL results are identical, with differences up to a factor of two being common. In addition, there is a small systematic bias between the DOH and PNNL results. The regression analysis of historical data indicates that PNNL on average reports slightly higher concentrations at the lower range of results, while DOH on average reports slightly higher concentrations at the upper range.

The DOH and Duratek gross beta concentrations in biweekly colocated 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 for 2006 and historical DOH and Duratek gross beta concentrations are shown in Figures 3.1.6 and 3.1.7. These plots show the data from all sites that are colocated with Duratek. The DOH and Duratek data follow the same general trend. However, there is significant scatter about the theoretical line where the DOH and Duratek results are identical, with differences up to a factor of two being common. In addition, there is a small systematic bias between the DOH and Duratek results. The regression analysis of historical data indicates that Duratek on average reports slightly higher concentrations at the lower range of results, while DOH on average reports slightly higher concentrations at the upper range.

In general, the DOH and DOE contractor data sets are not expected to match identically because the sampling frequencies and equipment are different, and therefore the results correspond to an averaging of the air concentration over different time periods.

Quarterly Composite Results

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

The DOH and PNNL Co-60, Cs-134, and Cs-137 quarterly composite concentrations are in good agreement, with all results below the detection limits listed in Appendix B. In addition, neither DOH or PNNL reported measurable concentrations of the gamma emitting radionuclides Eu-152, Eu-154, Eu-155, Ru-106, and Sb-125.

The isotopic uranium concentrations are only in fair agreement, as the PNNL concentrations are systematically less than those reported by DOH. The reason for the bias is under investigation (see Section 4 for a detailed discussion). The U-238 concentrations for each quarter at Station 8 are shown in Figure 3.1.8. The PNNL uranium concentrations are systematically less than those reported by DOH. The results for U-234 and U-235 are similar.

The historical DOH and PNNL quarterly composite U-238 concentrations for the years 1999 through 2006 are shown in the scatter plot of Figure 3.1.9. The discrepancy appears for samples in which DOH measures U-238 concentrations greater than the detection limit of 2.5E-5 pCi/m^3. In these cases, the corresponding PNNL data do not confirm the elevated DOH results. The scatter plot clearly shows that DOH consistently reports higher concentrations than PNNL.

Semi-Annual Composite Results

DOH and Duratek analyzed colocated semiannual composite air samples at C Farm, ERDF-SE, 100K East Basin, and IDF. The DOH and Duratek airborne concentrations are in good agreement for Co-60, Cs-134, and Cs-137. Most results are below detection limits, although Cs-137 was detected in air at C Farm, as shown in Figure 3.1.10.

The DOH and Duratek Pu-238 and Pu-239/240 airborne concentrations are also in good agreement, and most results are below detection limits. See Section 3.1.5 below for a discussion of the concentrations considered detectable. The Pu-239/240 split results are shown in Figure 3.1.11. Historically, Duratek occasionally reports a Pu-239/240 concentration several times higher than DOH, although this was not the case in 2006.

The isotopic uranium concentrations are only in fair agreement, as the Duratek concentrations are systematically less than those reported by DOH. The reason for the bias is under investigation (see Section 4 for a detailed discussion). The DOH and Duratek U-238 data for 2006 are shown in Figure 3.1.12, and the historical data are shown in the scatter plot of Figure 3.1.13. The U-234 results are similar. All of the U-235 results are below the detection limit.

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 decay products due to decreased atmospheric mixing during the winter months when there is decreased atmospheric heating. The annual cycle of increased gross beta activity in the winter months can easily be seen in Figure 3.1.14, which shows gross beta activity at Wye Barricade over the last decade from 1997 through 2006.

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 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, 100K East Basin, and IDF).

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.

Site	**Average DOH Gross Beta Concentration (pCi/m^3)**
100K East Basin	0.016
Battelle Complex	0.017
C Farm	0.018
ERDF-SE	0.016
IDF	0.021
Prosser Barricade	0.019
Station 8	0.013
Wye Barricade	0.019
Yakima Barricade	0.015

Table 3.1.2 Summary Statistics for Gross Beta Concentrations in Air

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). One exception is Cs-137 at C Farm, with a concentration of 0.0012 pCi/m^3 (see Figure 3.1.10). Historical Cs-137 concentrations in air samples at C Farm are shown in Figure 3.1.15, where it can be seen that Cs-137 concentrations appear to have increased since 2005.

Uranium-234 and U-238 were detected in most air samples, with concentrations ranging from 0.00002 pCi/m^3 to 0.00017 pCi/m^3. These uranium concentrations are consistent with historical results, and most likely originate from natural uranium in the soil.

From Figure 3.1.12, note that the uncertainties (error bars) in the first of the two composite samples at each site are much larger than those from the second half of the year. Realized detection limits are dependant upon the chemical yield achieved during the elemental separation process, and this in turn is largely a matter of how non-radioactive materials in the sample interact with those processes. It is normal to see variability in these factors across samples and time. When comparing samples where activities are near the detection limits, small variations in yield and the background of the analytes of interest in the sampling media become evident. For these reasons, variability in detection limits and uncertainty is expected in environmental samples, as seen in the figure.

Plutonium-238 was detected at C Farm at a concentration of 0.00034 pCi/m^3. Historically, Pu-238 is usually not detected in composite air samples. Plutonium-239/240 was detected at KE Basin, at a concentration of 0.00001 pCi/m^3 (see Figure 3.1.11). Historical Pu-239/240 concentrations in air samples at 100K East Basin are shown in Figure 3.1.16, where it can be seen that Pu-239/240 concentrations appear to have increased since 2004. The levels of plutonium detected in Hanford air samples are very low, and are near the laboratory's capability for detection.

DOH is looking at two solutions to improve the data related to plutonium in composite air samples. The first solution is a review and revision of laboratory procedures to improve recovery of plutonium. Plutonium in the environment is found in two forms; a non soluble high fired oxide that tightly absorbs to soil, sediment, and air particulates; and a more soluble form. Historically, DOH used an acid leach procedure to separate plutonium from the particulates on the air filter. This procedure does not effectively separate the tightly bound, high fired oxide form of plutonium and make it available for quantification. Beginning in 2008, DOH will change the initial sample preparation from acid leaching to total dissolution of air filters in order to capture the high fired oxide form of plutonium.

The second solution is a review and revision of statistical parameters that are used to describe whether or not an analyte is present in a particular sample. DOH intends to measure to the lowest concentration practical and minimize the error of reporting a non-detectable analyte concentration when an analyte is actually present.

DOH has traditionally used the measured concentration, uncertainty, and minimum detectable activity (MDA) values to indicate if an analyte is present. The MDA represents the balance point between the probability functions that describe the likelihood of false-detection and false-rejection; it is not the point above which calculated activity can be considered to be positively detected.

One additional statistical term that applies to data interpretation where the results are at the limit of detection is the critical level. This key concept describes the minimum significant concentration that can be discriminated from the concentration observed for a blank sample, thus allowing a decision to be made that the radionuclide was detected or not. DOH is revising data interpretation procedures to include evaluation of the critical level when samples are at the edge of detection capabilities, such as with plutonium in air composite samples.

The maximum radionuclide concentrations detected in DOH quarterly and 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).

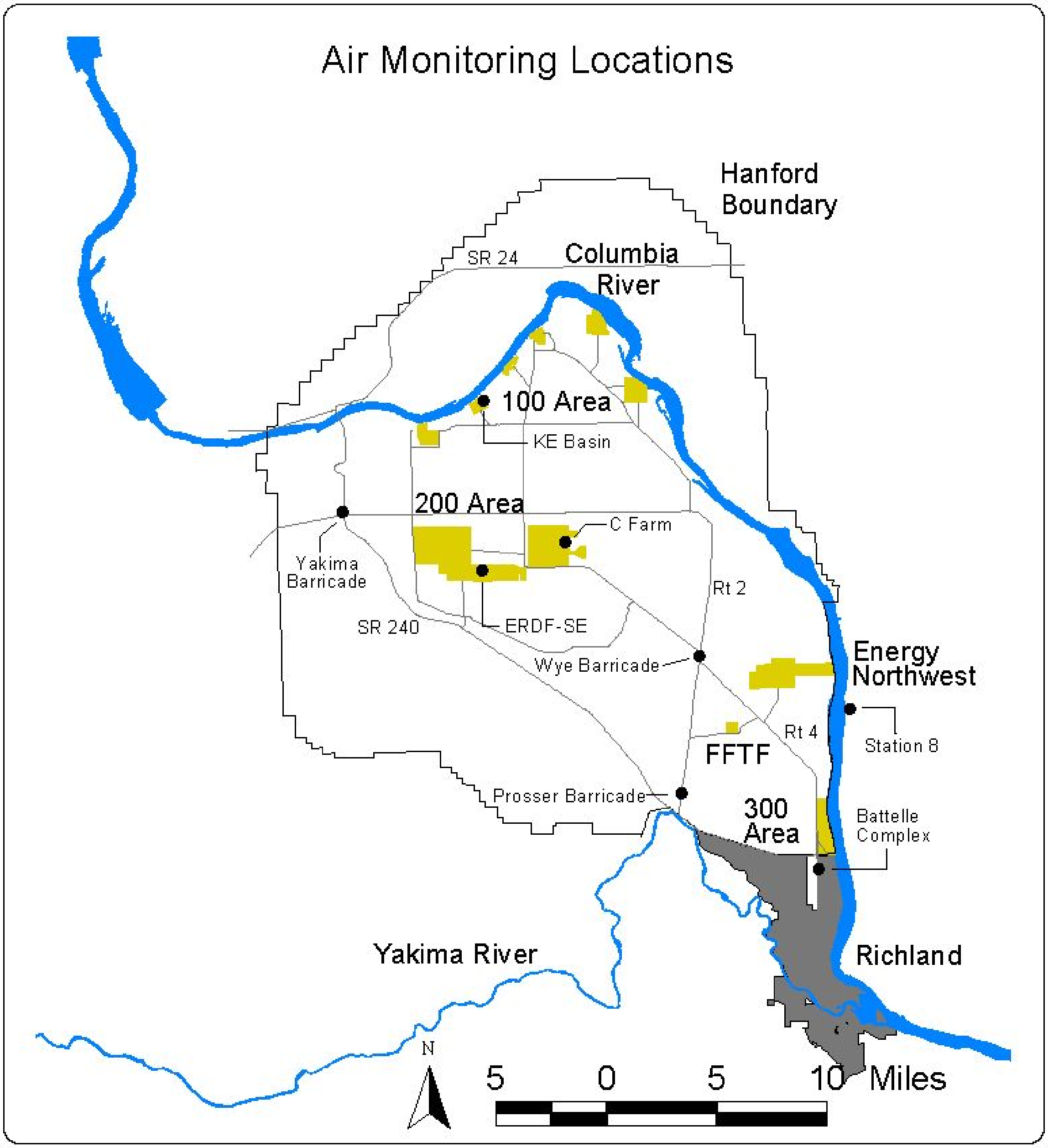

Figure 3.1.1 Air Monitoring Locations

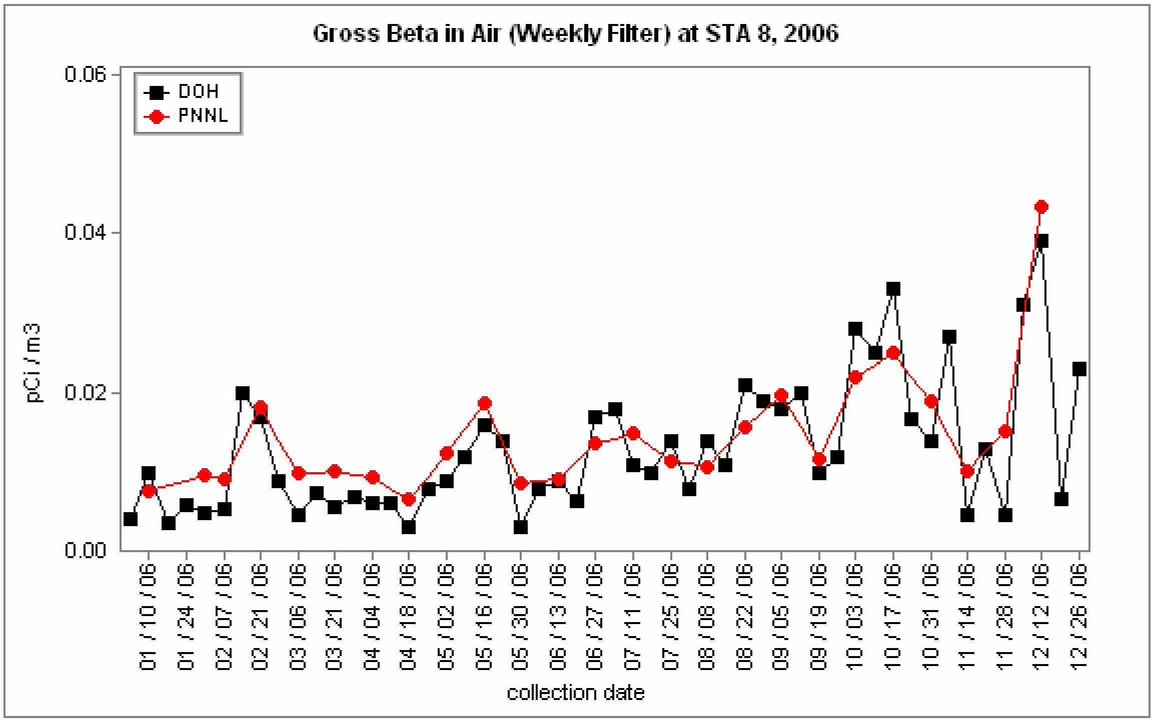

Figure 3.1.2 DOH and PNNL Gross Beta Concentrations in Air at Station 8

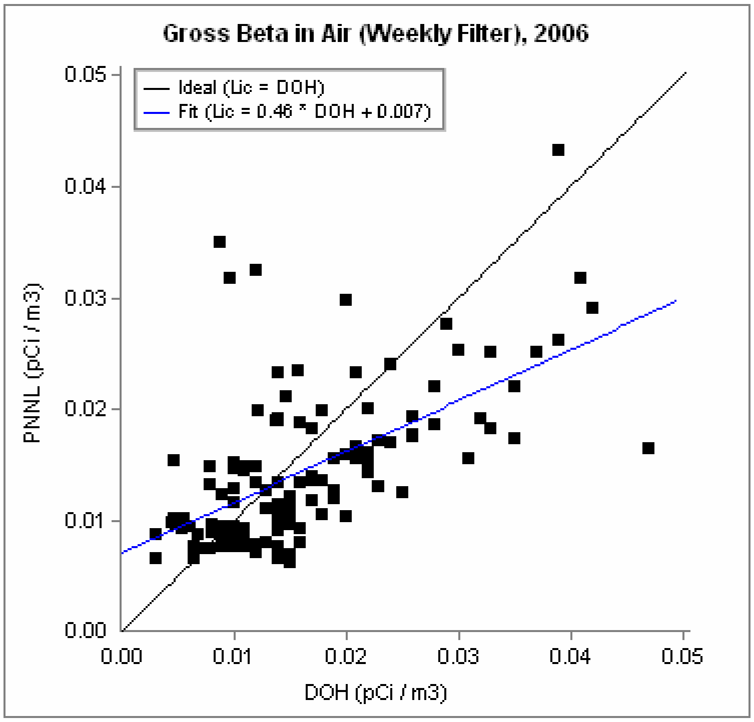

Figure 3.1.3 DOH and PNNL Scatter Plot for Gross Beta Concentrations in Air (2006)

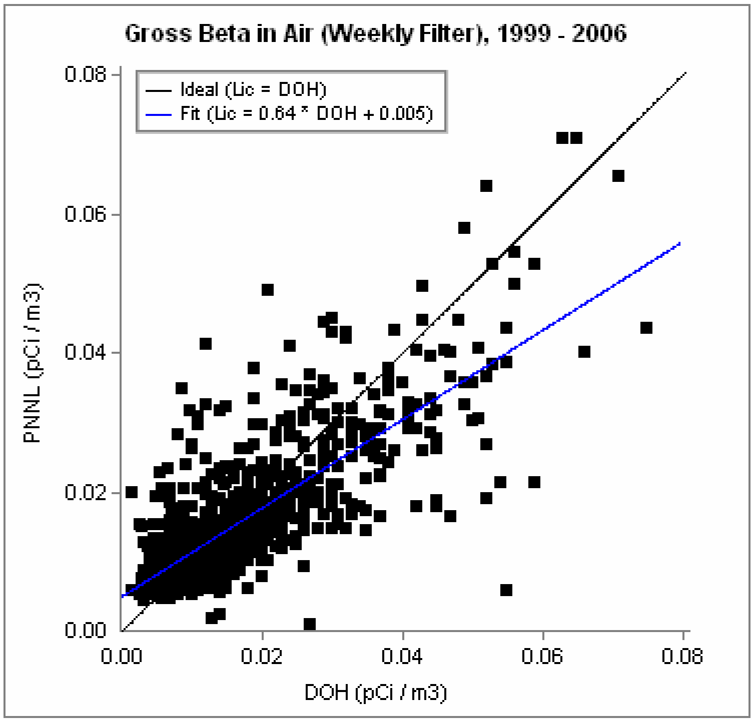

Figure 3.1.4 DOH and PNNL Scatter Plot for Historical Gross Beta Concentrations in Air

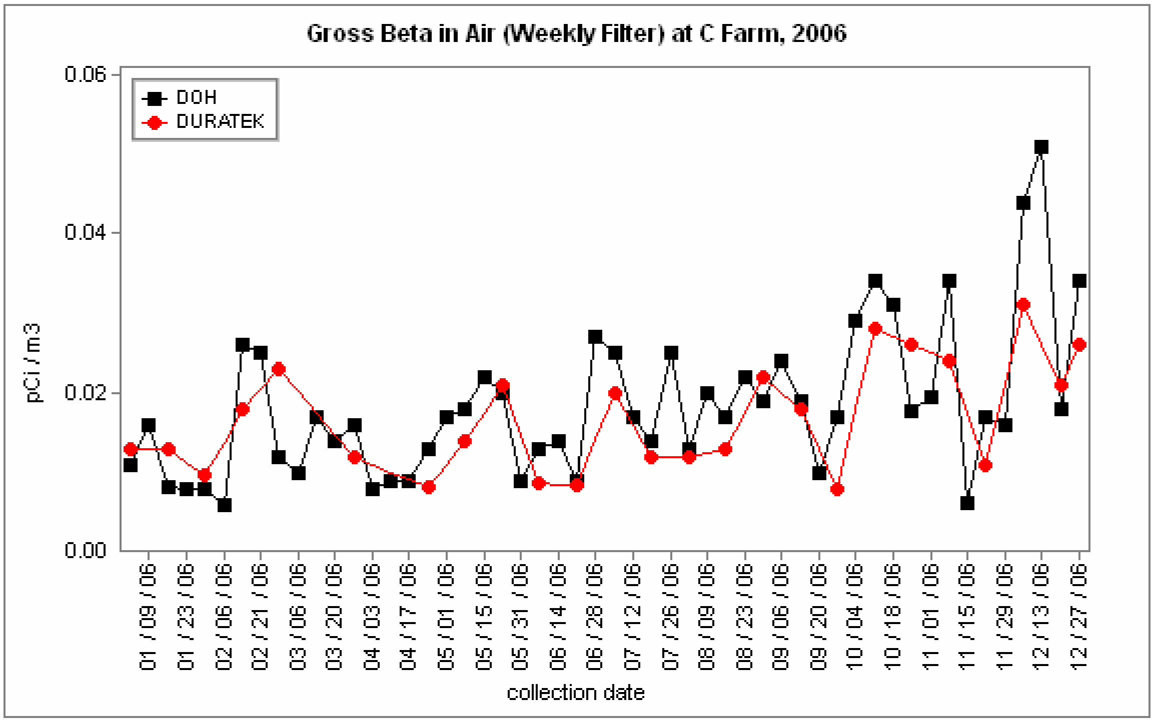

Figure 3.1.5 DOH and Duratek Gross Beta Concentrations in Air at C Farm

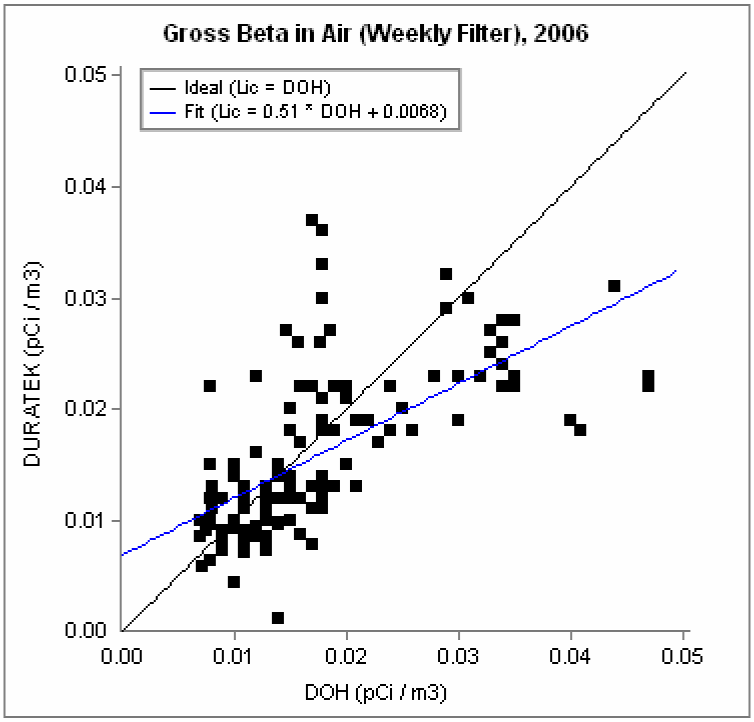

Figure 3.1.6 DOH and Duratek Scatter Plot for Gross Beta Concentrations in Air (2006)

