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STATE OF WASHINGTON

DEPARTMENT OF HEALTH
DIVISION OF RADIATION PROTECTION

7171 Cleanwater Lane, Bldg. 5 • P.O. Box 47827 • Olympia, Washington 98504-7827
TDD Relay 1-800-833-6388

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February 22, 2005

TO: Interested Parties
FROM: Debra McBaugh
SUBJECT: HANFORD ENVIRONMENTAL OVERSIGHT PROGRAM
2002 DATA SUMMARY REPORT

The Department of Health has a legislative mandate to conduct radiation monitoring at nuclear facilities and in the environment to determine the presence and significance of radiation in the environment and to verify the adequacy of environmental radiation surveillance programs conducted by the federal government and licensees.

This report documents how we met the legislative mandate in 2002 for the Hanford Site and the surrounding communities. It provides technical data covering radiation measurements and environmental sampling. It also describes the Department of Health sampling program, summarizes sample results and describes how they compare to contractors' results. This report will be available online at www.doh.wa.gov/ehp/rp/rp-publ.htm.

If you have any questions, please do not hesitate to contact me at (360) 236-3251 or by e-mail at Debra.McBaugh@doh.wa.gov.

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Environmental Radiation Program

*Hanford Environmental Oversight Program
2002 Data Summary Report*



Environmental Health Programs

Environmental Radiation Program

*Hanford Environmental Oversight Program
2002 Data Summary Report*

Scott Van Verst
Lynn Albin

Washington State Department of Health

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

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

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

Summary

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

Since 1985, the Washington State Department of Health's Hanford Environmental Oversight Program has participated with the U.S. Department of Energy (DOE) in the collection of environmental samples on or near the Hanford Site. The purpose of the program is to independently verify the quality of DOE environmental monitoring programs at the Hanford Site, and to assess the potential for public health impacts. This report is a summary of the data collected for the Hanford Environmental Oversight Program in 2002.

The Oversight Program's objectives are met through collection and analyses of environmental samples and interpretation of results. DOH samples are either split or co-located with samples collected by DOE contractors, and the results are compared to verify the quality of the DOE monitoring programs at Hanford. In 2002, samples of air, groundwater, surface water, riverbank seep water, drinking water, discharge water, soil, sediment, food and farm products, and fish and wildlife were collected. In addition, dosimeters measuring ambient external radiation levels were collected. In 2002, no vegetation samples were split with DOE contractors.

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

Discrepancies between DOH and DOE split data in 2002 included a systematic bias in results for gross beta and uranium activity in air samples; gross alpha, gross beta, and I-129 activity in water samples; uranium activity in soil and sediment samples; and Sr-90 activity in fish and wildlife samples. The systematic bias indicates a probable difference in laboratory procedures. In the case of uranium, the discrepancy is understood as due to a difference in laboratory analytical methods.

Most environmental samples analyzed by DOH had radioactivity concentrations either below detection limits or consistent with background. A few samples had concentrations elevated above background which are attributed to Hanford operations; however, in most cases the results are consistent with historical trends. For example, technetium 99 (Tc-99), strontium 90 (Sr-90), iodine 129 (I-129), uranium isotopes (U-234, 238), and tritium (H-3) were detected above background levels in some Hanford Site groundwater wells in 2002. Tritium and uranium isotopes in some riverbank seep water samples, and tritium in some Columbia River surface water samples were also detected at concentrations greater than background.

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

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Acronyms

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

1. Introduction

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

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

The primary objectives of the oversight program are:

- To independently verify the quality of the U.S. Department of Energy monitoring programs at the Hanford Site by conducting split, co-located, and independent sampling at locations which have the potential to release radionuclides to the environment or locations which may be impacted by such releases.
- To use the DOH oversight data to assess impacts to the public. (With the primary role of oversight, the DOH monitoring program is not intended to completely characterize environmental radiation from the Hanford Site, nor is it intended to find and report the highest environmental contaminant concentrations. Therefore, assessment of impacts to the public based on DOH data do not necessarily represent worst-case scenarios).
- To address public concerns related to environmental radiation at Hanford.

This report presents the results of environmental radiation measurements made by the Washington State Department of Health's Hanford Environmental Oversight Program for the calendar year 2002.

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

2. The Hanford Environmental Oversight Program Description

The Oversight Program's objectives (see Section 1. Introduction) are met through collection and analyses of environmental samples and interpretation of results. DOH samples are either split or co-located with samples collected by the DOE contractors. In 2002, samples were split with the Pacific Northwest National Laboratory (PNNL), Duratek, and Waste Management Federal Services NW (WMFS).

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

2.1 Laboratory Qualifications

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

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

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

2.2 Interpretation of Results

Environmental radiation data are reported as the number of radiation decays per minute per unit quantity of sample material. Most results are reported in units of picocuries. A picocurie equals 2.22 decays per minute. Airborne radioactivity is expressed as picocuries per cubic meter (pCi/m³); radioactivity in liquids such as water and milk is expressed as picocuries per liter (pCi/L); and radioactivity in solid material such as soil, vegetation, and food is expressed as picocuries per gram (pCi/g). Ambient gamma radiation is expressed as radiation exposure, measured in milli-Roentgens per day (mR/day). Radiation exposure is defined in Appendix A.

2.2.1 Uncertainty in Radioactivity Measurements

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

2.2.2 Detection Limits

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

2.2.3 Background and Negative Results

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

A negative net sample activity is occasionally reported for environmental samples. When the amount of radioactivity in the sample is very small, the random nature of radioactive decay may result in a gross sample activity that is less than the background activity. In this case, the net result will be negative. In most cases, negative results have an

associated uncertainty range that includes zero activity. A negative result indicates that radioactivity in the sample was not detected at concentrations above the detection limit.

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

2.2.4 Techniques for Comparison of DOH and DOE Contractor Data

Since the primary purpose of the DOH Hanford Environmental Oversight Program is to verify DOE environmental monitoring programs, DOH either splits samples or collects co-located samples with DOE contractors. The DOH and DOE samples are independently analyzed and the results compared. Two techniques are used to compare the data; qualitative comparisons and linear regression analysis.

2.2.4.1 Qualitative Comparisons

All of the co-located or split data are sorted by sample type and analyte. Then, for each sample type and analyte, all of the DOH and DOE contractor data for each sample location are plotted on a graph and visually inspected to qualitatively assess the agreement of the data. The results of the assessment are discussed in the text of the report. When necessary or helpful to the reader, figures of the graphical representation of the data are included in the report.

2.2.4.2 Regression Analysis

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

Assuming there is a sufficient amount of data above the detection limit for a meaningful regression analysis, each of the split or co-located DOH and DOE results for a given sample type and analyte are formed into an (x, y) pair. The x-value represents the DOH result and the y-value represents the DOE result for a particular sample. The paired data for all samples of a given sample type and analyte are plotted on a two-dimensional scatter plot. The correlation coefficient R is then calculated for the set of (x, y) pairs. R can vary from -1 to +1. A value near ± 1 implies a strong correlation, while a value near 0 implies a weak or no correlation.

If the two data sets are sufficiently correlated (in this report, the criterion is $R > 0.75$), the best-fit straight line that describes the relationship between the two monitoring programs

is determined. The parameters that describe the straight line are the slope and y-intercept. The functional form of the straight line is $y = ax + b$, where a is the slope and b is the y-intercept.