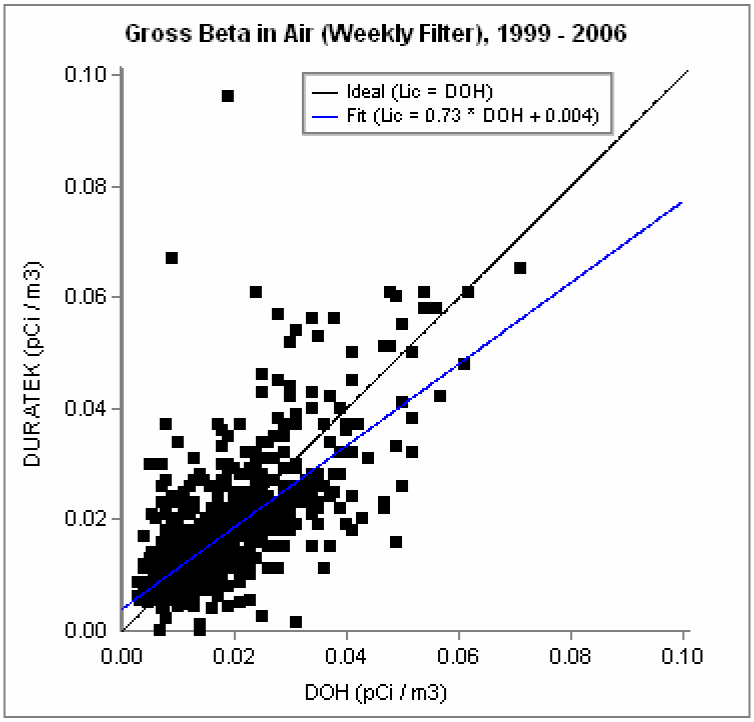

Figure 3.1.7 DOH and Duratek Scatter Plot for Historical Gross Beta Concentrations in Air

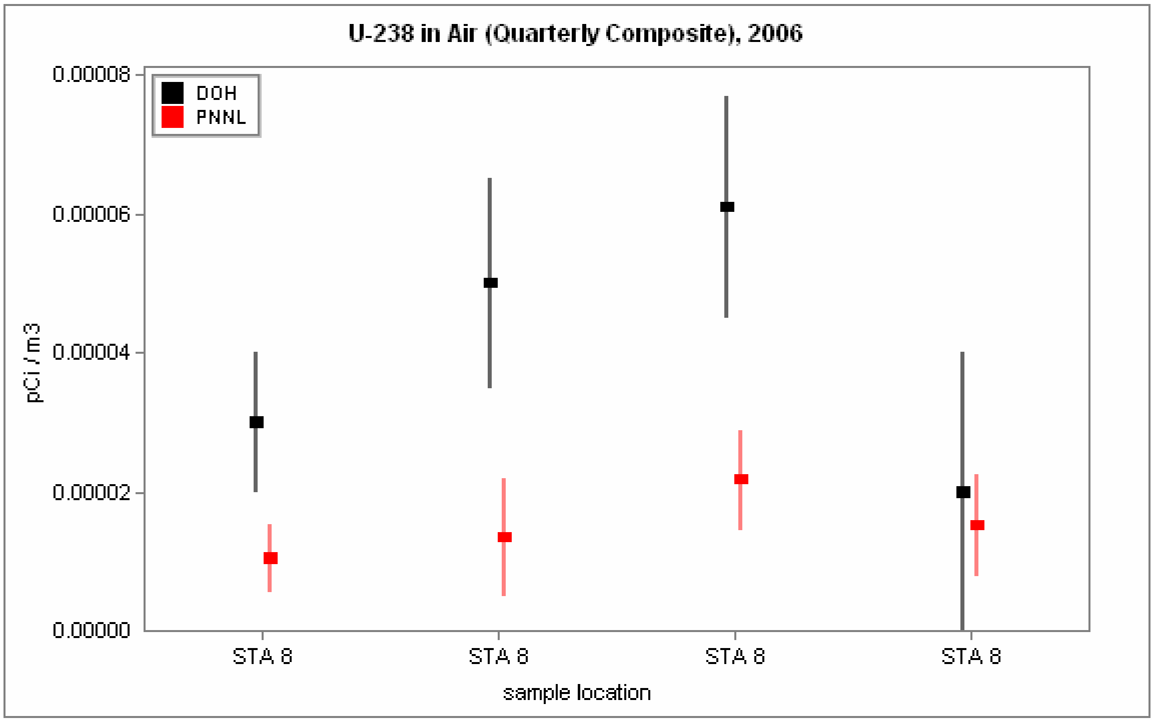

Figure 3.1.8 DOH and PNNL U-238 Concentrations in Air

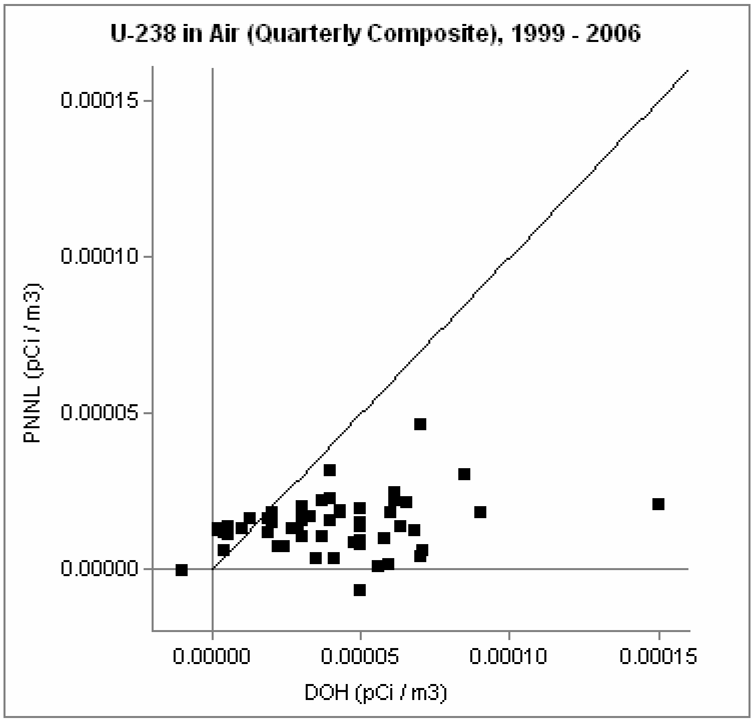

Figure 3.1.9 DOH and PNNL Scatter Plot for Historical U-238 Concentrations in Air

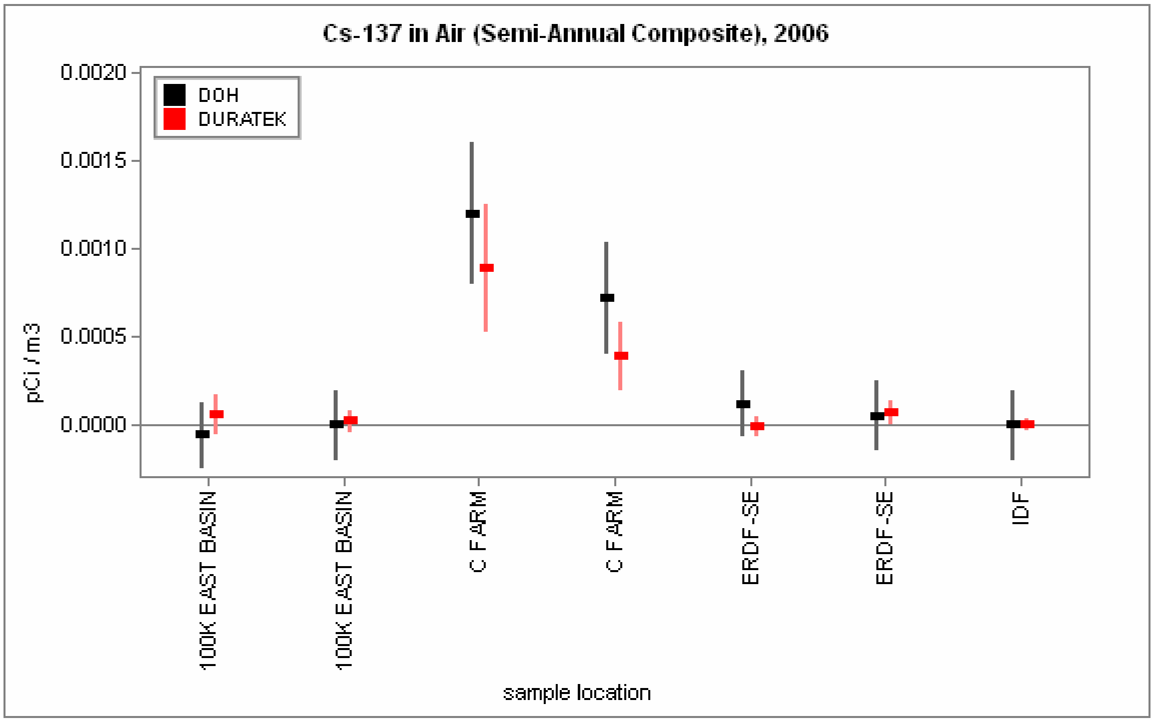

Figure 3.1.10 DOH and Duratek Cs-137 Concentrations in Air

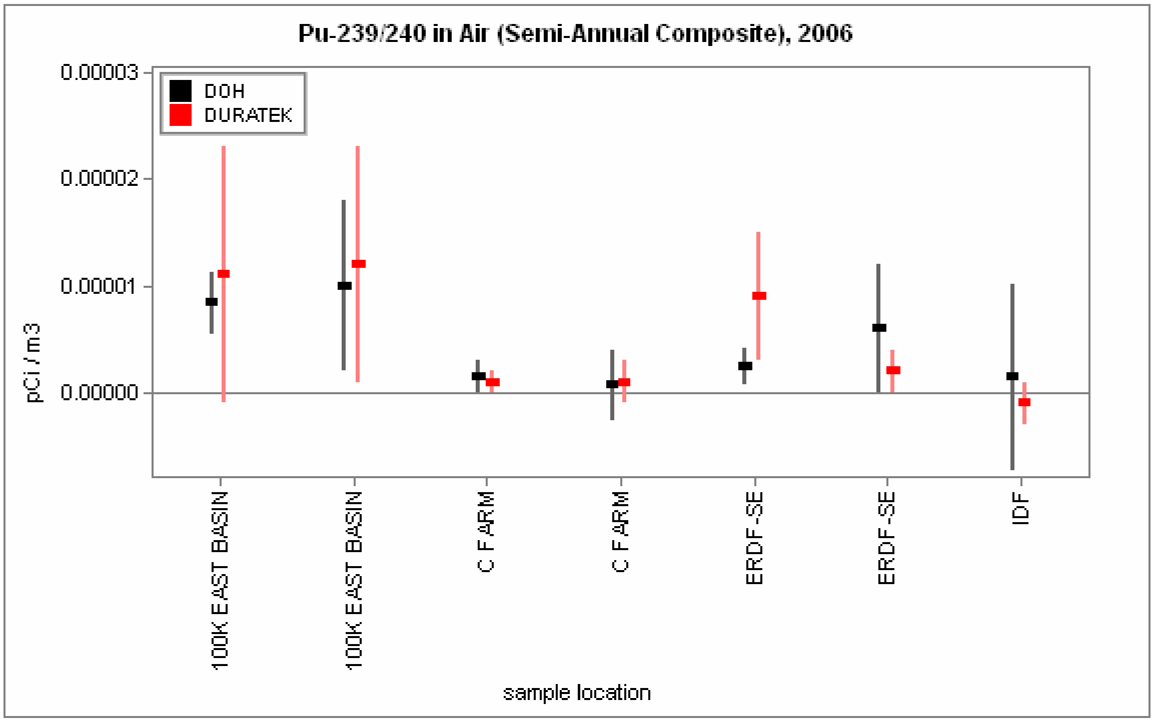

Figure 3.1.11 DOH and Duratek Pu-239/240 Concentrations in Air

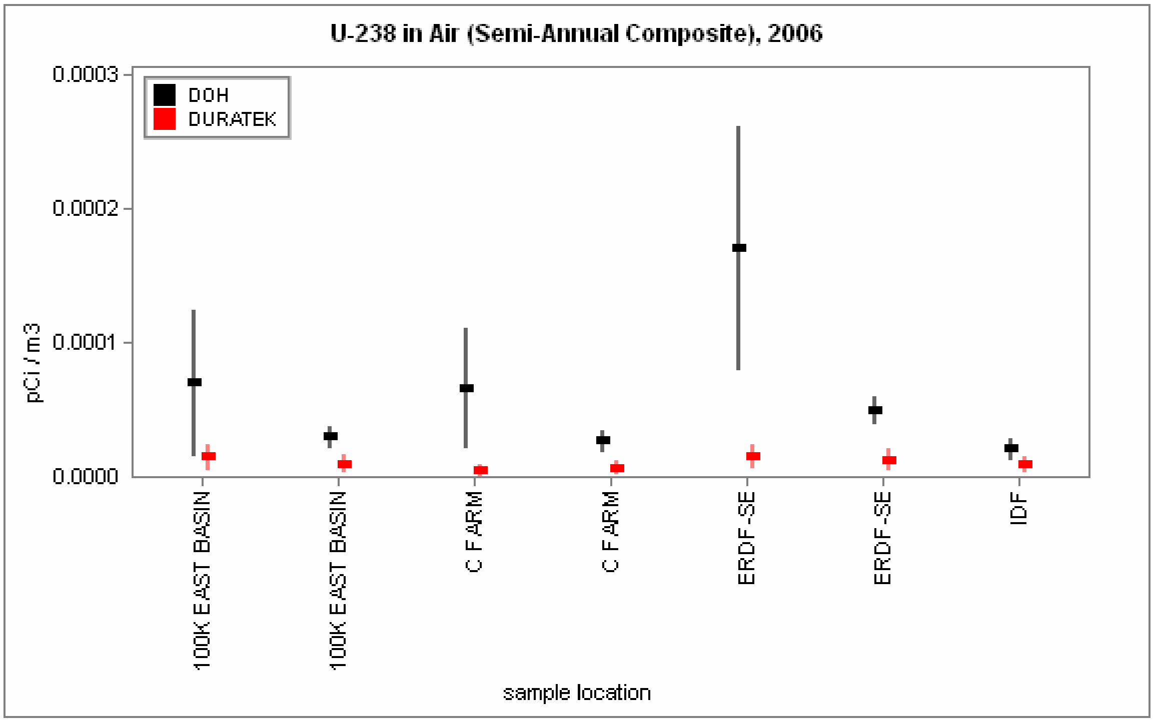

Figure 3.1.12 DOH and Duratek U-238 Concentrations in Air

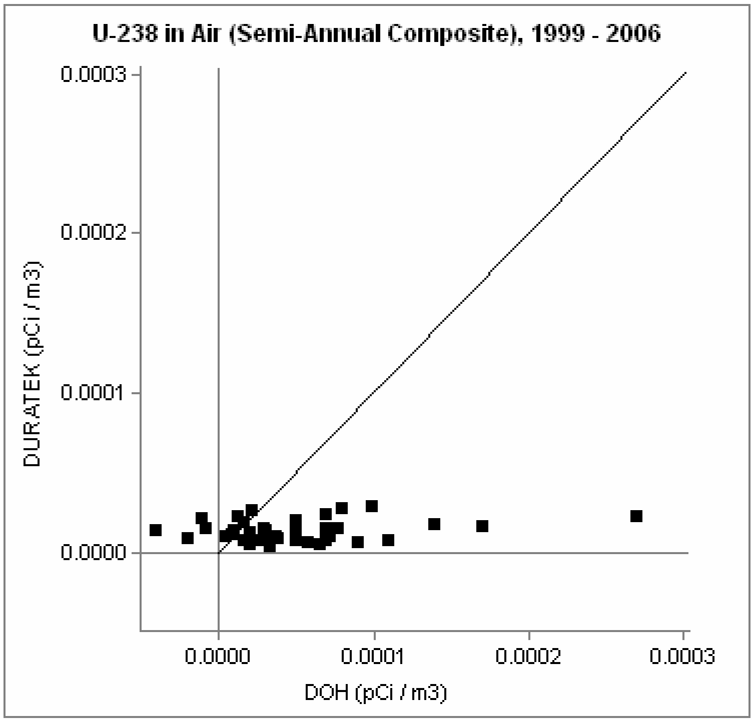

Figure 3.1.13 DOH and Duratek Scatter Plot for Historical U-238 Concentrations in Air

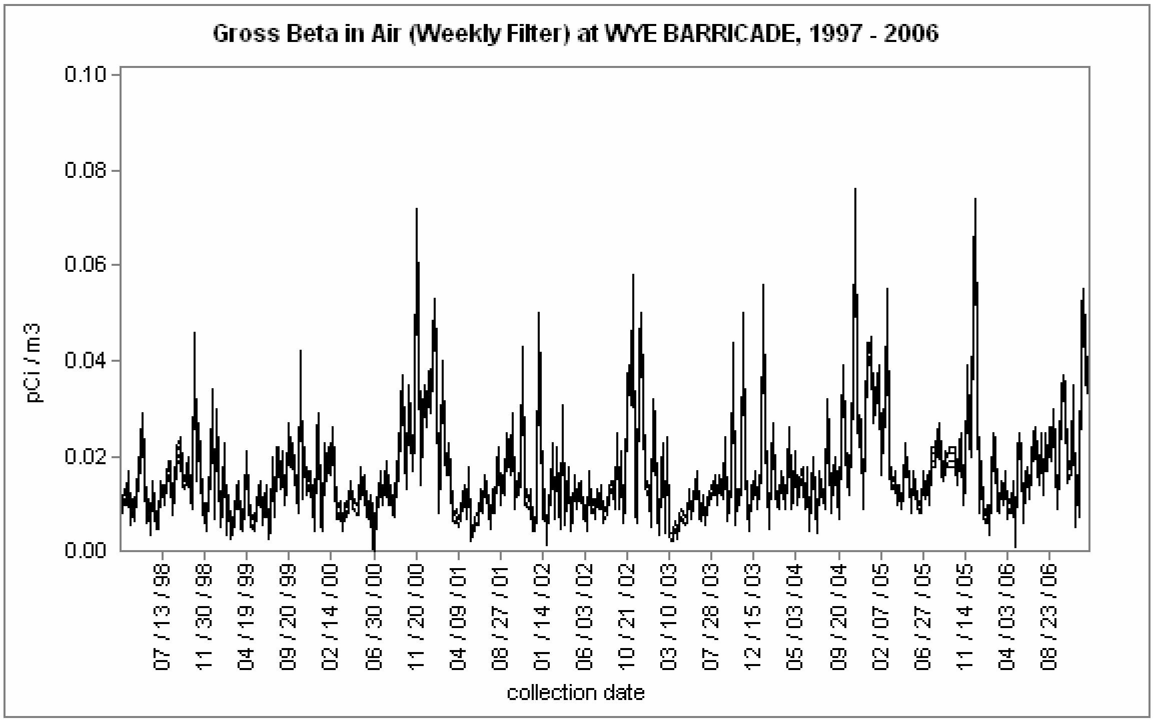

Figure 3.1.14 DOH Historical Gross Beta Concentrations in Air at Wye Barricade

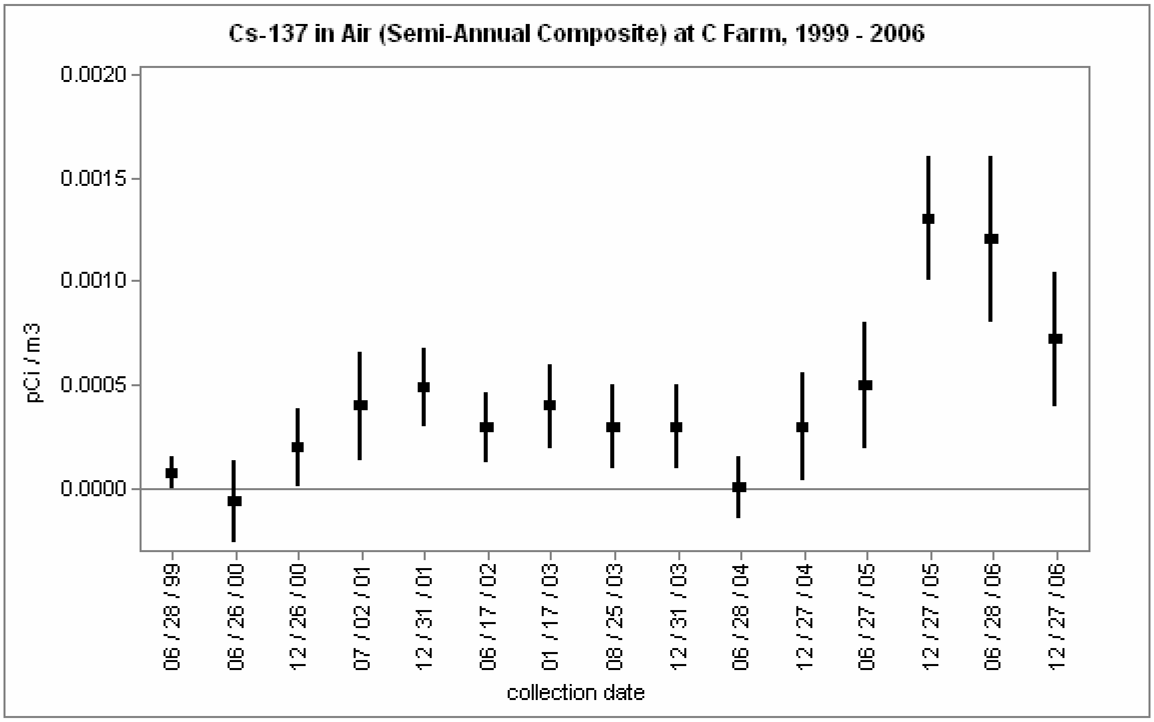

Figure 3.1.15 DOH Historical Cs-137 Concentrations in Air at C Farm

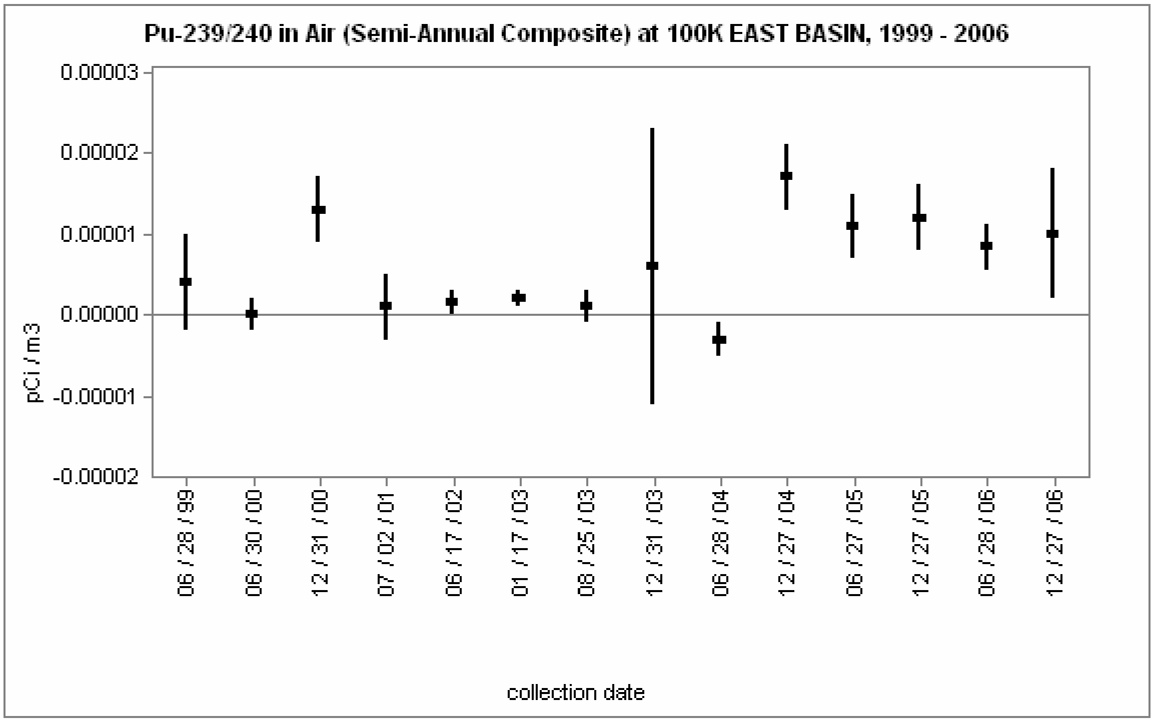

Figure 3.1.16 DOH Historical Pu-239/240 Concentrations in Air at KE Basin

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. Historically, the agreement for I-129 is poor; however, detectable concentrations were not found in any of the 2006 split samples. A small systematic bias exists in the gross alpha and gross beta results. The DOH and Duratek split water results are also in good agreement, with the exception of one H-3 result in a groundwater well.
- 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 some Hanford groundwater, seep water, and surface water samples. Most concentrations in 2006 samples are consistent with historical trends.
- Radionuclide concentrations in drinking water samples analyzed by DOH are all below federal standards.
- Radionuclide concentrations in TEDF discharge water samples are all below Washington State standards.

3.2.1 Purpose and General Discussion

Operations at the Hanford Site have resulted in contaminated groundwater and surface water. Radioactive contaminants have leached from waste sites in the soil to groundwater beneath the Site, and then have migrated with groundwater to the Columbia River. 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 typically splits groundwater, surface water, riverbank seep water, and drinking water samples 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 assess impacts to the public. In addition, DOH and DOE contractors split discharge water samples from an effluent treatment facility.

3.2.2 Monitoring Locations

The locations of water samples collected in 2006 are shown in Figure 3.2.1.

Groundwater

In 2006, DOH split 19 groundwater samples from 16 groundwater wells with PNNL, and split two samples from two groundwater wells with Duratek. Most co-sampled well locations are on the Hanford Site, either within contaminated plumes, near waste sites, or along the Columbia River shoreline. A few of the co-sampled well locations are off the Hanford Site, located just south of Hanford in the northern part of Richland.

Groundwater sampling is conducted in the 100, 200, 300, 400, and 600 Areas of the Hanford Site. The 100 Area consists of nine retired reactors and support facilities located along the Columbia River. Tritium (H-3) and Sr-90 are contaminants commonly found in groundwater beneath the reactor facilities. A primary objective of the groundwater collection in the 100 Area is to monitor contaminants that may enter the Columbia River. At the 100K Area, groundwater is sampled to evaluate potential changes in radioactivity as spent nuclear fuel, shield water, and sludge are removed from the 100 KE Fuel Storage Basin. Eight samples were split from this area in 2006.

The 200 Area consists of retired reactor fuel processing facilities located in the center of the Hanford Site on the central plateau. Common groundwater contaminants include H-3, I-129, Sr-90, Tc-99, and isotopes of uranium. A primary objective of groundwater collection in the 200 Area is to track radioactive plume movement and monitor potential leaks from waste storage tanks. One sample was split from this area in 2006.

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. Two samples were split from this area in 2006.

The 400 Area is the location of the Fast Flux Test Facility, a liquid sodium cooled test reactor that ceased operation in 1993. Tritium originating from the 200 Area is a common contaminant found in 400 Area groundwater. The primary objective of groundwater monitoring in this area is to assess impacts to the primary drinking water source for this part of Hanford. One sample was split from this area in 2006.

The 600 Area includes all the land outside the operational areas of the Hanford Site. Tritium originating from the 200 Area is a common contaminant found in 600 Area groundwater. The major objective of sampling 600 Area groundwater is to assess the nature and extent of radioactive plumes originating in the 200 Area that may be moving off-site. Nine samples were split from this area in 2006.

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 Town Site, and the 300 Area. DOH and PNNL split four Columbia River riverbank seep samples in 2006. Sample locations included the 100K and 100N areas, the Old Hanford Town Site (Spring 28.2), and the 300 Area.

Surface Water

DOH and PNNL split 20 surface water samples in 2006. Eighteen of the samples were collected from the Columbia River - two from near Priest Rapids Dam located upstream of Hanford, four from the 100N Area, four from the Old Hanford Town Site, four from the 300 Area, and four from near the Richland drinking water pump house. Two of the samples were collected from irrigation canals, one located across the Columbia River at Riverview, and the other at the southern boundary of the Hanford Site at the Horn Rapids Yakima River irrigation pumping station.

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

Discharge Water

DOH conducts discharge effluent monitoring at the 310 Treated Effluent Disposal Facility (TEDF) as acknowledged in the Aquatic Lands Sewer Outfall Lease No. 20-013357. This agreement between the Department of Natural Resources (DNR) and DOE requires DOH to provide oversight of the discharge effluent monitoring program by splitting approximately 15% of the 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 Duratek split two discharge water samples in 2006.

Drinking Water

Drinking water is supplied to DOE facilities on the Hanford Site by numerous water systems, most of which use water from the Columbia River. One of these systems, in the 400 Area–the Fast Flux Test Facility (FFTF), uses groundwater from the unconfined aquifer beneath the site. Typically, DOH and PNNL split one or more drinking water samples each year. One sample from FFTF was split in 2006. In addition to the split FFTF sample, DOH collected a drinking water sample from the Laser Interferometer Gravitational-Wave Observatory (LIGO) Facility and from the Edwin Markham elementary school in Pasco, of which both results are presented in this report.

3.2.3 Monitoring Procedures

Groundwater

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

Riverbank Seeps

Columbia River 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 samples are also collected from near the Hanford shoreline at locations where known groundwater plumes are near the river. In addition, Columbia River water is collected at Richland. Finally, surface water samples are collected from irrigation pumping stations located at Horn Rapids (Yakima River water) and Riverview (Columbia River water).

Samples were split in the field and analyzed unfiltered. All samples were analyzed for isotopes of uranium and for H-3. Analyses for gross alpha, gross beta, gamma emitting radionuclides, Sr-90, and Tc-99 were added where appropriate. Discharge samples from the 310 Treated Effluent Disposal Facility (TEDF) were analyzed for gross alpha, gross beta, gamma emitting radionuclides, and H-3.

Drinking Water

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

Summary

A summary of the 2006 water samples is presented in Table 3.2.1.

Water Matrix	Analytes	Number of Sample Sites	Number of Samples
Groundwater	C-14; Co-60; Cs-134, 137; Eu-152, 154, 155; gross alpha; gross beta; H-3; I-129; Ru-106; Sb-125; Sr-90; Tc-99; U-234, 235, 236, and 238	17	21
Riverbank Seep	Co-60; Cs-134, 137; Eu-152, 154, 155; gross alpha; gross beta; H-3; I-129; Ru-106; Sb-125; Sr-90; Tc-99; U-234, 235, 236, and 238	4	4
Surface Water	Co-60; Cs-134, 137; Eu-152, 154, 155; gross alpha; gross beta; H-3; Ru-106; Sb-125; Sr-90; Tc-99; U-234, 235, and 238	19	20
Discharge Water	Co-60, Cs-137, gross alpha, gross beta, H-3	1	2

Table 3.2.1 Summary of Water Samples

3.2.4 Comparison of DOH and DOE Contractor Data

In 2006, DOH split groundwater, surface water, riverbank seep water, and drinking water samples with PNNL. In addition, DOH split groundwater and discharge water samples with Duratek. 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.

DOH/PNNL Results - Gamma Emitting Radionuclides

Gamma emitting radionuclides also emit beta particles, and in some cases (for example, I-129), the beta particle is more important from the standpoint of health impacts. In this report, the term *gamma emitting radionuclide* refers to the fact that radioactivity concentrations were obtained by measuring gamma ray activity using gamma spectroscopy.

The DOH and PNNL concentrations of gamma emitting radionuclides in split water samples are all in agreement, and all results are below detection limits.

Historically, DOH and PNNL split water results are in good agreement for all gamma emitting radionuclides except I-129, in which case discrepancies have been observed. In 2006, two split groundwater samples included analysis for I-129, and the DOH and PNNL concentrations are in agreement, but the results are below the detection limit. See Section 4 of this report for a further discussion of I-129.

DOH/PNNL Result - Gross Alpha and Gross Beta

The DOH and PNNL gross alpha concentrations in water samples are in fair agreement. The split gross alpha results in all water samples collected in 2006 are shown in Figure 3.2.2, where it can be seen that the DOH and PNNL data generally agree. However, a 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 concentrations in water samples. This scatter plot, and all others in this section, show data for all water samples, which include groundwater, surface water, riverbank seep water, drinking water, and discharge water. The figure shows that DOH disproportionately reports higher concentrations than PNNL, as indicated by the data points to the right of the solid black line.

The DOH and PNNL gross beta concentrations in water samples are in fair agreement. The split gross beta results in all water samples are shown in Figure 3.2.4, where it can be seen that the DOH and PNNL data generally agree. However, a 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, specifically for data with concentrations below 150 pCi/L. The figure indicates that for the lower range of gross beta concentrations, there is a systematic bias in the results in which DOH disproportionately reports higher concentrations than PNNL, as indicated by the data points to the right of the solid black line. For the higher range of concentrations, most of the DOH and PNNL concentrations are in agreement.

DOH/PNNL Results - H-3, Sr-90, and Tc-99

The DOH and PNNL tritium (H-3) concentrations in water samples are in fair agreement. Figure 3.2.6 shows H-3 results in split water samples for cases where concentrations are greater than 500 pCi/L. As can be seen, the DOH and PNNL reported concentrations are similar; however, there are several cases where the split concentrations do not agree. This phenomenon has been observed historically, as seen in Figure 3.2.7, which shows the scatter plot of historical H-3 water sample results. The regression analysis indicates that PNNL results are typically 8% less than those reported by DOH.

For H-3 concentrations less than 500 pCi/L, there is a systematic discrepancy between the DOH and PNNL results, as shown in Figures 3.2.8 and 3.2.9, where most of the DOH concentrations are about twice as high as those reported by PNNL. This discrepancy for low concentrations of H-3 has not been observed in the past.

The DOH and PNNL concentrations for Sr-90 and Tc-99 in water samples are in good agreement. As an example, Figure 3.2.10 shows the split Sr-90 concentrations in water samples in which the concentrations are above the DOH detection limit of 0.7 pCi/L. Historically, the DOH and PNNL split results for Sr-90 and Tc-99 in water are in fair to good agreement. Scatter plots for historical Sr-90 and Tc-99 results are shown in

Figures 3.2.11 and 3.2.12, in which most of the data fall near the line where DOH and PNNL concentrations are equal.

DOH/PNNL Results - Uranium Isotopes

The DOH and PNNL isotopic uranium concentrations for U-234, 235, and 238 in water samples collected in 2006 are in good agreement. Historically, the DOH and PNNL split results for these uranium isotopes in water are in good agreement.

DOH detected U-236 in several groundwater and seep water samples. No U-236 results were reported by PNNL. Section 3.2.5 discusses the DOH U-236 results.

DOH/Duratek

DOH split two discharge water samples and two groundwater samples with Duratek. The DOH and Duratek concentrations are in good agreement for gamma emitting radionuclides (Co-60 and Cs-137), gross alpha, gross beta, and Tc-99. Most of the H-3 concentrations are in good agreement, with one exception at groundwater well 699-31-31, where DOH measured 9,000 pCi/L while Duratek measured 6,000 pCi/L. Historically, DOH and Duratek results for H-3, and all other analytes, in water samples are in good agreement, so this particular H-3 result appears to be an anomaly.

3.2.5 Discussion of DOH Results

In addition to the split water samples discussed above, DOH collected and analyzed drinking water samples from the LIGO Facility and the Edwin Markham elementary school in Pasco; and groundwater samples from wells 699-31-31, 699-35-70, and 699-49-100C. DOH also reported C-14 and U-236 in some of the split water samples. Results from these additional DOH samples and analyses are included in the discussion below.

Concentrations of gamma emitting radionuclides in all 2006 water samples analyzed by DOH were below detection limits, except for two I-129 samples from groundwater well 699-35-70. Gamma emitting radionuclides include Co-60, Cs-134, Cs-137, Eu-152, Eu-154, Eu-155, I-129, Ru-106, and Sb-125. Detection limits are listed in Appendix B. All 2006 results for gamma emitting radionuclides in water samples are similar to historical data.

Iodine-129 was detected by DOH in two samples from groundwater well 699-35-70 at 10 pCi/L. These samples were not split with a DOE contractor. DOH typically detects I-129 in this well, at concentrations ranging from 5 to 35 pCi/L.

DOH detected C-14 in groundwater wells 199-K-27 and 199-K-109A. DOE contractors did not report C-14 results for these split samples. Both of these wells are in the vicinity of a known C-14 groundwater plume at the 100K Area. Carbon-14 has been detected in well 199-K-27 for the past several years at concentrations ranging from 300 to 700 pCi/L.

However, a concentration of 1,600 pCi/L was detected in 2006. DOH has analyzed for C-14 in well 199-K-109A since 1999, with all historical results below detectable concentrations. However, a concentration of 1,550 was detected in 2006, indicating the C-14 plume is moving through this well location. The EPA drinking water standard for this radionuclide is 2,000 pCi/L.

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 2006, 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 267,000 pCi/L (well 699-35-70). Concentrations above the 20,000 pCi/L EPA drinking water standard were detected in wells 199-K-27, 199-N-14, 699-26-33, 699-35-70, 699-41-1A, and 699-60-60. Tritium (H-3) concentrations in most wells historically sampled by DOH continue to steadily decrease with time. Groundwater wells 199-K-109A and 199-K-27, at the 100K Area, had sharp increases in H-3 concentrations in 2003; however, the concentrations have since been decreasing.

DOH detected H-3 in all riverbank seep water samples, with concentrations ranging from 100 to 8,800 pCi/L (100N Area seep). Tritium concentrations in all riverbank seep samples analyzed by DOH were below the EPA drinking water standard of 20,000 pCi/L. These results are consistent with historical DOH riverbank seep results. Tritium was also detected at low levels in several of the Columbia River surface water samples, with a maximum concentration of 8,000 pCi/L adjacent to the Old Hanford Townsite. Tritium was detected in TEDF discharge water at 180 pCi/L, and in FFTF drinking water at 2,900 pCi/L (well below the EPA drinking water standard of 20,000 pCi/L). Tritium was detected at very low levels in the LIGO and Edwin Markham drinking water samples (both at 90 pCi/L).

DOH detected Sr-90 in groundwater wells at concentrations ranging from below the detection limit to 1,200 pCi/L (well 199-N-14). Concentrations above the 8 pCi/L EPA drinking water standard were detected at wells from the 100F, 100K, and 100N Areas, where the 2006 results are consistent with historical concentrations at these locations. Concentrations of Sr-90 in riverbank seep water ranged from below the detection limit to 1.3 pCi/L at a seep in the 100K Area. Strontium-90 was not detected in the 100N Area seep water sample, however, it was detected at 1.7 pCi/L in two Columbia River samples adjacent to the 100N Area. Strontium-90 was not detected in any other Columbia River surface water samples. The concentrations of Sr-90 measured in 2006 water samples are consistent with historical results

DOH detected Tc-99 in groundwater wells at concentrations ranging from below the detection limit to 185 pCi/L (well 699-60-60). Technetium-99 was detected in Old Hanford Town Site seep water at 10 pCi/L, and was not detected in any of the Columbia River surface water samples. The concentrations of Tc-99 measured in 2006 water samples are consistent with historical results, and all concentrations are below the EPA drinking water standard of 900 pCi/L.

DOH detected total uranium (the sum of all uranium isotopes) concentrations in water samples ranging from below the detection limit to approximately 100 pCi/L at a 300 Area riverbank seep and groundwater well. The EPA drinking water standard for total uranium is 21 pCi/L. The 2006 results at these locations are consistent with historical results.

Isotopic uranium results are typically reported for U-234, U-235, and U-238. Uranium-236 is another isotope of uranium, one that does not occur in nature, but rather is a byproduct of Hanford reactor operations. Uranium-236 is occasionally detected in Columbia River sediments and in water samples. In 2006, DOH detected U-236 in groundwater samples from the 100H and 300 Areas, and in a riverbank seep from the 300 Area. Concentrations ranged from 0.1 to 1.6 pCi/L, and the 2006 concentrations are consistent with historical results.

Uranium-234 and uranium-238 concentrations in water samples ranged from below the detection limit to 58 pCi/L (300 Area groundwater well). Uranium-235 concentrations ranged from below the detection limit to 2.3 pCi/L (300 Area groundwater well). Isotopic uranium results in 2006 are consistent with 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 C-14, H-3, I-129, Sr-90, Tc-99, and isotopes of uranium. Most radionuclide concentrations in 2006 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. Most radionuclide concentrations in 2006 were similar to historical data, and were detected in the vicinity of where groundwater plumes are known to be entering the Columbia River.

Radionuclides detected in surface water include H-3, Sr-90, and isotopes of uranium. Most radionuclide concentrations were either below detection limits or were similar to background concentrations detected at Priest Rapids Dam upstream of the Hanford Site. Elevated H-3 concentrations were detected in near-shore Columbia River surface water from the Old Hanford Townsite. However, all surface water concentrations were below EPA drinking water standards.

Radionuclides detected in drinking water samples include H-3. However, all concentrations were below EPA drinking water standards (20,000 pCi/L for H-3).

Radionuclides detected in discharge water include H-3. 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.