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

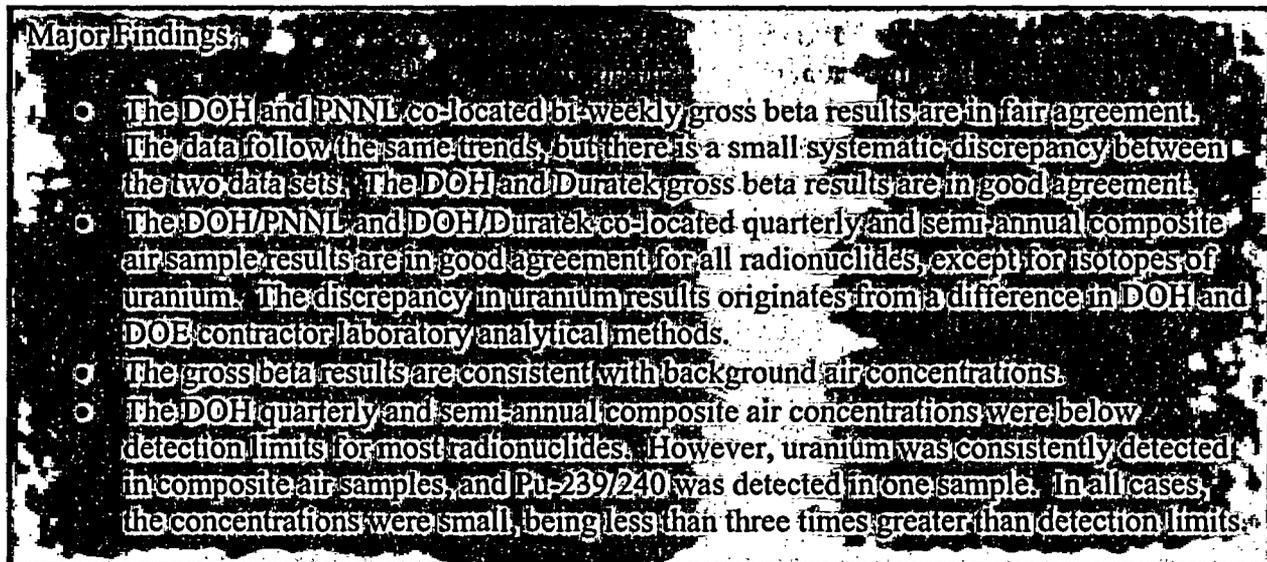
If a regression analysis is carried out, a scatter plot (x, y paired data) of the DOH and DOE split or co-located data is presented in this report. Also shown in the plot are straight lines representing the ideal case where the data sets are in perfect agreement, and the best-fit straight line. The slope and y-intercept of the best-fit straight line are shown in the plot legend.

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

3. Environmental Monitoring Results

This section presents the DOH and DOE contractor results for the Hanford Environmental Oversight Program. The types of samples collected are intended to encompass all of the potential public exposure pathways. These samples include air (Section 3.1); groundwater, riverbank seep water, surface water, drinking water, and discharge water (Section 3.2); dosimeters measuring external gamma radiation (Section 3.3); soil and sediment (Section 3.4); food and farm products (Section 3.5); and fish and wildlife (Section 3.6). 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



3.1.1 Purpose and General Discussion

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

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

3.1.2 Monitoring Locations

In 2002, DOH collected air samples co-located with PNNL at five locations. These locations include Wye Barricade, Prosser Barricade, Battelle Complex, and Station 8, which are in the prevailing downwind direction of most Hanford Site operating and contaminated facilities. The fifth location at the Yakima Barricade is in the prevailing upwind direction of operating and contaminated facilities.

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

3.1.3 Monitoring Procedures

Airborne particles are sampled by continuously drawing air through a filter. DOH collects the filter at each sample location once a week, while PNNL and Duratek collect their co-located filters every other week (bi-weekly). The filters are stored for three days and then analyzed for gross beta activity. The storage period allows naturally occurring short-lived radionuclides to decay that would otherwise obscure detection of radionuclides potentially present from Hanford Site emissions.

The amount of radioactive material collected on a filter in a one or two week time period is typically too small to accurately detect concentrations of individual radionuclides. In order to increase the sensitivity and accuracy so that individual radionuclide concentrations can be determined, the weekly (or bi-weekly) filter samples for a three or six-month period are dissolved and combined into quarterly or semi-annual composite samples. The composite samples are analyzed for gamma emitting radionuclides and isotopes of uranium and plutonium. A summary of the monitoring program is shown in Table 3.1.1.

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

Table 3.1.1 Radionuclides Monitored in Air Samples

3.1.4 Comparison of DOH and Contractor Data

The DOH and PNNL gross beta results follow the same trend at each of the monitoring locations. The DOH/PNNL data at the Wye Barricade are shown in Figure 3.1.2. The DOH and Duratek gross beta results also follow the same trend at each of the sites. The DOH/Duratek data at C Farm are shown in Figure 3.1.3. In general, the DOH and DOE contractor data sets are not expected to match identically because the sampling frequencies are different, and therefore the results correspond to an averaging of the air concentration over different time periods. The agreement between the DOH and DOE

contractor gross beta results at the other sampling locations is similar to that at Wye Barricade and C Farm.

The DOH vs. PNNL scatter plot for co-located gross beta results is shown in Figure 3.1.4. The DOH vs. Duratek scatter plot is shown in Figure 3.1.6. The scatter plots show all data from all sites that are co-located with the particular contractor. For example, Figure 3.1.6 shows the DOH and Duratek data for C Farm, ERDF-SE, and KE Basin. The x-coordinate of each data point represents the DOH result, while the y-coordinate represents the PNNL result. Ideally, if the DOH and PNNL results were identical, all the points would fall on the straight line with slope equal to unity and y-intercept equal to zero (shown as the black line in the figures).

Regression analysis was used to fit a straight line to the DOH vs. PNNL and DOH vs. Duratek data (blue lines in Figures 3.1.4 and 3.1.6). The resulting slope and y-intercept quantifies the agreement between the two data sets.

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

This systematic discrepancy in the DOH and PNNL gross beta results has been observed historically. The scatter plot and regression analysis for the years 1999 - 2002 are shown in Figure 3.1.5. The slope and y-intercept for the historical data are similar to those for the 2002 data. Despite the discrepancy in the regression analysis, qualitatively the DOH and PNNL data consistently follow the same trend (for example, see Figure 3.1.2). DOH is currently investigating this discrepancy and will report its findings in a future annual report.

The scatter plot and regression analysis for the DOH and Duratek co-located gross beta data are shown in Figure 3.1.6. The slope of 0.98 in the regression analysis indicates that the data are in good agreement. However, the y-intercept indicates a very small bias between the two data sets. On average, Duratek reports a gross beta concentration 0.004 pCi/m^3 greater than DOH. This difference is small and is not considered to be significant.

DOH and PNNL analyzed co-located quarterly composite air samples for Co-60, Cs-134, and Cs-137 at Battelle Complex, Prosser Barricade, Station 8, and Yakima Barricade. Co-located quarterly composite air samples were analyzed for isotopes of uranium at Station 8. The DOH and PNNL results are in good agreement for Co-60, Cs-134, and Cs-137 (all results are below detection limits). The agreement is only fair for isotopes of uranium due to a systematic discrepancy between the two data sets. The DOH and PNNL quarterly composite U-238 concentrations are shown in Figure 3.1.7. The PNNL uranium concentrations are systematically less than those reported by DOH. The results for U-234 are similar. All U-235 concentrations are below detection limits.

The discrepancy between DOH and PNNL uranium concentrations in air exists historically, and originates from different laboratory procedures. DOH completely dissolves samples prior to analysis and reports uranium present in the entire sample, whereas the contractor laboratory reports only the uranium that can be leached from the sample surface. The U-238 quarterly composite concentrations for years 1999 through 2002 are shown in Figure 3.1.8. The scatter plot for the same data is shown in 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/m³. In these cases, the corresponding PNNL data do not confirm the elevated DOH results.

DOH and Duratek analyzed co-located semi-annual composite air samples at C Farm, ERDF-SE, and KE Basin. The DOH and Duratek results are in good agreement for Co-60; Cs-134, 137; U-235; and Pu-238, 239/240 (most of these data are below detection limits). The DOH and Duratek U-234 and U-238 results are in good agreement except for the sample at ERDF-SE. The DOH and Duratek U-238 data are shown in Figure 3.1.10. The U-234 data are similar.

3.1.5 Discussion of Results

The gross beta results at all sites show a trend of higher concentration during the winter months, typically October through February. These higher gross beta activities are attributed to increased concentrations of radon daughter products due to decreased atmospheric mixing during the winter months when there is decreased atmospheric heating. The annual cycle of increased gross beta activity in the winter months can easily be seen in Figure 3.1.11, which shows gross beta activity at Wye Barricade from 1988 through 2002.

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

The average air concentration at upwind sites and downwind sites are not significantly different, indicating that Hanford is not impacting air quality at locations where the public may be exposed. In addition, the average air concentration at the locations near operating facilities is also not significantly different from the upwind site. For the year 2002, all of the weekly DOH gross beta results ranged between 0.0015 and 0.062 pCi/m³, with an annual average of 0.015 pCi/m³.