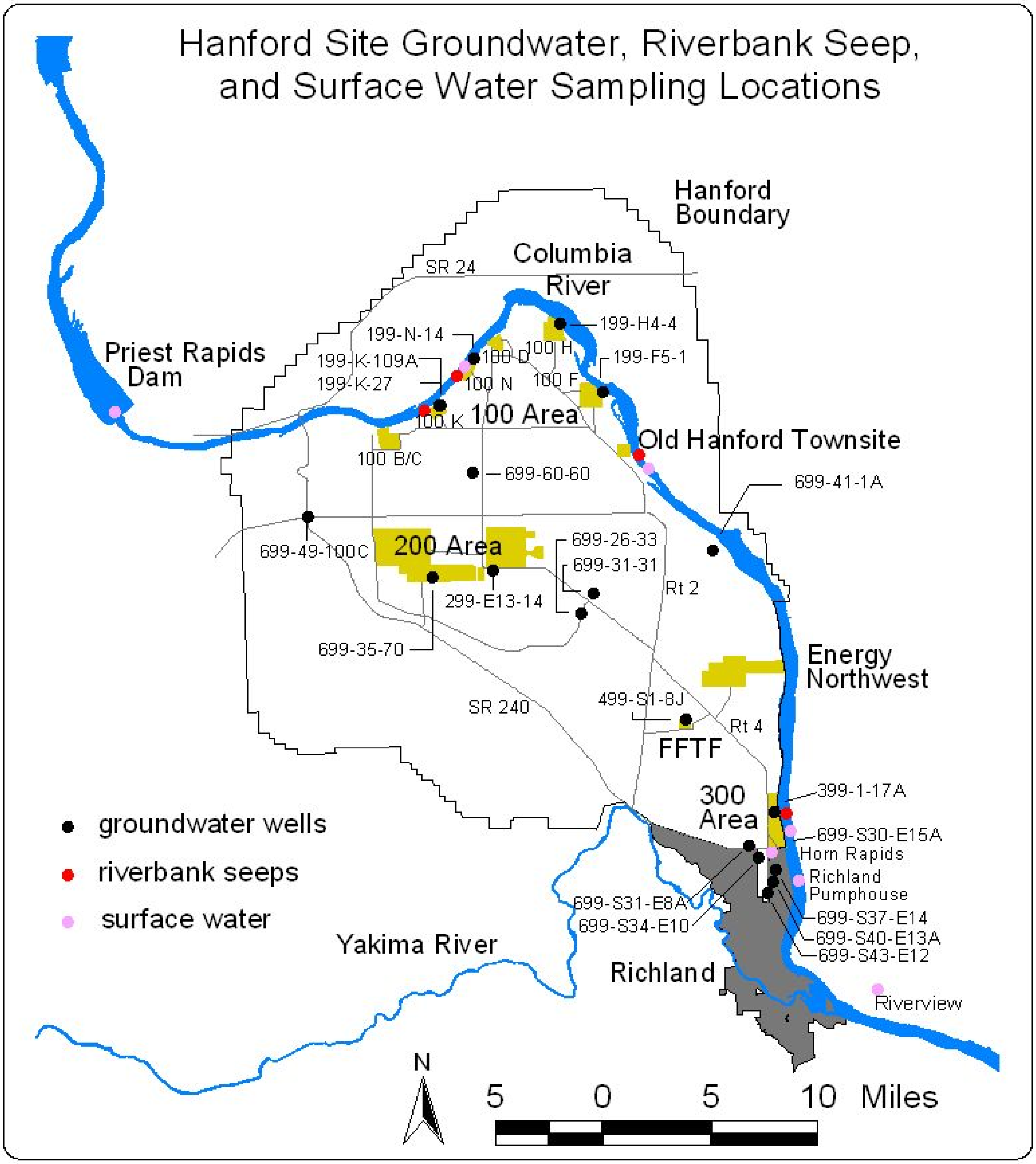

Figure 3.2.1 Water Monitoring Locations

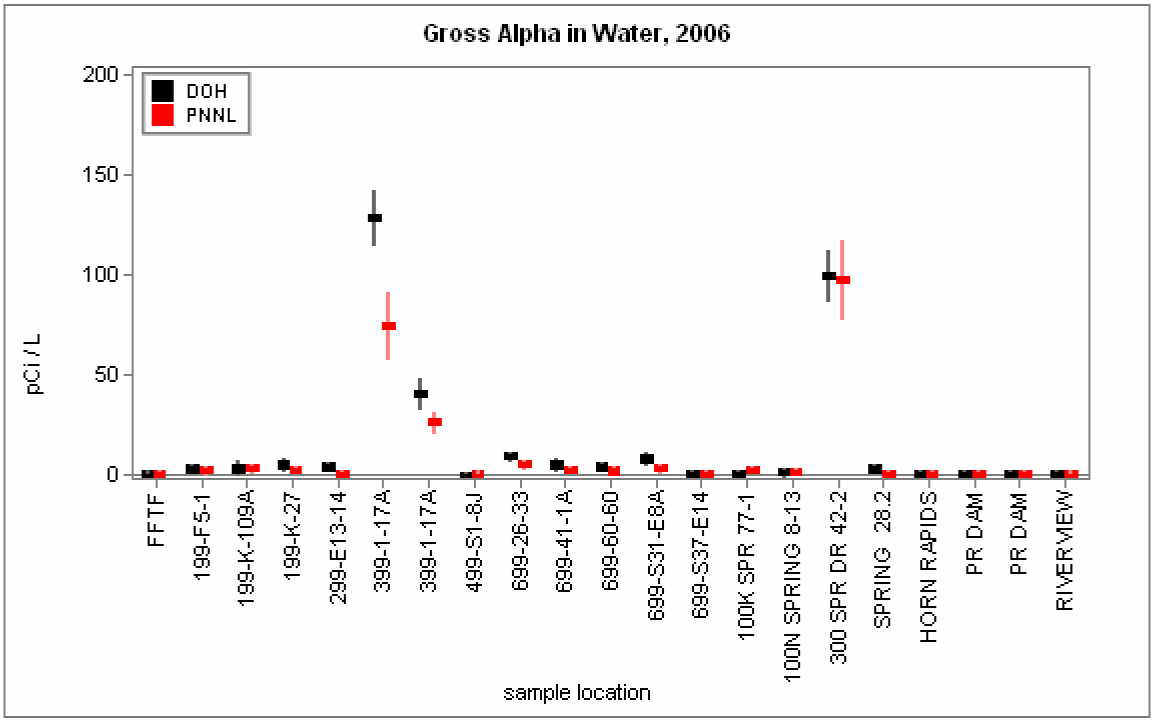

Figure 3.2.2 DOH and PNNL Gross Alpha Concentrations in Water Samples

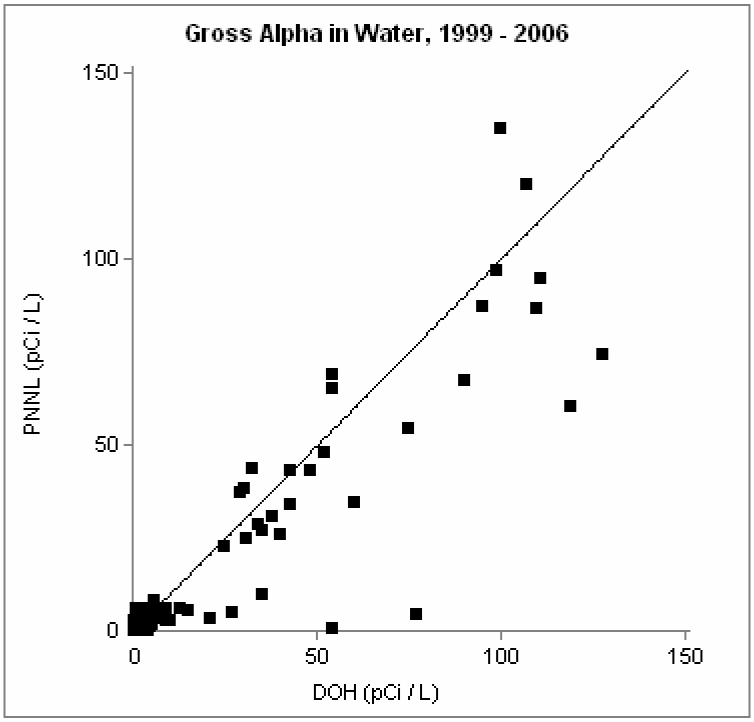

Figure 3.2.3 DOH and PNNL Scatter Plot for Historical Gross Alpha Concentrations in Water Samples

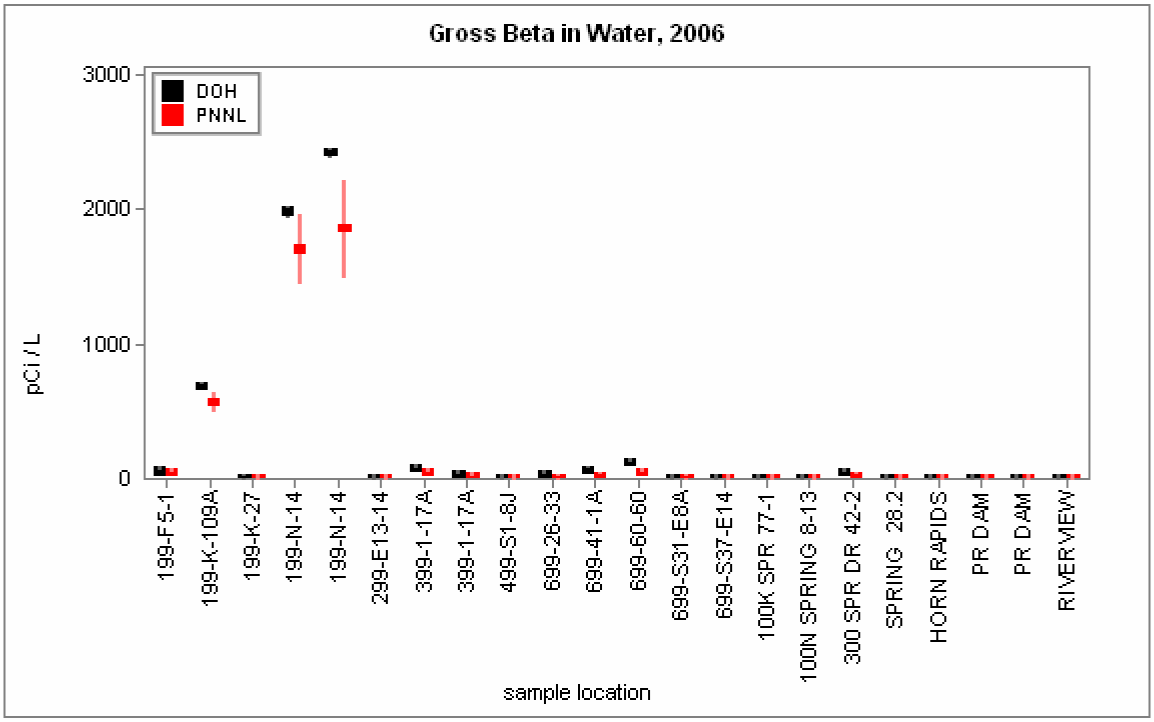

Figure 3.2.4 DOH and PNNL Gross Beta Concentrations Water Samples

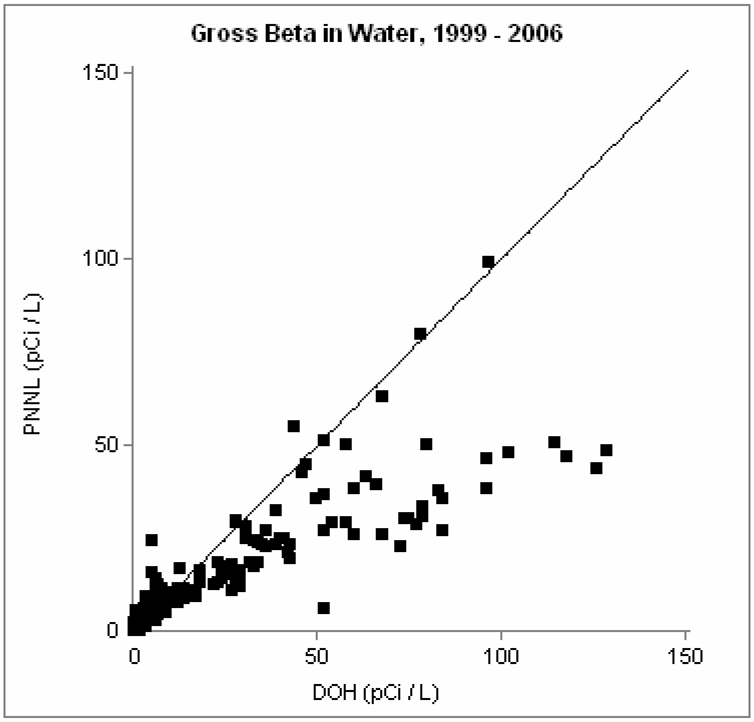

Figure 3.2.5 DOH and PNNL Scatter Plot for Historical Gross Beta Concentrations in Water Samples (results less than 150 pCi/L)

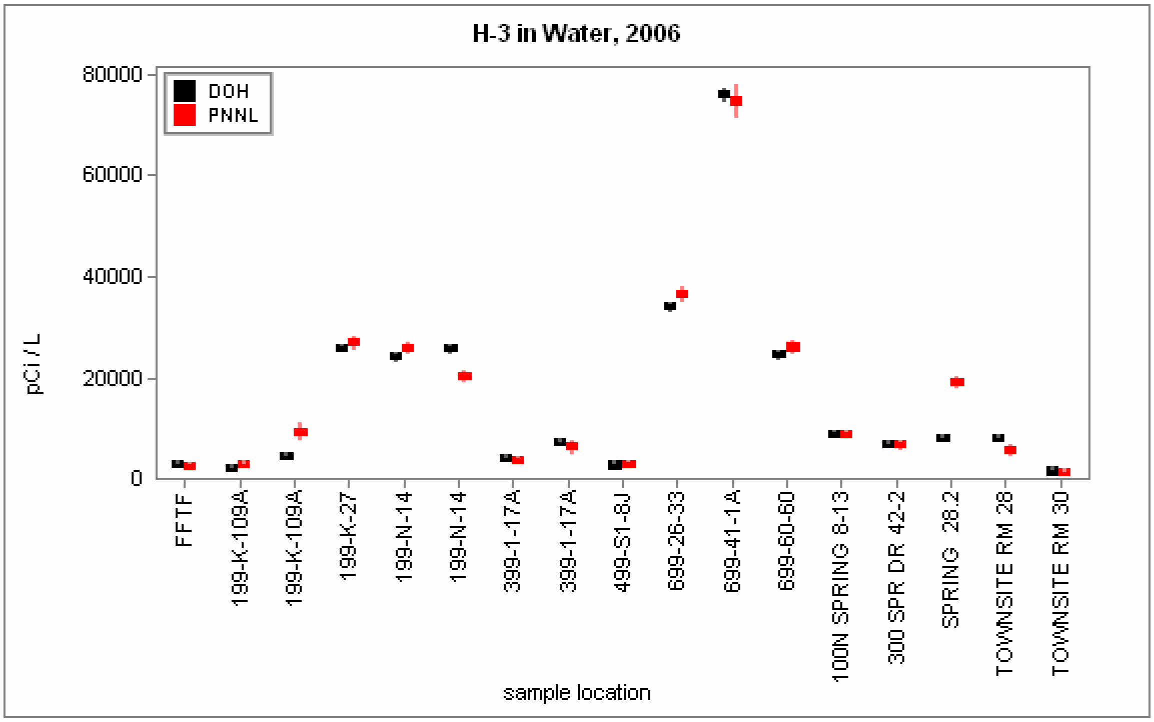

Figure 3.2.6 DOH and PNNL H-3 Concentrations in Water Samples for Concentrations Greater than 500 pCi/L

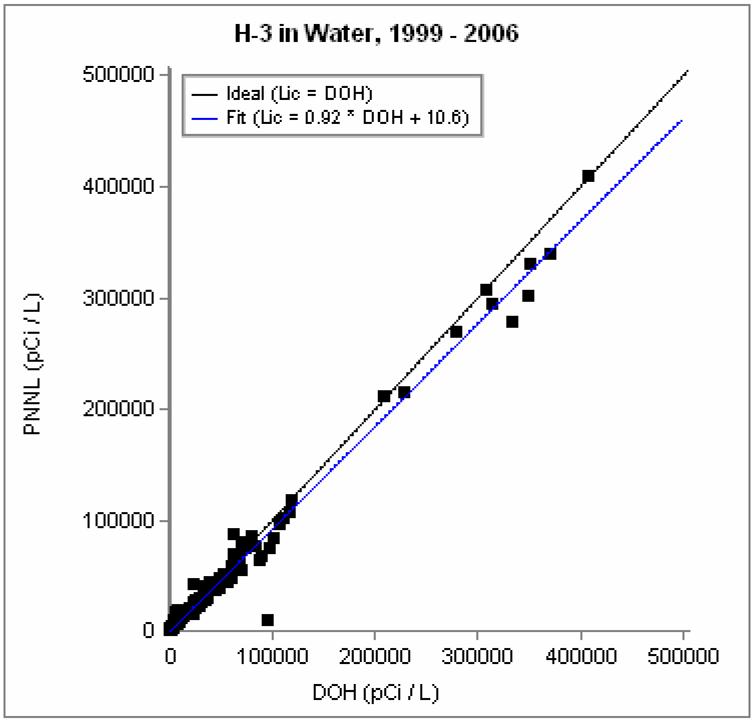

Figure 3.2.7 DOH and PNNL Scatter Plot for Historical H-3 Concentrations in Water

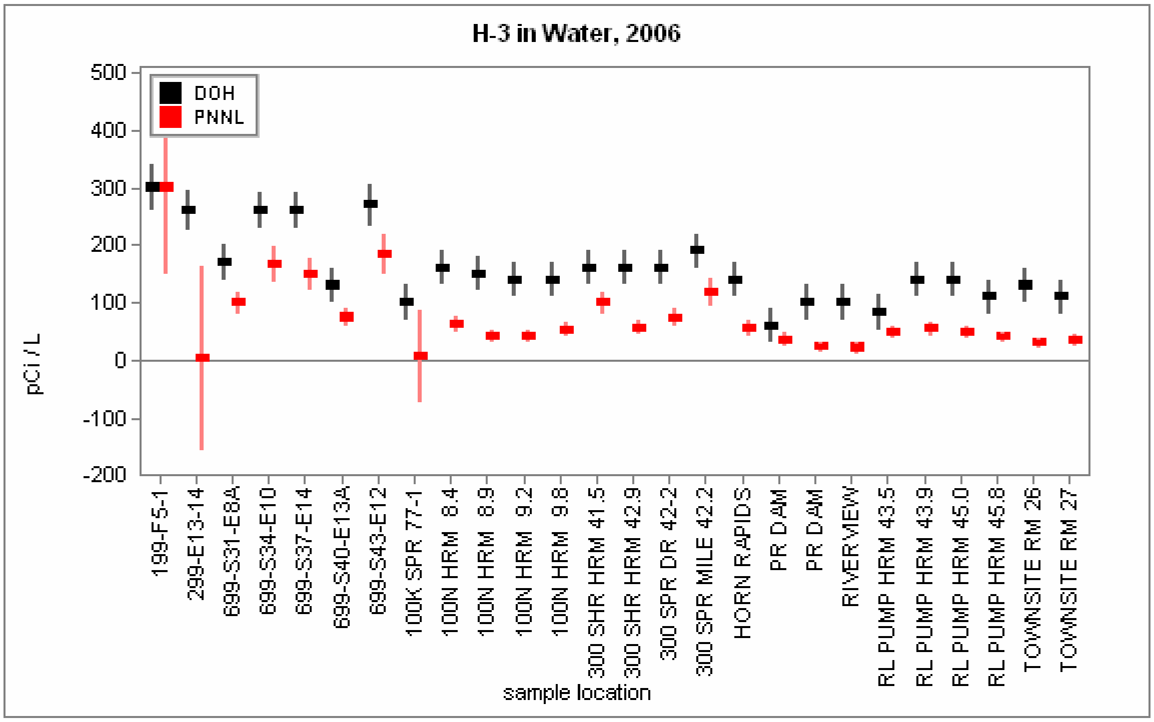

Figure 3.2.8 DOH and PNNL H-3 Concentrations in Water Samples For Concentrations Less than 500 pCi/L

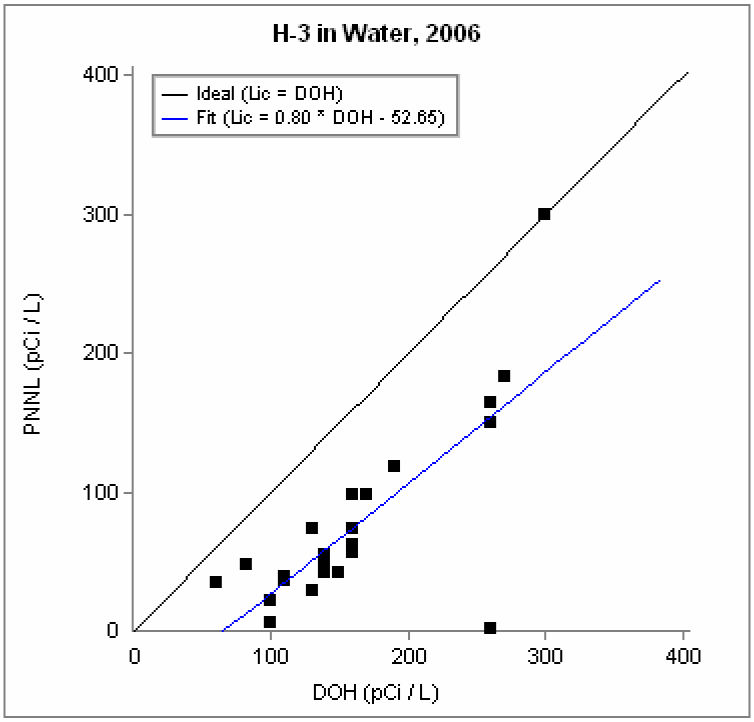

Figure 3.2.9 DOH and PNNL Scatter Plot for H-3 Concentrations in Water For Concentrations Less than 500 pCi/L

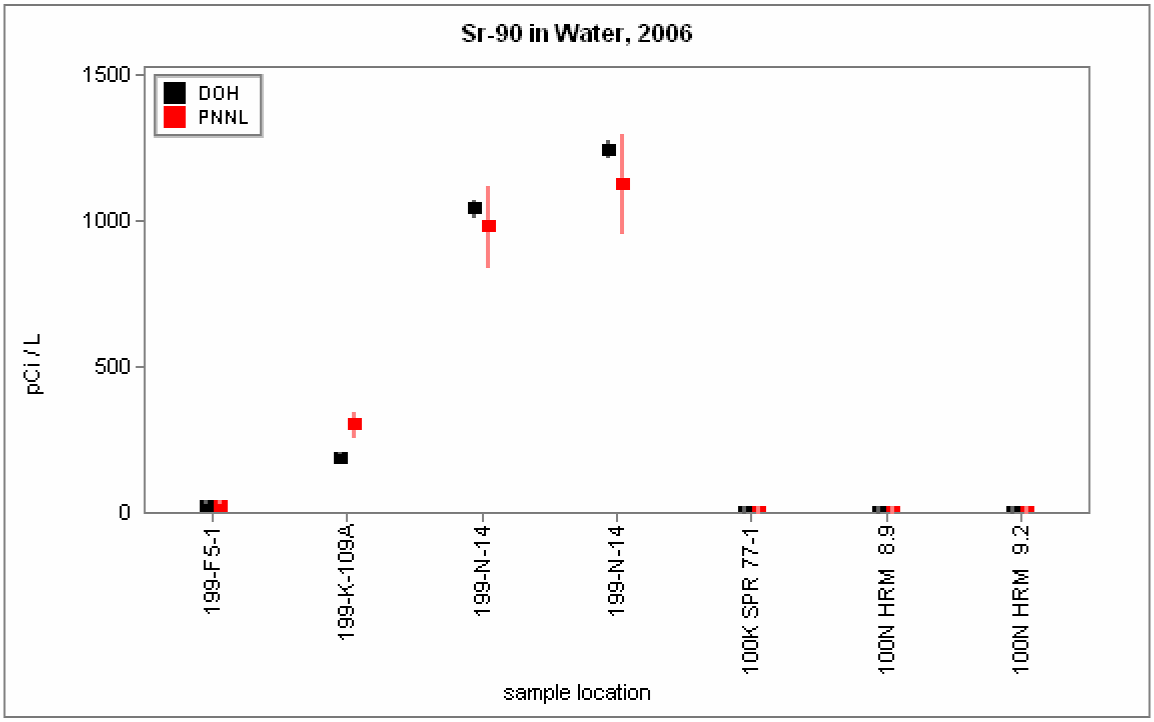

Figure 3.2.10 DOH and PNNL Sr-90 Concentrations in Water Samples for Concentrations Greater than the DOH Detection Limit of 0.7 pCi/L

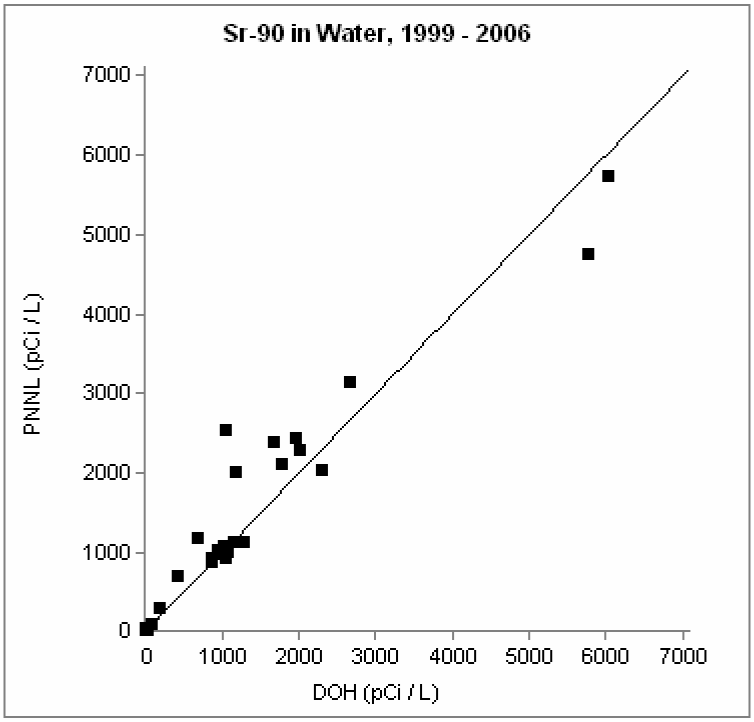

Figure 3.2.11 DOH and PNNL Scatter Plot for Historical Sr-90 Concentrations in Water

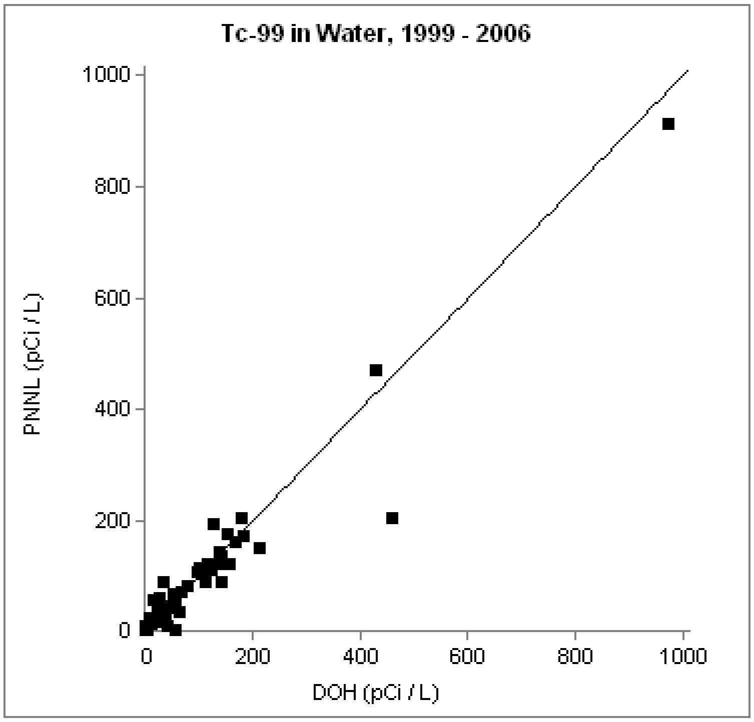

Figure 3.2.12 DOH and PNNL Scatter Plot for Historical Tc-99 Concentrations in Water

3.3 External Gamma Radiation Monitoring

Major Findings:

- The DOH and Duratek external radiation rate (TLD) results are in good agreement.
- Radiation exposure rates at most DOH TLD locations on the Hanford Site are consistent with historical results and are similar to rates at locations outside the Hanford perimeter.
- Exposure rates near the KE Basin at Hanford's 100K East Area were anomalously high in 2006 due to temporary outdoor storage of radioactive materials. Exposure rates along the Columbia River were consistent with background.

3.3.1 Purpose and General Discussion

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

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

DOH has historically maintained TLD monitoring sites colocated with (1) Duratek, which runs the Near-facility TLD monitoring program; and (2) PNNL, which ran the site-wide and off-site locations TLD monitoring program. In 2006, PNNL dropped their TLD program. In response, DOH has added 26 new TLD locations along the Columbia River to monitor locations that were previously monitored by PNNL. In addition, DOH will continue to maintain its original TLD sites that were colocated with PNNL. Therefore, from 2006 forward, the TLD section of this report will cover the sites colocated with Duratek, as well as the sites operated independently by DOH.

3.3.2 Monitoring Locations

In 2006, DOH operated 52 terrestrial and Columbia River external radiation monitoring sites (TLD sites). Forty-three of these sites are operated under the Hanford Environmental Oversight Program, in which five sites are colocated with Duratek and the remaining sites are independently monitored. DOH also maintains numerous sites colocated with the Columbia Generating Station monitoring program, and the DOH results for nine of these sites, which are located along the Hanford perimeter, are also included in this report.

The DOH TLD site locations are shown in Figure 3.3.1. Nine of the sites are near Hanford facilities with known, suspected, or potential radiation sources. Three sites (Yakima and Wye Barricades, and LIGO Facility) are located on the Hanford Site, but away from radiation sources. Twenty-six sites are along the Columbia River shoreline from the Vernita Bridge to downstream of Bateman Island at the mouth of the Yakima River. Ten sites are located around 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 colocated with air monitoring sites.

3.3.3 Monitoring Procedures

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

The twenty-six new sites described above were deployed in the summer of 2006, and therefore only third and fourth quarter data were collected. In addition, the distant site at Toppenish was discontinued midyear of 2006, so only first and second quarter data are presented at this site.

3.3.4 Comparison of DOH and Contractor Data

The DOH and Duratek TLD results for the five colocated sites are shown in Figure 3.3.2. This figure shows the first, second, third, and fourth quarter results at 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 dose rates are typically slightly higher than those reported by DOH.

A scatter plot of historical DOH/Duratek TLD data for all the colocated sites is shown in Figure 3.3.3. The small discrepancy between DOH and Duratek results is seen by the preponderance of points to the left of the solid black line, which indicates that the DOE contractor is reporting slightly higher exposure rates (about 10%) than DOH. This discrepancy is small, and is not considered significant.

3.3.5 Discussion of DOH Results

The DOH external radiation rates measured in 2006 are shown in Figures 3.3.4 through 3.3.9. Sites near known, suspected, or potential sources of radiation (with the exception of the site at 100K East, which is discussed separately) are shown in Figure 3.3.4, while sites on the Hanford Site, but away from sources of contamination, are shown in Figure 3.3.5. Data for sites along the Columbia River are shown in Figures 3.3.6 and 3.3.7, sites around the Hanford perimeter are shown in Figure 3.3.8, and sites distant from Hanford are shown in Figure 3.3.9. The average annual exposure rate from each of these location categories is listed in Table 3.3.1.

Location Category	Average Exposure Rate
Near known, suspected, or potential radiation sources	0.22 mrem/day
Away from contaminated areas	0.23 mrem/day
Along the Columbia River	0.20 mrem/day
Around the Hanford perimeter	0.23 mrem/day
Distant from Hanford	0.19 mrem/day

Table 3.3.1 Average External Exposure Rates

The average exposure rate from sites near radiation sources is 0.22 mR/day, which is similar to the value of 0.23 mrem/day from sites at Hanford but away from contaminated facilities and sites around the Hanford perimeter. The data indicate that areas monitored on-site do not contribute additional exposure rates above background.

The average exposure rates at locations along the Columbia River and distant from Hanford, 0.20 and 0.19 mR/day respectively, are slightly lower than the rates on-site and at perimeter locations. Along the Columbia River, lower exposure rates are expected due to shielding of natural terrestrial radiation by water in the Columbia River. The distant sites are located in areas covered by concrete or gravel, whereas most other sites are located directly over soil. For example, the Yakima Airport site is on a concrete tarmac. Concrete and gravel, like water in the river, shield the terrestrial component of natural radiation. Therefore, lower exposure rates are expected at these sites.

Historically, DOH has measured elevated exposure rates at site 100N Spr, which is within Hanford's 100N Area (see Figure 3.3.10). The exposure rate at this site has steadily been decreasing with time due to the natural decay of Co-60 surface contamination. With the recent cleanup of contaminated surface soil, exposure rates over the past few years now appear constant, at rates similar to those at perimeter locations. In 2006, the average exposure rate at this site was 0.23 mR/day.

Anomalous results were seen in 2005 at location 100K East Basin within Hanford's 100K East Area. Figure 3.3.11 shows historical TLD data at this location. Radioactive material was temporarily stored outside of the KE Basin facility in 2005 and 2006. The TLD detected increased radiation exposure rates due to this material. The storage area was properly posted and access was restricted. Measurements along the Columbia River at the 100K Area, the closest public access point, did not detect elevated exposure rates.

An annual exposure of 140 mrem/year greater than background was recorded at KE Basin for the period from June 2005 to June 2006. This exposure is well below radiation exposure limits for workers. Exposure rates have returned to normal during the last half of 2006. All other sites monitored by DOH in 2006 had TLD results consistent with historical data.

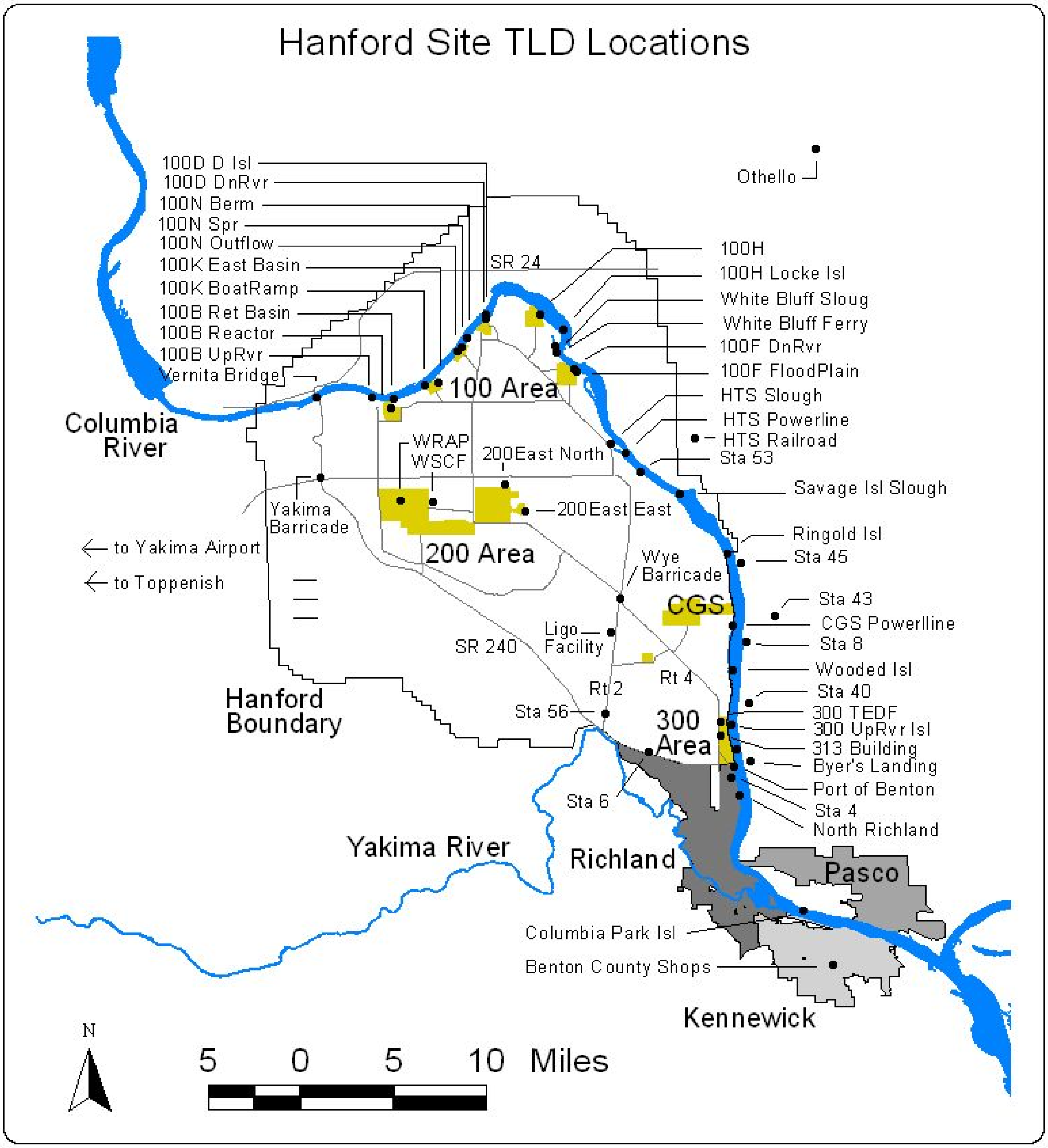

Figure 3.3.1 External Radiation Monitoring (TLD) Locations

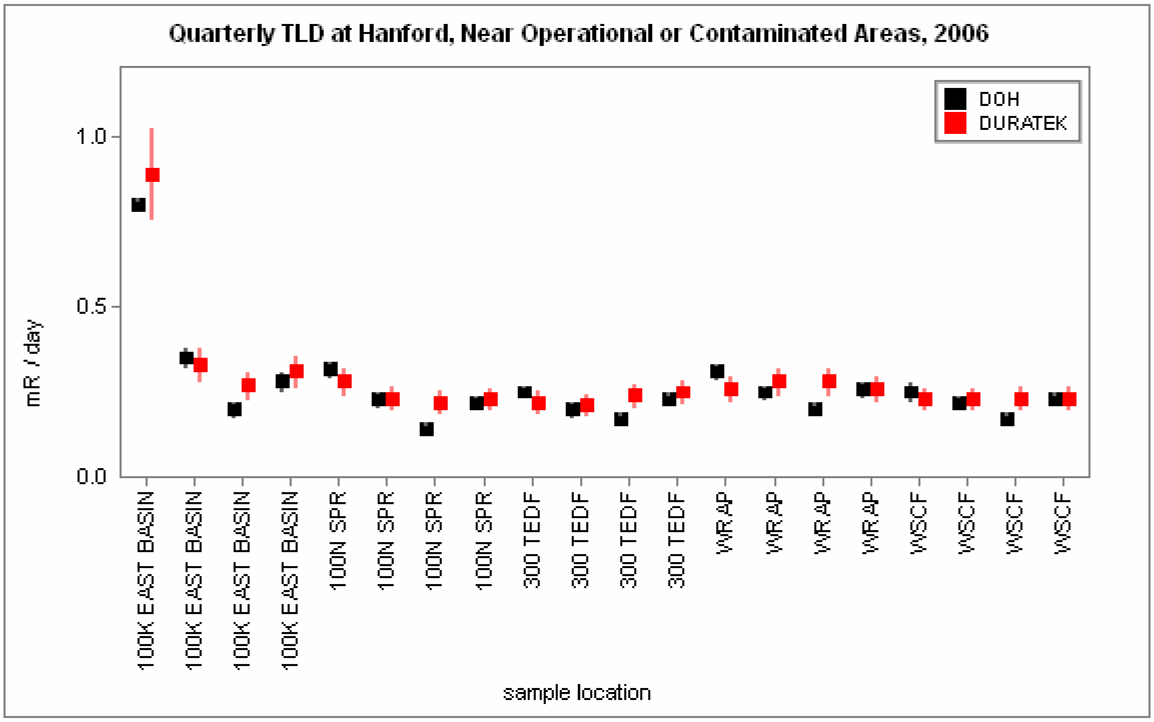

Figure 3.3.2 DOH and Duratek Quarterly TLD Results at Sites Near Operational or Contaminated Facilities

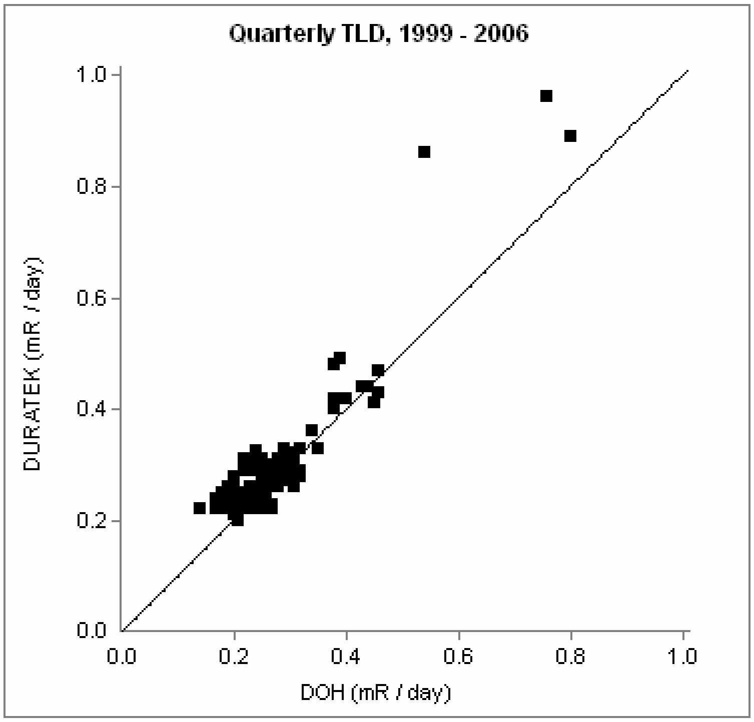

Figure 3.3.3 DOH and Duratek Scatter Plot for Historical TLD Results

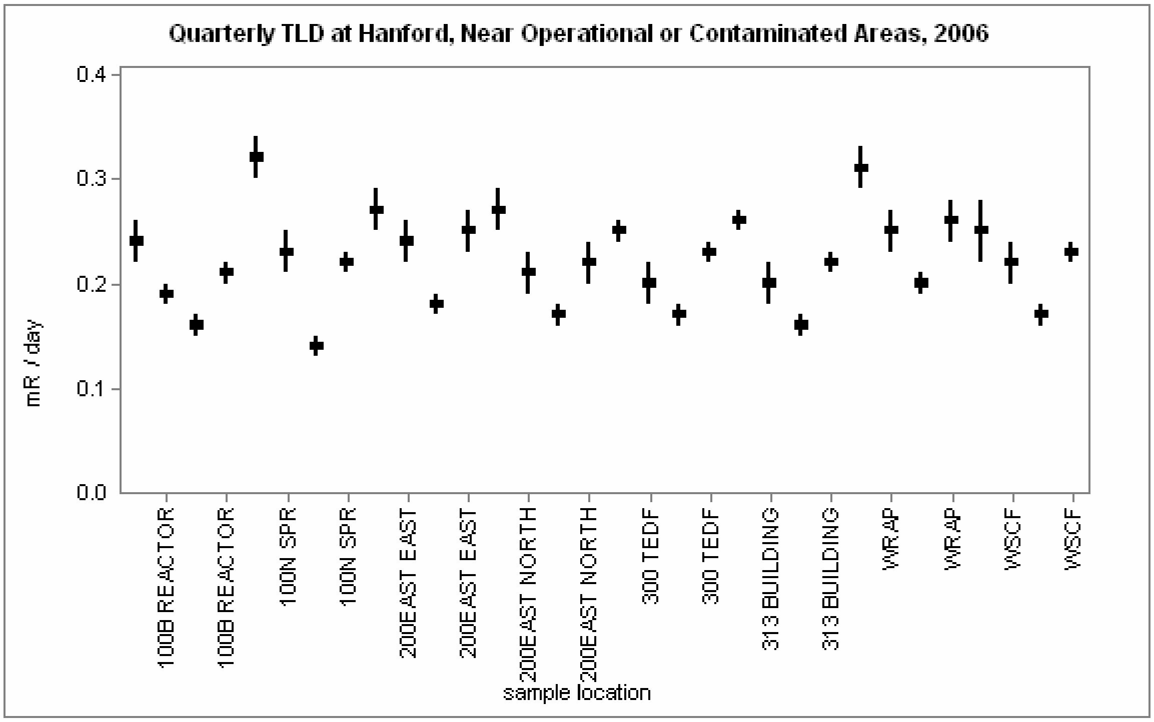

Figure 3.3.4 DOH Quarterly TLD Results at Sites Near Operational or Contaminated Areas