Site	DOH (pCi/m ³)			Contractor (pCi/m ³)			
	Min	Max	Average	Name	Min	Max	Average
Battelle Complex	0.0028	0.056	0.016	PNNL	0.0069	0.053	0.018
C Farm	0.0025	0.056	0.015	Duratek	0.0080	0.058	0.019
ERDF-SE	0.0046	0.049	0.015	Duratek	0.0083	0.060	0.018
KE Basin	0.0023	0.054	0.013	Duratek	0.0068	0.067	0.020
Prosser B.	0.0017	0.055	0.014	PNNL	0.0054	0.045	0.016
Station 8	0.0015	0.062	0.014	PNNL	0.0052	0.030	0.012
Wye B.	0.0024	0.055	0.015	PNNL	0.0066	0.042	0.015
Yakima B.	0.0023	0.055	0.014	PNNL	0.0060	0.040	0.015

Table 3.1.2 Summary Statistics for Gross Beta Concentrations in Air

In addition to the co-located results discussed above, DOH also analyzed quarterly composite air samples for Co-60 and Cs-134,137 at C Farm, ERDF-SE, KE Basin, Station 4 (not shown on map), and Wye Barricade; and for isotopes of uranium at Station 4, and Wye and Yakima Barricades.

All 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). Uranium-234 and U-238 were detected in most samples, with concentrations ranging from the detection limit of approximately 0.000025 pCi/m³ to 0.00006 pCi/m³. The highest uranium concentrations were found at Station 4 and Station 8. A Pu-239/240 concentration of 0.000005 pCi/m³ was detected at ERDF-SE. Plutonium-239/240 was also detected at ERDF-SE in 2001.

These uranium and plutonium concentrations are very small, and are only a few times greater than the detection limits. Continuous breathing of air with a Pu-239/240 concentration of 0.000005 pCi/m³ would result in an annual radiation dose of approximately 0.02 mrem/yr. Both the U.S. Environmental Protection Agency (40 CFR part 61) and Washington State (Chapter 246-247 WAC) limit radiation dose to the public from air emissions to 10 mrem/year. The maximum radionuclide concentrations detected in DOH composite air samples are all several orders of magnitude less than EPA Concentration Levels for Environmental Compliance (as listed in 40 CFR part 61, Appendix E, Table 2).