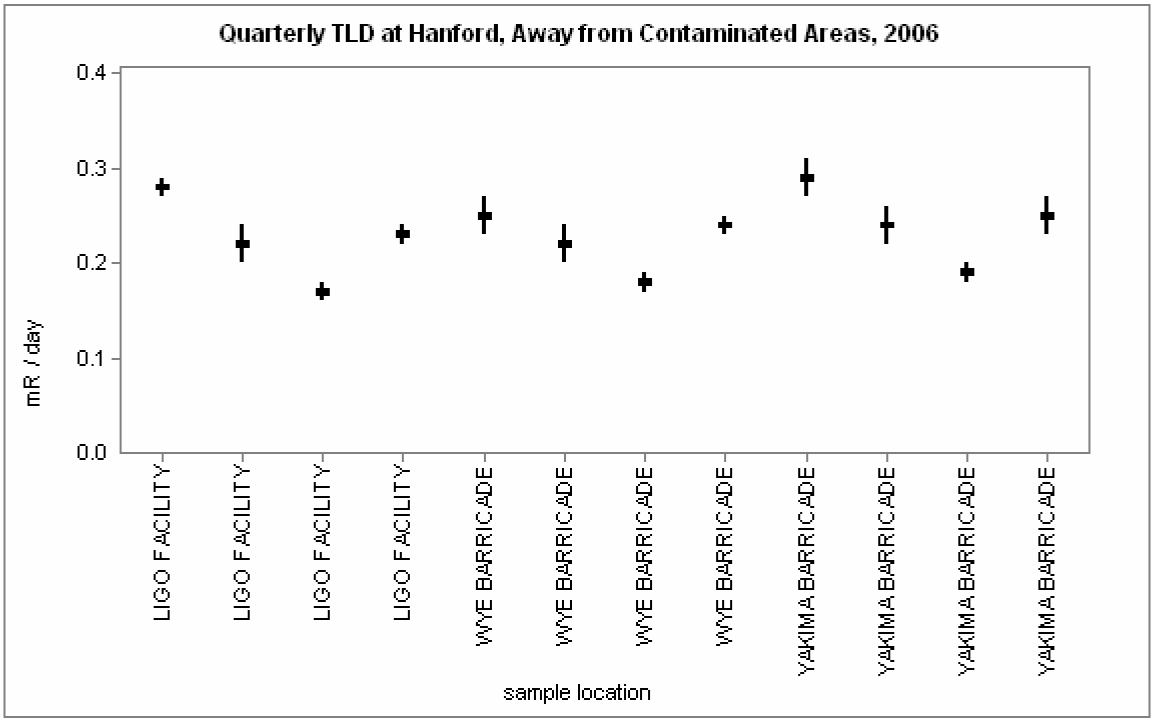

Figure 3.3.5 DOH Quarterly TLD Results at Sites Away from Contaminated Areas

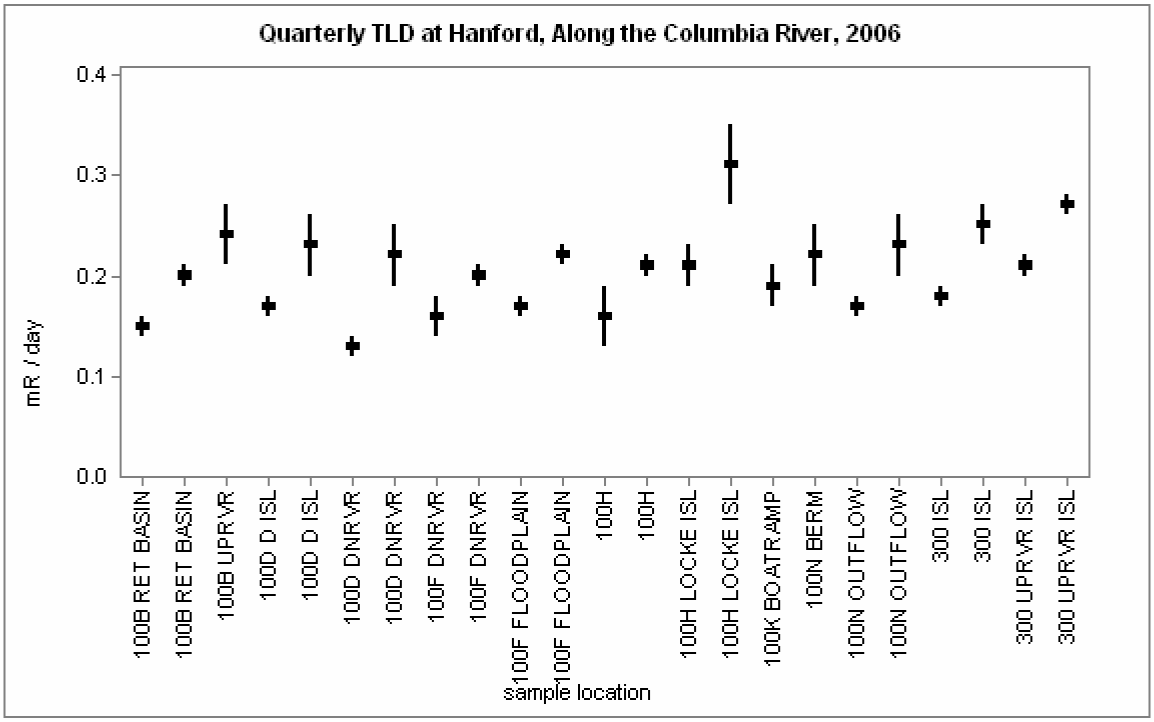

Figure 3.3.6 DOH Quarterly TLD Results at Sites Along the Columbia River (1 of 2)

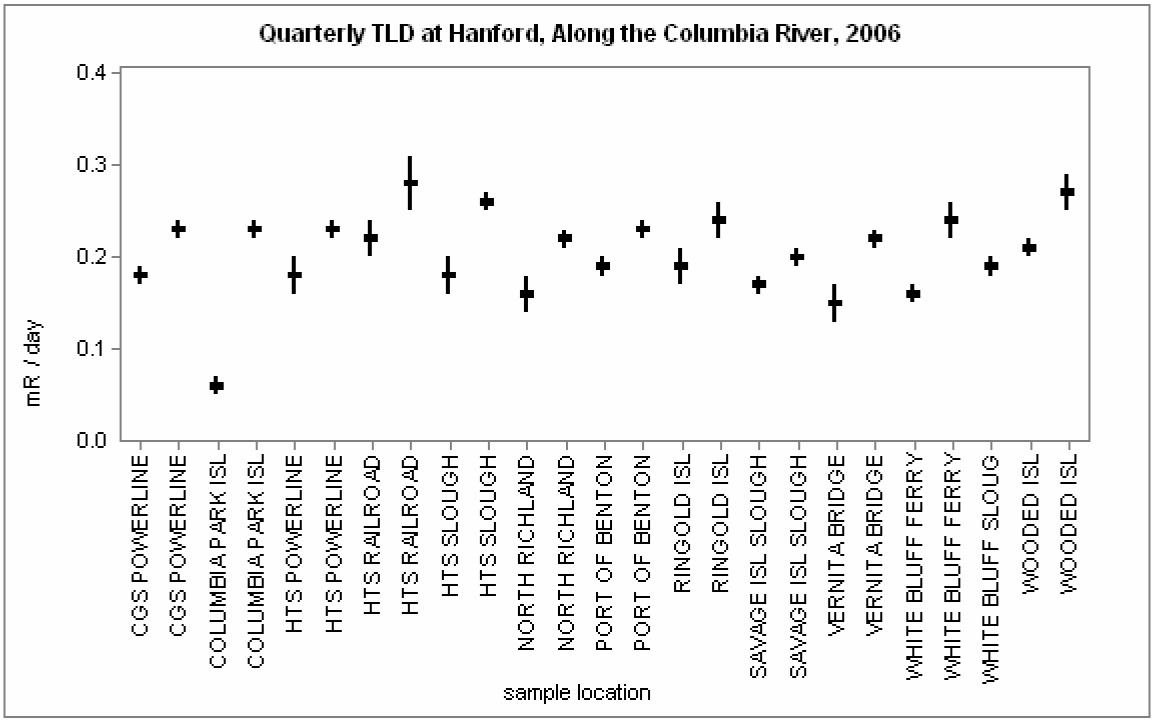

Figure 3.3.7 DOH Quarterly TLD Results at Sites Along the Columbia River (2 of 2)

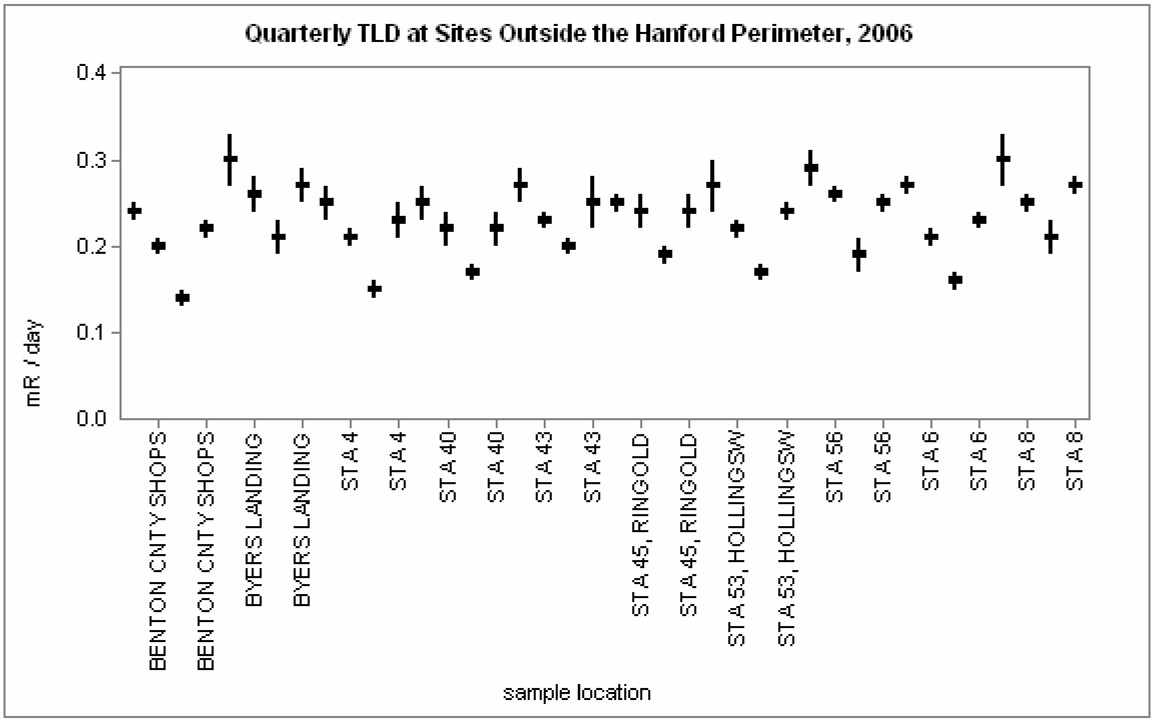

Figure 3.3.8 DOH Quarterly TLD Results at Sites Located Outside the Hanford Perimeter

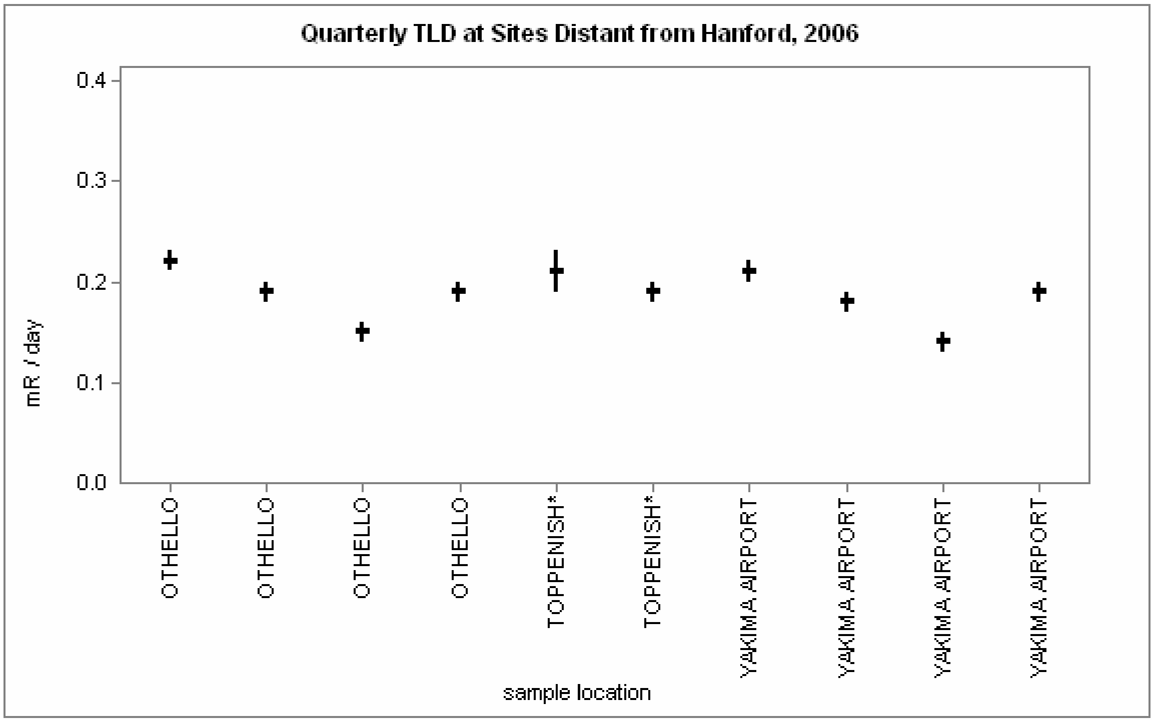

Figure 3.3.9 DOH Quarterly TLD Results at Sites Distant from Hanford

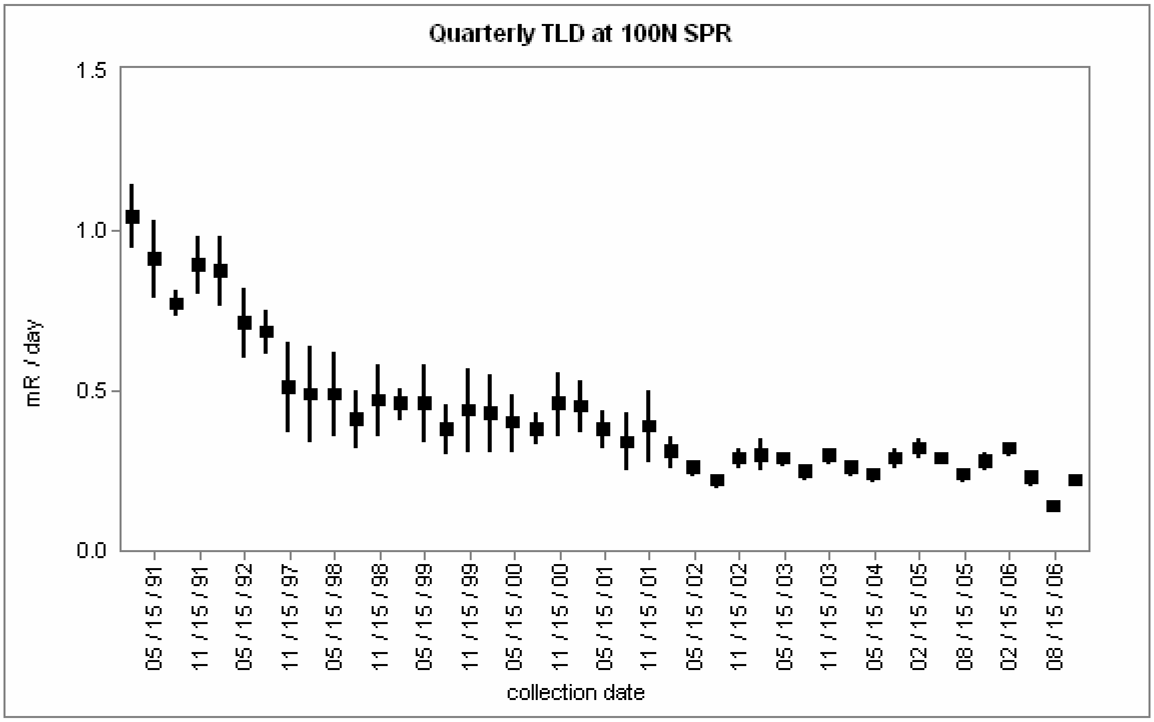

Figure 3.3.10 DOH Historical TLD Results at Location 100N SPR in the 100N Area

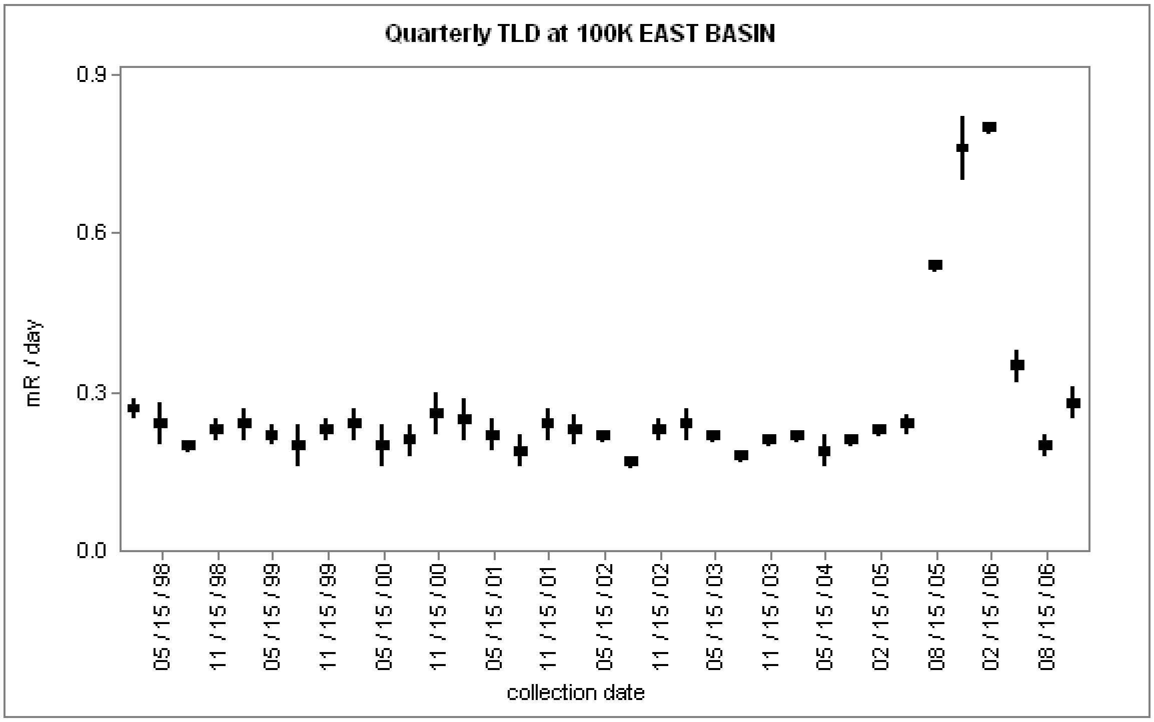

Figure 3.3.11 DOH Historical TLD Results at Location 100K East Basin, at 100K Area

3.4 Soil and Sediment Monitoring

Major Findings:

- DOH and PNNL results in sediment samples are in good agreement for all radionuclides, except for isotopes of uranium. The discrepancy in uranium originates from a difference in DOH and PNNL laboratory analytical methods.
- Concentrations of most radionuclides in sediment samples from locations adjacent to or downriver from Hanford are consistent with those at locations upriver from Hanford. Europium-152 was detected at locations adjacent to and downriver from Hanford, but not at the location upriver from Hanford. The Eu-152 results are consistent with historical results.

3.4.1 Purpose and General Discussion

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

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

3.4.2 Monitoring Locations

In 2006, eight Columbia River sediment samples were split with PNNL. No split soil samples were collected in 2006. The sediment samples were collected upriver from Hanford at Priest Rapids Dam; on the Hanford Site at the 100F and 100H Areas, the Old Hanford Townsite, and the 300 Area; and downriver from Hanford at McNary Dam.

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 2006, on-site sediment sample locations included the 100F, 100H, and 300 Areas, and the Old Hanford Townsite.

3.4.3 Monitoring Procedures

Split soil samples were not collected in 2006, but the monitoring procedures are discussed here for reference. Soil samples are collected by compositing four one-square foot areas, each excavated to a depth of one inch. The composited samples are split, and then dried prior to radiochemical analysis. Samples are analyzed for radionuclides that are most likely present in the area sampled, which at Hanford typically include gamma emitting radionuclides, Sr-90, isotopic uranium, and isotopic plutonium.