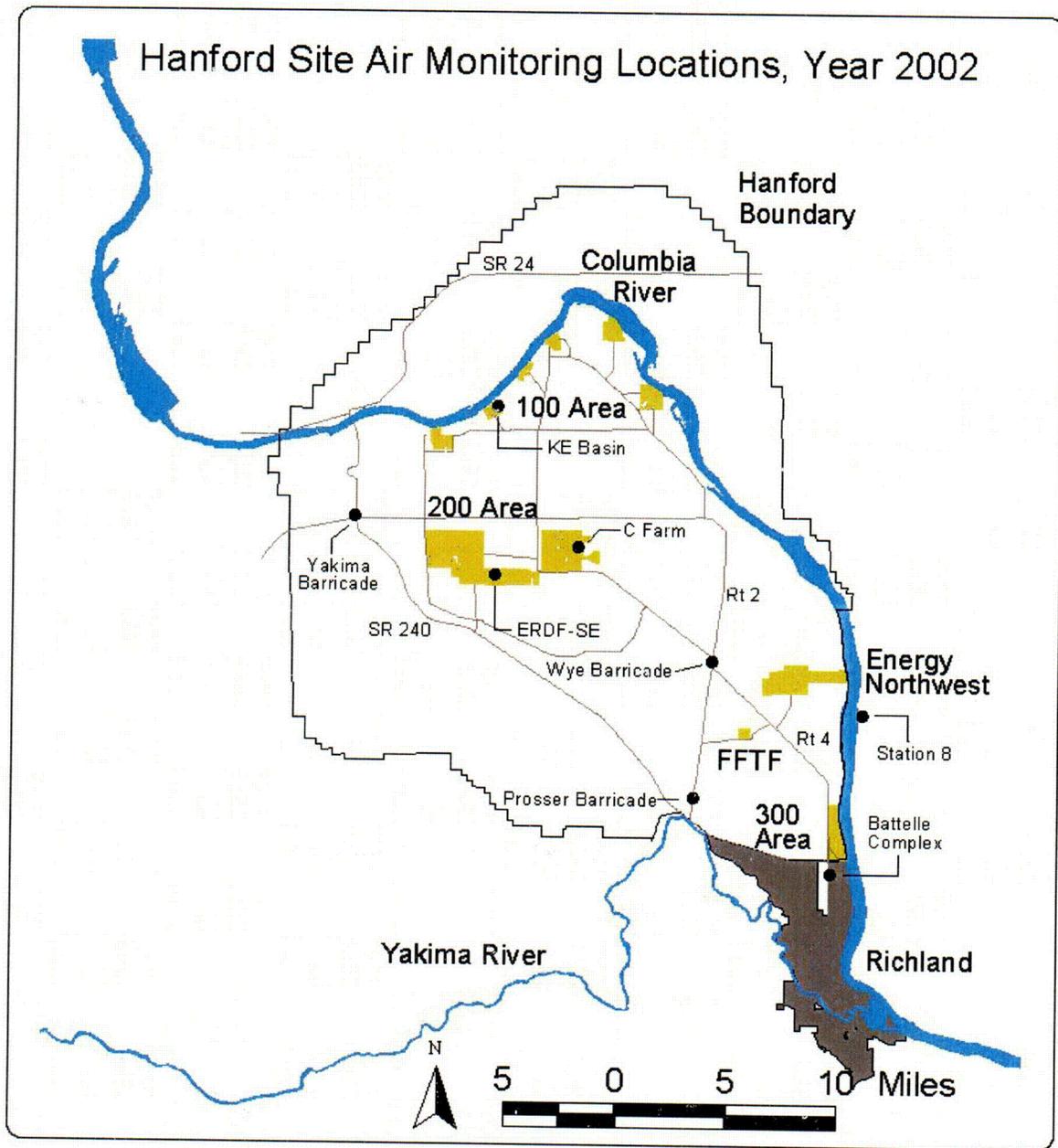


Figure 3.1.1 Air Monitoring Locations

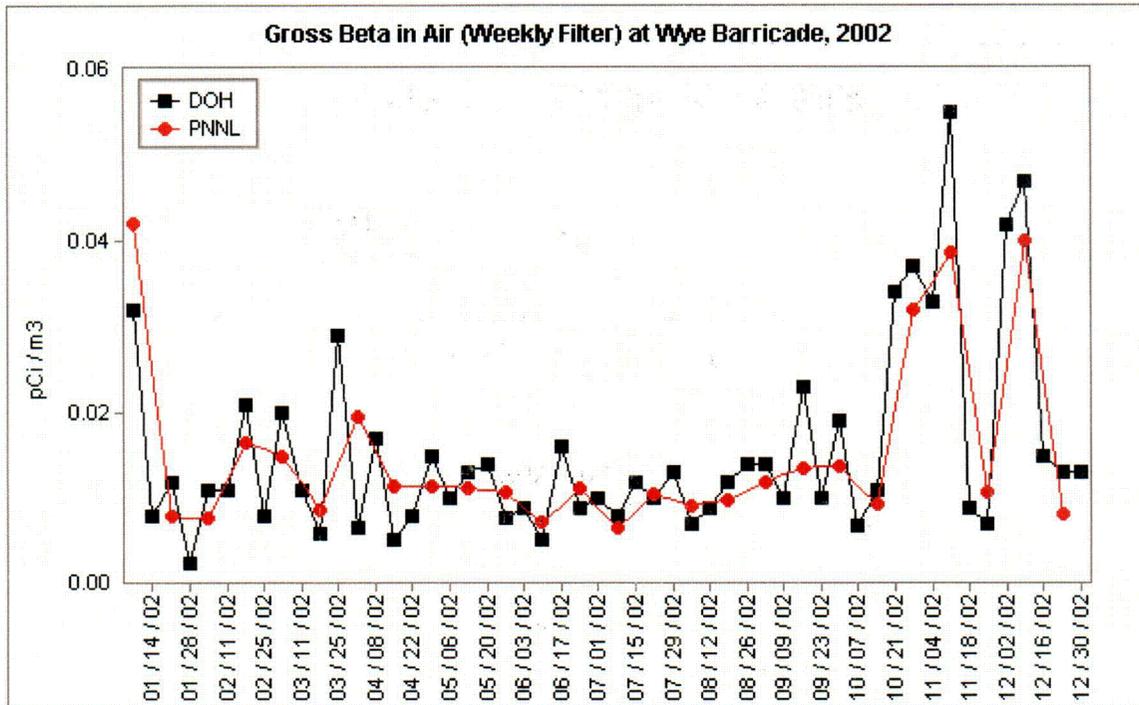


Figure 3.1.2 DOH and PNNL Gross Beta Concentrations in Air at Wye Barricade

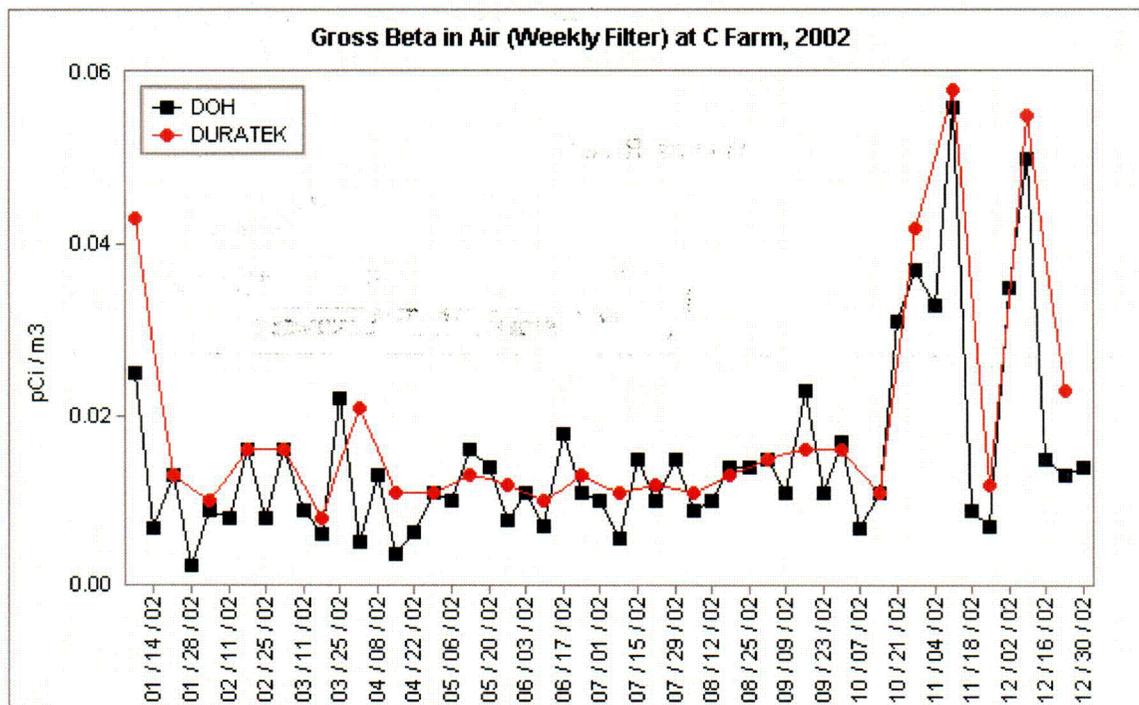


Figure 3.1.3 DOH and Duratek Gross Beta Concentrations in Air at C Farm

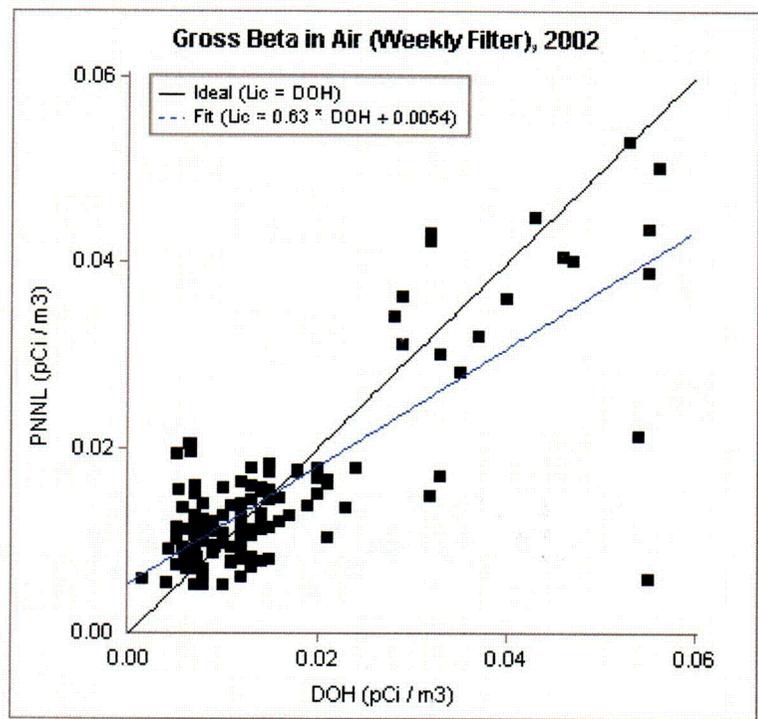


Figure 3.1.4 DOH and PNNL Scatter Plot for Gross Beta Concentrations in Air (2002)