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

3.4.4 Comparison of DOH and Contractor Data

The DOH and PNNL split sediment sample concentrations for the gamma emitting radionuclides Co-60, Cs-134, Cs-137, Eu-152, Eu-154, Eu-155, Ru-106, and Sb-125 are in good agreement. Except for Cs-137 and Eu-152, all of the results are below detection limits. The split Cs-137 and Eu-152 results are shown in Figures 3.4.1 and 3.4.2.

Most of the split Sr-90 results, shown in Figure 3.4.3, are in good agreement, although there is a significant difference in the DOH and PNNL detection limits, as indicated by the size of the uncertainty bars in the figure. Most of the DOH concentrations are greater than the DOH detection limit of 0.002 pCi/g. However, the PNNL detection limit is much higher, and most of the PNNL concentrations are below their detection limit. Despite the difference in detection limits or the related difference in detection status, the DOH and PNNL data are considered in agreement because the range of the uncertainty bars overlap.

At site 100H SPR 145-1, PNNL reported a Sr-90 concentration of 0.1 pCi/g, which is ten times greater than the result reported by DOH. Historically, most DOH and PNNL results for Sr-90 in soil and sediment are in good agreement, so this one data point appears to be an anomaly. Split samples were collected at this same site in 2003, and in that case, the DOH and PNNL concentrations are in good agreement and consistent with the result DOH reported in 2006.

All of the split results for the alpha emitting radionuclides Pu-238 and Pu-239/240 are in good agreement, although there is a significant difference in detection limits for Pu-238. For Pu-238 (Figure 3.4.4), all of the DOH concentrations are less than the DOH detection limit of 0.005 pCi/g. PNNL has a much lower detection limit, and the four results at McNary and Priest Rapids Dam are greater than their detection limit, although at concentrations less than the DOH detection limit. Despite the difference in detection limits or the related difference in detection status, the DOH and PNNL data are considered in agreement because the range of the uncertainty bars overlap. The split Pu-239/240 results are shown in Figure 3.4.5.

The DOH and PNNL split soil and sediment results for isotopes of uranium are in fair agreement. The split U-238 results in soil for 2006 are shown in Figure 3.4.6. In addition, the historical U-238 results for both soil and sediment (1999 through 2006) are shown in a scatter plot in Figure 3.4.7. The slope of the best-fit straight line to the data indicates that on average, the PNNL U-238 concentrations are approximately 80% of the concentration reported by DOH. The agreement for U-234 and U-235 is similar.

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

Radionuclides consistently identified by DOH in soil and sediment samples include Cs-137, Pu-239/240, U-234, U-235, and U-238. Uranium-233 (lower limit of detection approximately 0.1 pCi/g) has not been detected by DOH in any sediment samples. Cesium-137 and plutonium isotopes exist in world-wide fallout as a result of nuclear weapons testing and may also exist in effluent from the Hanford Site. Uranium isotopes occur naturally in the environment and may also be present in Hanford Site effluent.

Concentrations of Cs-137 in sediment collected in 2006 ranged from 0.1 to 0.3 pCi/g, which is consistent with historical results. The concentrations at sites adjacent to and downriver from Hanford are not significantly different than those at the background location at Priest Rapids Dam, indicating the source of the Cs-137 is most likely world-wide fallout.

Concentrations of Pu-239/240 in sediment collected in 2006 ranged from below the detection limit of 0.005 pCi/g to 0.014 pCi/g, which is consistent with historical results. There is no significant difference in historical Pu-239/240 concentrations in sediment from sampling locations upstream (Priest Rapids Dam) and downstream (McNary Dam) of Hanford, as the historical average at both locations is approximately 0.009 pCi/g. This indicates the most likely source of Pu-239/240 in sediment is world-wide fallout.

Most of the sediment samples, including the background location near Priest Rapids Dam, had U-234 and U-238 concentrations near 1 pCi/g. The maximum concentration of 3 pCi/g was found in the sample from the 300 Area shoreline (see Figure 3.4.6). Historically, it is typical to measure U-234 and U-238 concentrations near 3 pCi/g in 300 Area sediment samples. Higher uranium concentrations in sediment are expected from the 300 Area, since a known uranium groundwater plume is entering the Columbia River at this location.

Most of the sediment samples, including the background location near Priest Rapids Dam, had U-235 concentrations near 0.04 pCi/g. The maximum concentration of 0.16 pCi/g was found in the same 300 Area shoreline sample that had the maximum U-234 and U-238 concentrations.

Other radionuclides identified in some of the sediment samples include Eu-152, Sr-90, and U-236.

DOH detected Eu-152 in several sediment samples, with concentrations ranging from 0.03 to 0.1 pCi/g (see Figure 3.4.2). All 2006 Eu-152 concentrations in sediment are consistent with historical results. The maximum concentration was found at McNary Dam, downriver from Hanford, where Eu-152 is historically detected in sediment. Europium-152 has not been detected by DOH at the Priest Rapids Dam background location.

Note in Figure 3.4.2 that there are no DOH data points for Eu-152 at the Priest Rapids Dam locations. This is because none of the europium isotopes were identified by the gamma scan, and therefore no results were reported.

Strontium-90 concentrations in sediment samples collected in 2006 ranged from below the detection limit of 0.002 pCi/g to 0.015 pCi/g (see Figure 3.4.3). Strontium-90, which is found in the environment from world-wide fallout of nuclear weapons testing, has been historically detected in sediment samples from both Priest Rapids Dam (upstream of Hanford) and McNary Dam (downstream of Hanford). There is no significant difference in historical Sr-90 concentrations between the upstream and downstream locations, as they both average approximately 0.017 pCi/g.

Uranium-236 is a byproduct of Hanford reactor operations and is occasionally detected by DOH in Columbia River sediment samples. Historical U-236 concentrations range from below the detection limit of 0.02 pCi/g to 0.26 pCi/g. DOH measured a concentration of 0.034 pCi/g from the 300 Area shoreline sample collected in 2006. PNNL did not report a U-236 concentration for this sample.

Americium-241, Co-60, Cs-134, Eu-154, Eu-155, Pu-238, Ru-106, and Sb-125 were not detected by DOH in any of the sediment samples collected in 2006.

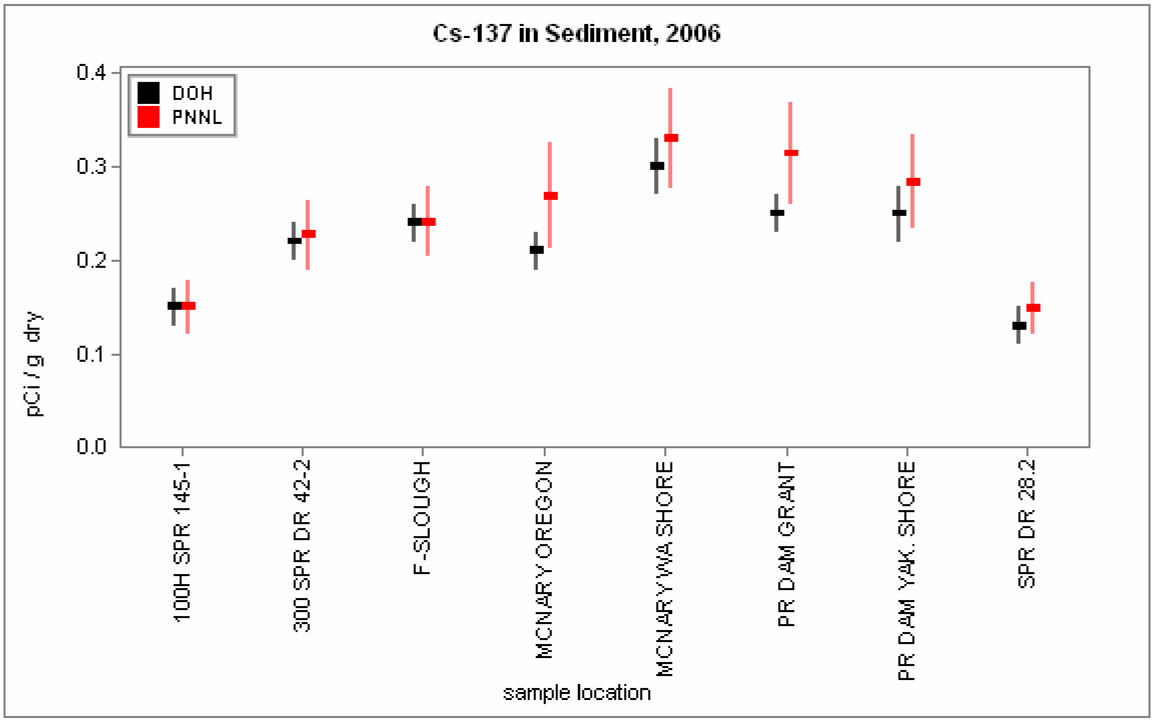

Figure 3.4.1 DOH and PNNL Cs-137 Concentrations in Columbia River Sediment

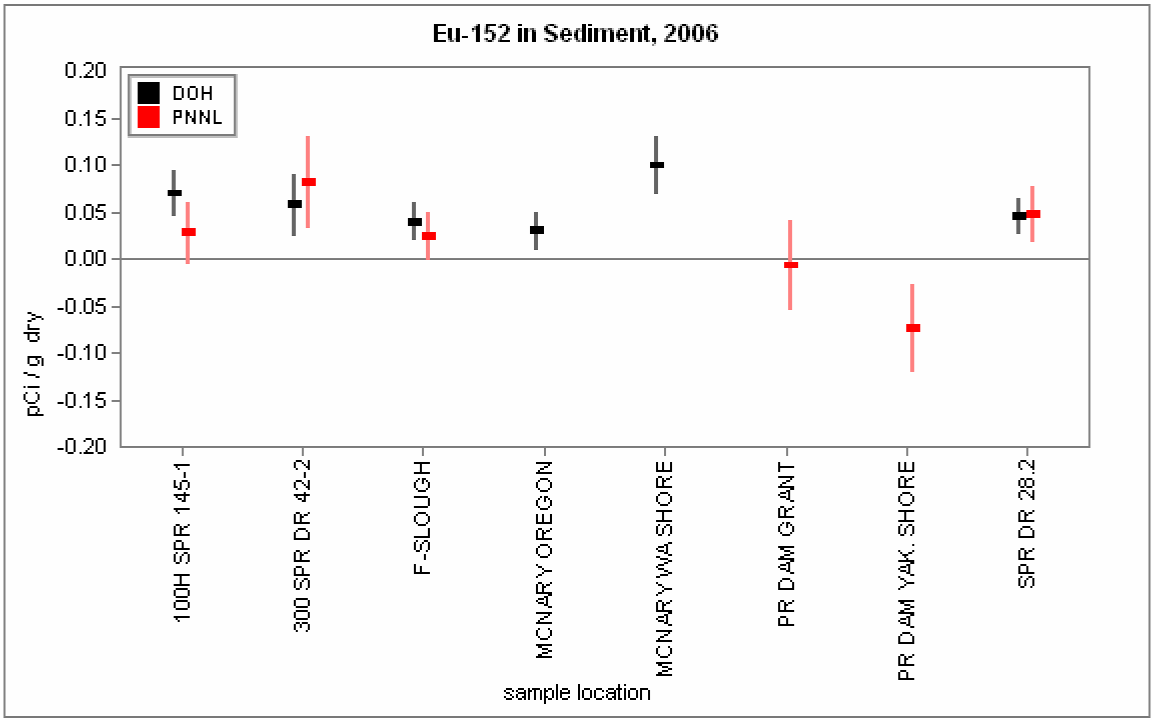

Figure 3.4.2 DOH and PNNL Eu-152 Concentrations in Columbia River Sediment

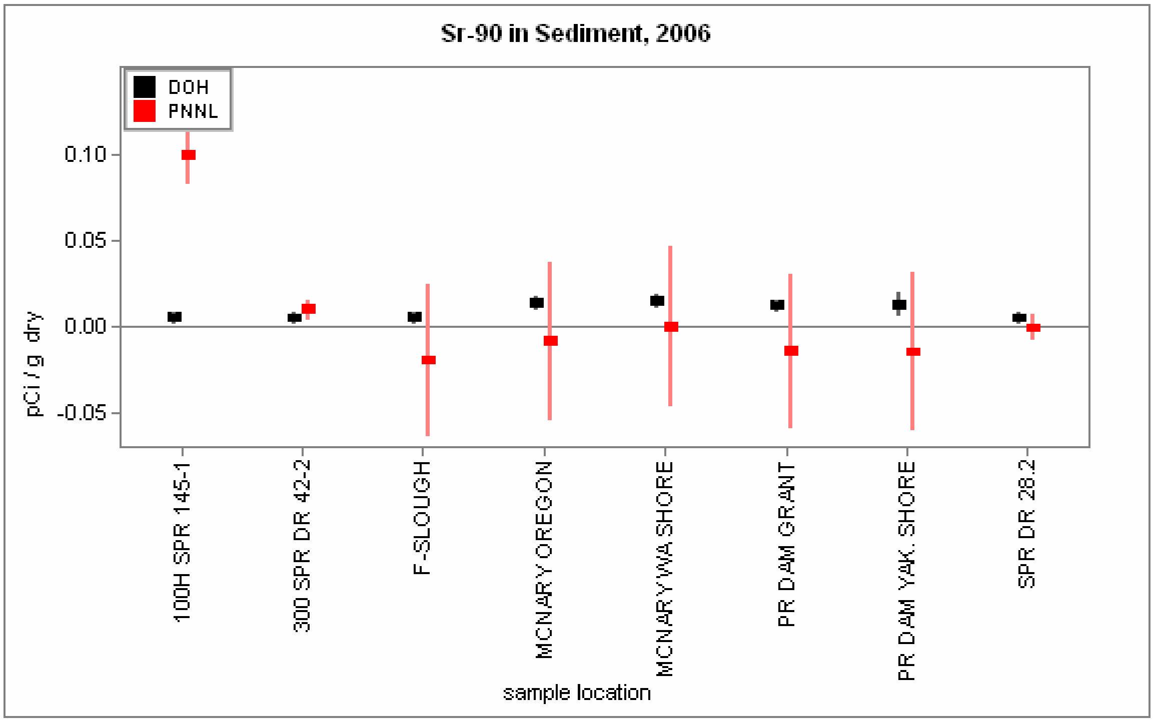

Figure 3.4.3 DOH and PNNL Sr-90 Concentrations in Columbia River Sediment

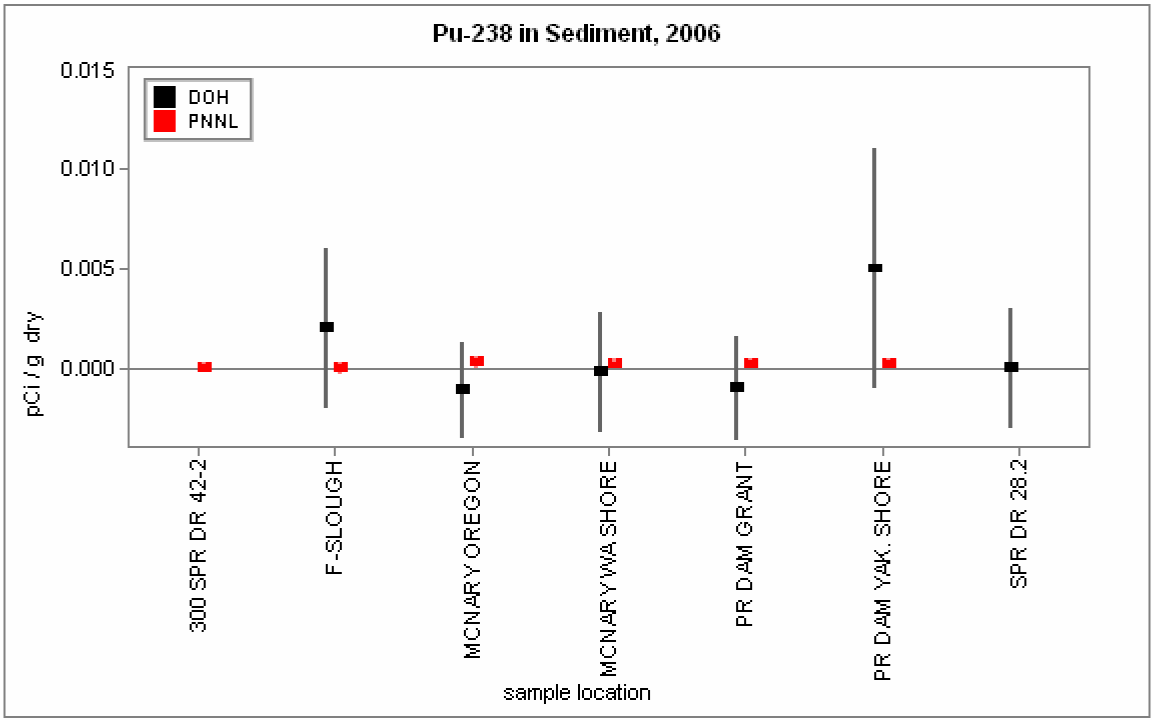

Figure 3.4.4 DOH and PNNL Pu-238 Concentrations in Columbia River Sediment

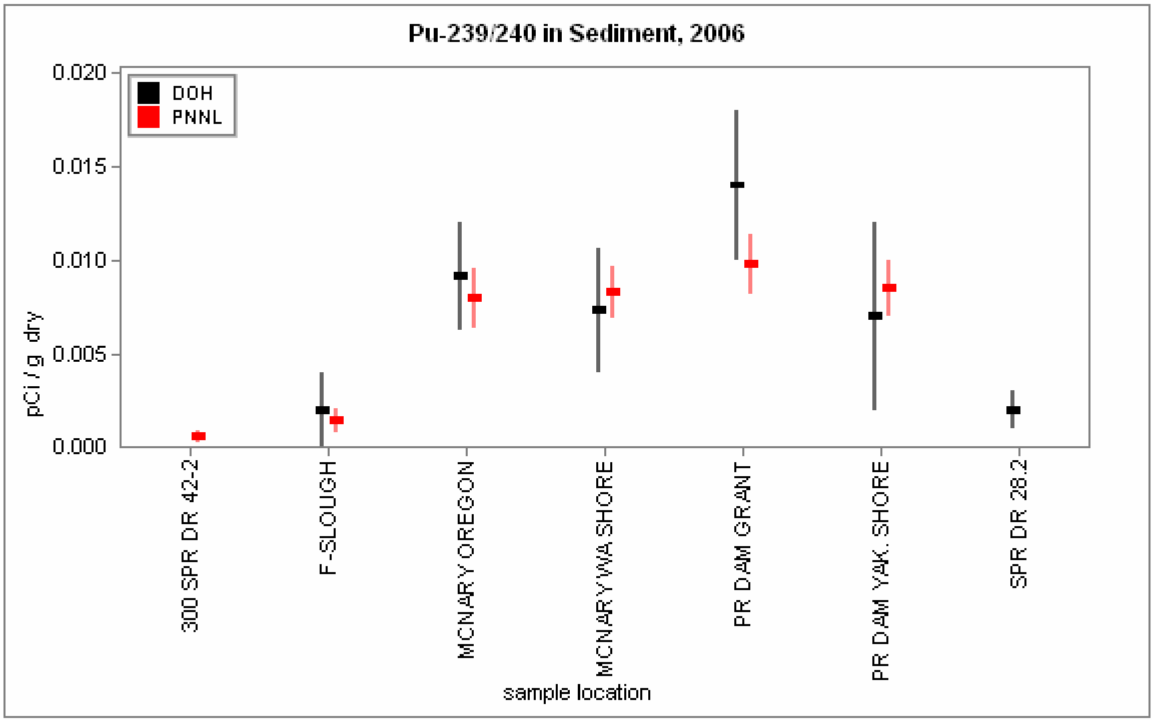

Figure 3.4.5 DOH and PNNL Pu-239/240 Concentrations in Columbia River Sediment

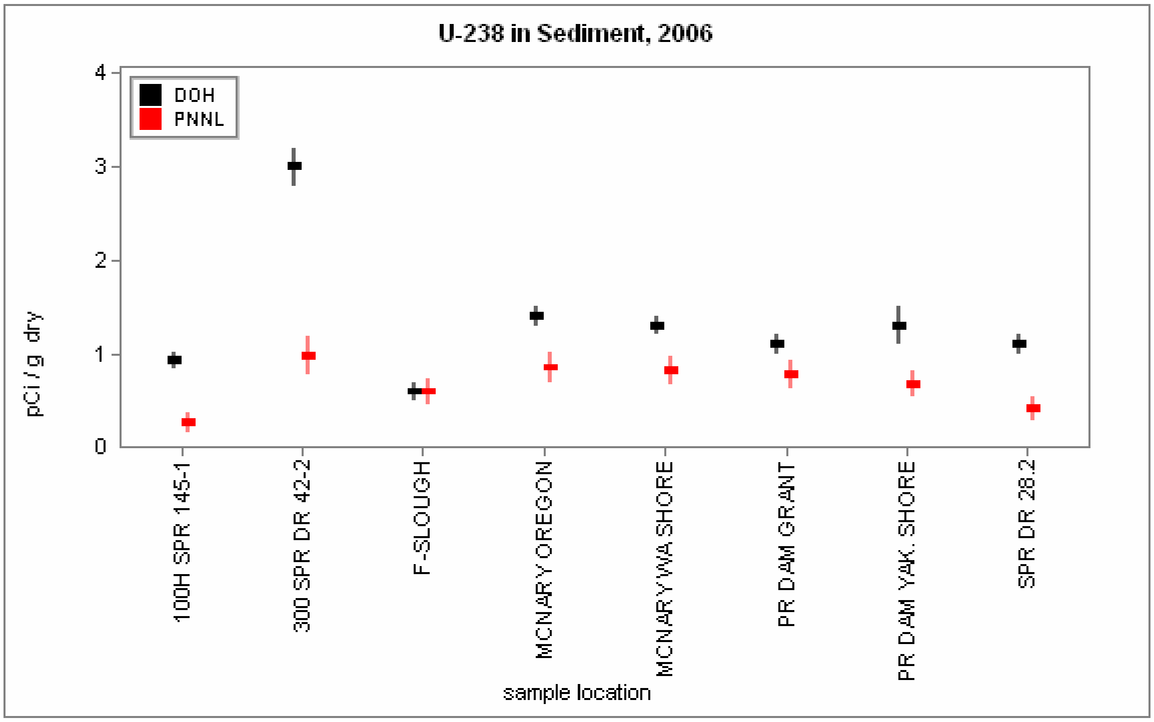

Figure 3.4.6 DOH and PNNL U-238 Concentrations in Columbia River Sediment

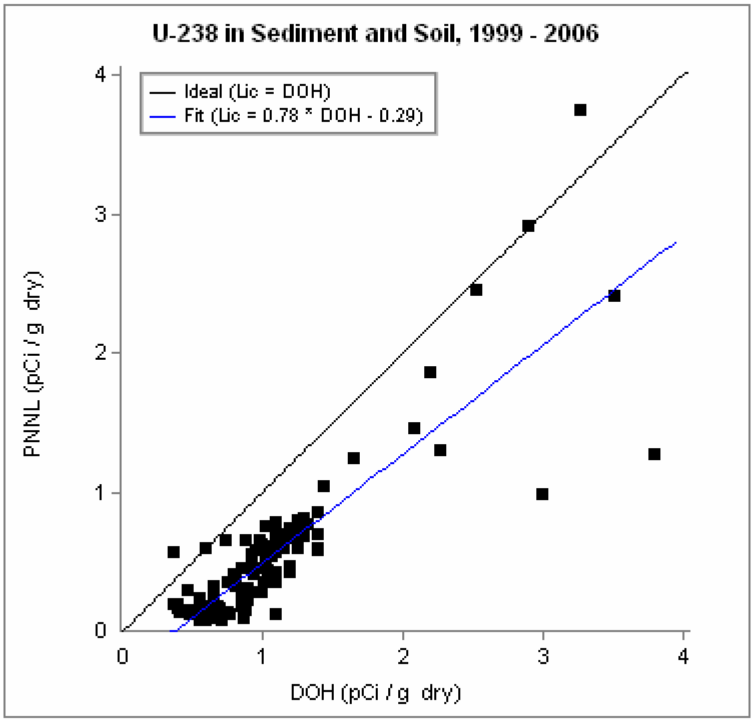

Figure 3.4.7 DOH and PNNL Scatter Plot for Historical U-238 Concentrations in Sediment and Soil

3.5 Farm Products Monitoring

Major Findings:

- All 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 grown in Washington State; 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 for 2006 are listed in Table 3.5.1.

Typically, H-3 is included in the analyte list for analysis of wine. However, the Washington State Public Health Laboratory's procedure for tritium analysis in wine is currently under review. The H-3 results for the wine samples collected in 2006 will be reported in the 2007 Annual Report.

Farm Product	Analyte	Number of Samples
Apples	Co-60, Cs-137, Sr-90	4
Asparagus	Co-60, Cs-137, Sr-90, U-234, U-235, U-238	1
Leafy Vegetables	Co-60, Cs-137, Sr-90	1
Potato	Co-60, Cs-137, Sr-90	1
Wine	Co-60, Cs-137	4

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 off-site of the Hanford Reservation. Samples were collected from farms located in the areas of Riverview, Sagemoor, Horn Rapids, East Wahluke, Ringold, Mattawa, Sunnyside, Yakima Valley, and the Columbia Valley.

3.5.3 Monitoring Procedures

Farm product samples were collected by PNNL and then split with DOH. 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 are reported in pCi/g wet weight.

3.5.4 Comparison of DOH and Contractor Data

All of the DOH and PNNL radionuclide concentrations reported for split food and wine samples are in good agreement, and most reported concentrations are below detection limits.

Historically, most DOH and PNNL concentrations in split food and wine samples are in good agreement.

3.5.5 Discussion of DOH Results

All DOH reported concentrations of Co-60, Cs-137, Sr-90, and U-235 in farm product samples collected in 2006 are below the detection limits listed in Appendix B. Historically, DOH occasionally detects small concentrations of Sr-90 in farm produce around the Hanford Site, with concentrations ranging from 0.01 to 0.1 pCi/g. However, Sr-90 was not detected in 2006 samples.

DOH detected very small concentrations of U-234 and U-238 in asparagus, 0.0015 and 0.0014 pCi/g respectively. These concentrations are most likely due to natural uranium in the soil, and they do not pose a health concern.

3.6 Fish and Wildlife Monitoring

Major Findings:

- DOH and PNNL results are in good agreement for gamma emitting radionuclides, and are in good to poor agreement for Sr-90.
- All of the DOH results for gamma emitting radionuclides are below detection limits.

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 2006, DOH split two wildlife samples and three fish samples. The type of samples, radionuclides analyzed, and number of samples are listed in Table 3.6.1.

Sample Type	Analyte	Number of Samples
Mule Deer Bone	Sr-90	1
Mule Deer Meat	Co-60, Cs-137	1
Sucker Carcass	Sr-90	3
Sucker Meat	Co-60, Cs-137	3
Quail Bone	Sr-90	1
Quail Meat	Co-60, Cs-137	1

Table 3.6.1 Radionuclides Analyzed in Fish and Wildlife

3.6.2 Monitoring Locations

The deer was collected from near the 100N Area; the three sucker samples were collected from the 100 Area, the 300 Area, and a background location near Vantage, Washington (upstream from Hanford); and the quail sample was collected from the 100 Area.

3.6.3 Monitoring Procedures

Fish and wildlife samples were collected and split by PNNL. Carcass and bone samples were analyzed for Sr-90. Meat samples were analyzed for gamma emitting radionuclides, which include Co-60, Cs-134, Cs-137, Eu-152, Eu-154, Eu-155, Ru-106, and Sb-125. DOH reports Co-60 and Cs-137 results whether they are detectable or not, whereas the remaining gamma emitting radionuclides are only reported if they are detectable.

3.6.4 Comparison of DOH and Contractor Data

The DOH and PNNL gamma emitting radionuclide concentrations in split fish and wildlife samples are in good agreement, and all results are below detection limits.

Most of the DOH and PNNL Sr-90 concentrations in split fish and wildlife samples are in good agreement. The results for one of the three sucker samples is in disagreement, as shown in Figure 3.6.1. Historically, the agreement between DOH and PNNL Sr-90 results in fish and wildlife range from good to fair to poor, as can be seen in the scatter plot of Figure 3.6.2. The points in the plot off the ideal fit line indicate disagreement between DOH and PNNL.

3.6.5 Discussion of DOH Results

In fish and wildlife samples all DOH gamma emitting radionuclide concentrations, including Co-60 and Cs-137, are below the detection limits.

Strontium-90 was detected at low concentrations in the mule deer bone sample and in two of the three sucker samples collected in 2006, with concentrations ranging from 0.02 to 0.32 pCi/g. The highest result was from the deer sample collected at the 100N Area. The Sr-90 concentrations measured in fish and wildlife samples in 2006 are similar to those measured by DOH in historical samples.

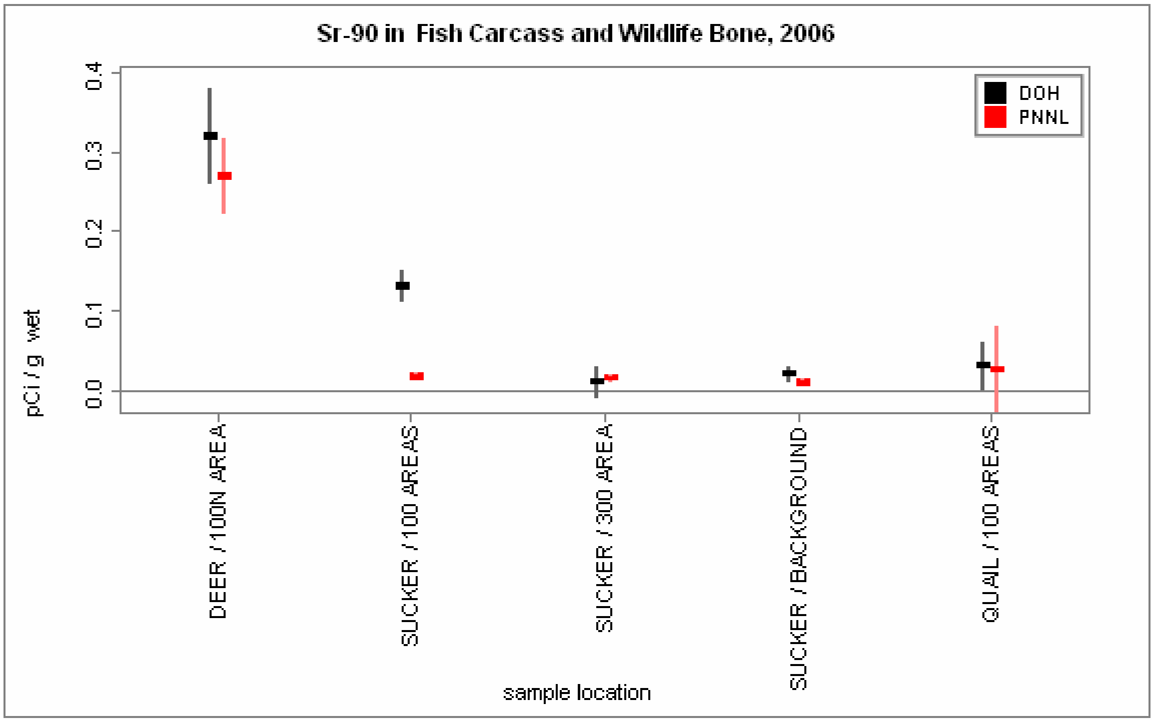

Figure 3.6.1 DOH and PNNL Sr-90 Concentrations in Fish and Wildlife

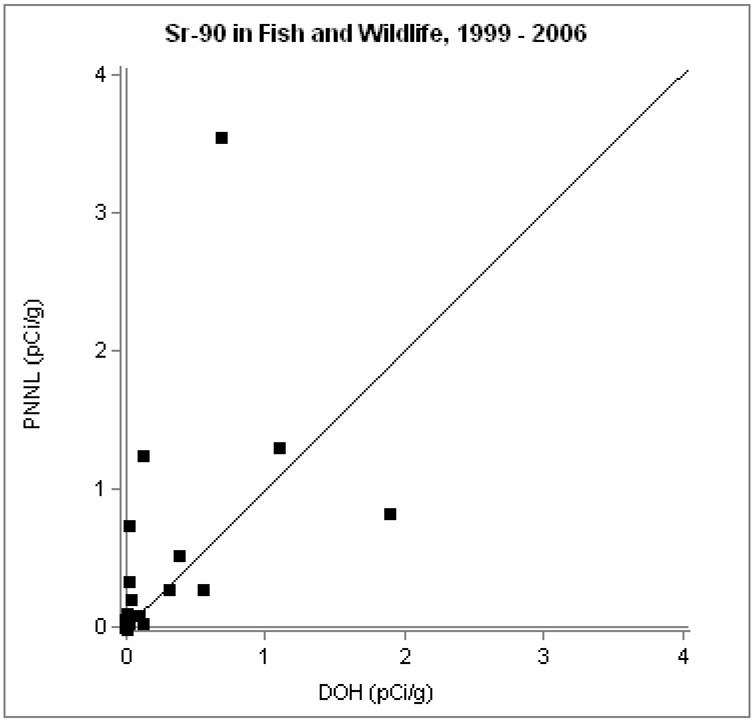

Figure 3.6.2 DOH and PNNL Scatter Plot for Historical Sr-90 Concentrations in Fish and Wildlife

3.7 Vegetation Monitoring

Major Findings:

- Starting in 2005, vegetation samples are scheduled to be split every other year. Therefore, no vegetation samples were split with DOE contractors in 2006. Vegetation samples were split in 2007, and the results will be reported in the 2007 version of the Annual Report.

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.

Starting in 2005, vegetation is monitored every other year. No split vegetation samples were collected in 2006 (this report). Vegetation samples were split in 2007, and the results will be reported in the 2007 version of the Annual Report.

4. Summary of Discrepancies Between DOH and DOE Contractor Results

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

The DOH and DOE contractor colocated biweekly gross beta results in air samples are in fair agreement. The DOH and DOE data follow the same trends; however, differences in concentration up to a factor of two are common, and there is a small systematic discrepancy between the two data sets. At the lower 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 2006 is also evident in historical DOH and DOE results.

The DOH and DOE colocated composite uranium results in air samples, for both quarterly and semiannual composite samples, are in fair agreement. The data generally follow the same trends; however, both PNNL and Duratek consistently report concentrations that are significantly lower than the concentrations reported by DOH. This discrepancy is currently under investigation, and the progress is discussed below.

First, DOH is evaluating laboratory procedures and sampling media to understand the discrepancy in uranium concentrations in air samples. Initial investigations indicate a difference in laboratory procedures between DOH and DOE contractors, that may contribute to the discrepancy. The final results of this investigation will be discussed in a future report.

Second, DOH is evaluating the sampling media. DOH and DOE contractors use different suppliers of filters for air particulate sampling. The preliminary results of blank samples show that the filters used by DOH give higher background counts than those used by DOE. To what extent using filters with higher background counts contributes to the observed bias is under investigation and will be discussed in a future report. Results of this investigation will be used to guide DOH in making appropriate changes in sampling media.

The DOH and PNNL split gross alpha and gross beta results in water samples are in fair agreement. The data generally follow the same trends; however, a systematic discrepancy is observed in which DOH disproportionately reports higher concentrations than PNNL. This discrepancy observed in 2006 is also evident in historical DOH and PNNL results.

The DOH and PNNL split H-3 results in water samples are in fair agreement. The data generally follow the same trends; however, a systematic discrepancy is observed in which DOH generally reports slightly higher concentrations than PNNL. The discrepancy is small, with an average difference in concentrations of 8%. This discrepancy observed in 2006 is also evident in historical DOH and PNNL results.

Historically, DOH and PNNL split I-129 results in water samples, most of which are groundwater, are in poor agreement. Three problems have been previously identified.

First, for samples in which I-129 is detected, DOH typically reports concentrations significantly lower than those reported by PNNL. Second and perhaps related to the first problem, for samples in which I-129 is not detected, DOH reports a disproportionate number of negative results, more so than statistically expected. This suggests a negative bias in the DOH laboratory analysis method. Third, some PNNL results are reported at concentrations greater than the sample's minimum detectable activity (MDA), although the results are tagged as not detectable.

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

For the second step, DOH reviewed sample collection practices and implemented a revised sample collection procedure that more immediately addresses sample preparation. In this procedure, iodine is converted to a more stable chemical form as soon as possible after sample collection. In 2006, the collection practice called for samples to be acidified in the field or upon receipt at the laboratory. At the laboratory, a portion of the sample was pH neutralized and the I-129 concentrated using an anion-exchange resin material with high specificity for I-129. This portion was taken after all other analyses were completed to ensure that sufficient sample was available for those tests. The problem with this collection practice is that the acid addition, which is good for keeping most radionuclides in solution, causes iodine to volatilize. Furthermore, iodine is strongly adsorbed by plastics, so that some quantity is likely lost to the walls of the container during holding. Converting the iodine to a more stable form and then trapping the iodine on resin as soon as the sample is collected eliminates these loss problems.

In 2008, DOH will conduct a set of experiments to evaluate the extent to which sample collection procedures and holding times contribute to reported result bias in historic samples. Results of this study will be used to guide interpretation of historical results.

The third step in resolving the I-129 question is to target several groundwater wells with historically elevated concentrations of I-129 for split sample collection and analysis. This will provide results over a wider range of activity with which to evaluate the changes in collection practices and laboratory procedures. In 2008, ten wells known to be associated with I-129 in groundwater will be sampled.

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

The DOH and PNNL split uranium results in sediment and soil samples are in fair agreement. The data generally follow the same trends; however, a systematic discrepancy is observed between the two data sets. PNNL typically reports uranium concentrations that are significantly lower than the values reported by DOH. This historically observed discrepancy is well understood, and results from different laboratory procedures.

Historically, DOH and PNNL results for Sr-90 concentrations in farm products, fish and wildlife, and vegetation samples range from good to fair to poor agreement. In 2006, most of the Sr-90 results are in agreement. The only exception is for a 100 Area fish sample, where DOH measured a Sr-90 concentration ten times that measured by PNNL, although in both cases the concentrations are very small.

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

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

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

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

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

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

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

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

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

A.2 Radiological Units and Measurement

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

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

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

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

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

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

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

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

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

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

Appendix B - Laboratory a priori Lower Limits of Detection

Air Cartridge (pCi/m^3)

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

Air Filter (pCi/m^3)

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

Quarterly Composite Air Filter (pCi/m^3)

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

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

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

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

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

Food (pCi/g)

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

Milk (pCi/L)

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

Meat (pCi/g)

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

Shellfish (pCi/g)

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

Soil/Sediment (pCi/g)

	Nuclide	Mass (g)	Method	Standard LLD (1000 min.)
Alpha	Nat U	1	Alpha Spec	4.00E-02
	U-234	1	Alpha Spec	3.00E-02
	U-235	1	Alpha Spec	2.00E-02
	U-238	1	Alpha Spec	3.00E-02
	Pu-238	10	Alpha Spec	5.00E-03
	Pu-239	10	Alpha Spec	4.00E-03
	Th-230	1	Alpha Spec	4.00E-02
	Th 232	1	Alpha Spec	4.00E-02
	Am-241	10	Alpha Spec	4.00E-03
	Ra - 226	1	αβ Cntr	1.00E-01
	Ra-226(DA)	600	INGe	2.00E-02
				Standard (100 min.)
Alpha	Gross	0.1	αβ Cntr	4.00E+01
				Standard LLD (1000 min.)
Gamma	K-40	600	INGe	1.50E-01
	Mn-54	600	INGe	1.00E-02
	Co-60	600	INGe	1.00E-02
	Zn-65	600	INGe	2.00E-02
	Zr-95	600	INGe	1.00E-02
	Ru-103	600	INGe	1.50E-02
	Ru-106	600	INGe	1.00E-02
	Sb-125	600	INGe	2.00E-02
	Cs-134	600	INGe	1.20E-02
	Cs-137	600	INGe	1.50E-02
	Ce-144	600	INGe	5.00E-02
	Eu-152	600	INGe	1.50E-02
	Eu-154	600	INGe	1.50E-02
	Eu-155	600	INGe	2.00E-02
	Ra-226(DA)	600	INGe	1.00E-01
	Am-241(GA)	600	INGe	2.00E-02
	Tot U(GA)	600	INGe	2.00E-01
				Standard (100 min.)
Beta	Sr-90	150	Nitric Acid/	1.80E-03
	Tc-99	10	3M/LS	2.00E-01
	Gross beta	0.4	αβ Cntr	1.50E+00

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

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

				Standard LLD (100 min.)
Beta	Gross	0.4	αβ Cntr	1.50E+00
	Sr-90	20	Nitric Acid/ αβ Cntr	5.00E-02
	Tc-99	5	3M/LS	1.50E+00

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

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

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

Water (pCi/L) Continued

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

*LLD for Air Cartridge is 3 days

METHOD

Preparation Methods

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

Counting Methods

INGe = Intrinsic Germanium Detector
αβ Cntr = Alpha, Beta Counter
Alpha Spec = Alpha Spectrometry
LS = Liquid Scintillation
LEP = Low Energy Photon Detector

Formulas

A. Random Uncertainty

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

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

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

C. Lower Limit of Detection (LLD)

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

D. Definitions

2.22 = conversion factor from dpm to picocuries
BKGCPM = background counts per minute
D = decay factor = $e^{-(ln2/T1/2)(t)}$
E = counting efficiency: counts per disintegration
LLD = the a priori determination of the smallest concentration of radioactive material sampled that has a 95 percent probability of being detected, with only five percent probability that a blank sample will yield a response interpreted to mean that radioactivity is present above the system background
n = number of samples analyzed (number of data points)
RU = random uncertainty at the 95 percent confidence level (sometimes referred to as counting error)
s = sample standard deviation
S = one standard deviation of the background count rate (which equals $(BKG/T_2)^{1/2}$)
sample cpm = counts per minute of sample
t = elapsed time between sample collection and counting
T_1 = sample count time
T_2 = background count time
$T_{1/2}$ = half-life of radionuclide counted
U = uncertainty (standard error) of the sample mean
V = volume in liters (or mass in grams) of sample
Y = fractional radiochemical yield (when applicable)

Appendix C - Glossary of Terms

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

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

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

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

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

Appendix D - List of Analytes

Am-241	Americium-241
Be-7	Beryllium-7
C-14	Carbon-14
Cm-244	Curium-244
Co-60	Cobalt-60
Cs-137	Cesium-137
Eu-152	Europium-152
Eu-154	Europium-154
Eu-155	Europium-155
H-3	Hydrogen-3
I-129	Iodine-129
K-40	Potassium
NO2+NO3	Nitrite + Nitrate
Pu-238	Plutonium-238
Pu-239/240	Plutonium-239/240
Ru-106	Ruthenium
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