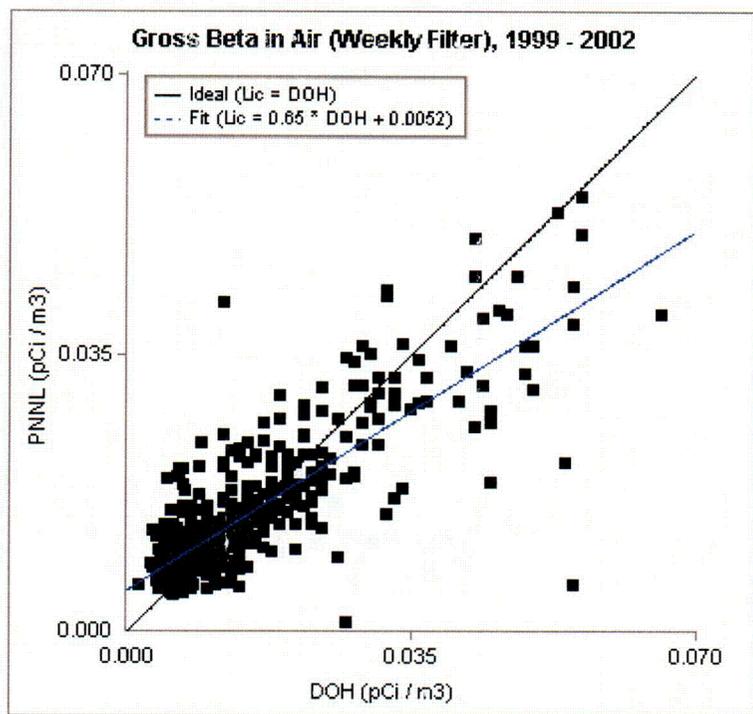


Figure 3.1.5 DOH and PNNL Scatter Plot for Gross Beta Concentrations in Air (1999 - 2002)

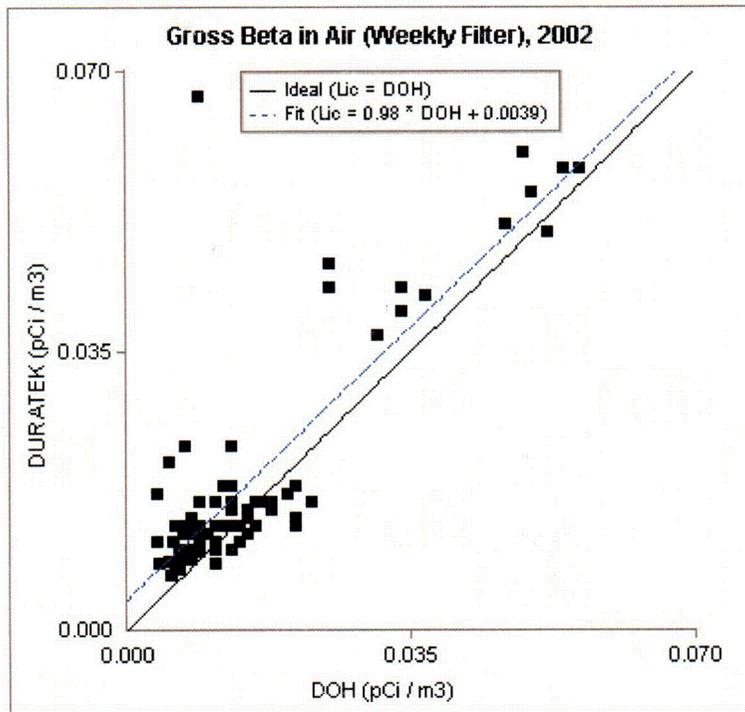


Figure 3.1.6 DOH and Duratek Scatter Plot for Gross Beta Concentrations in Air (2002)

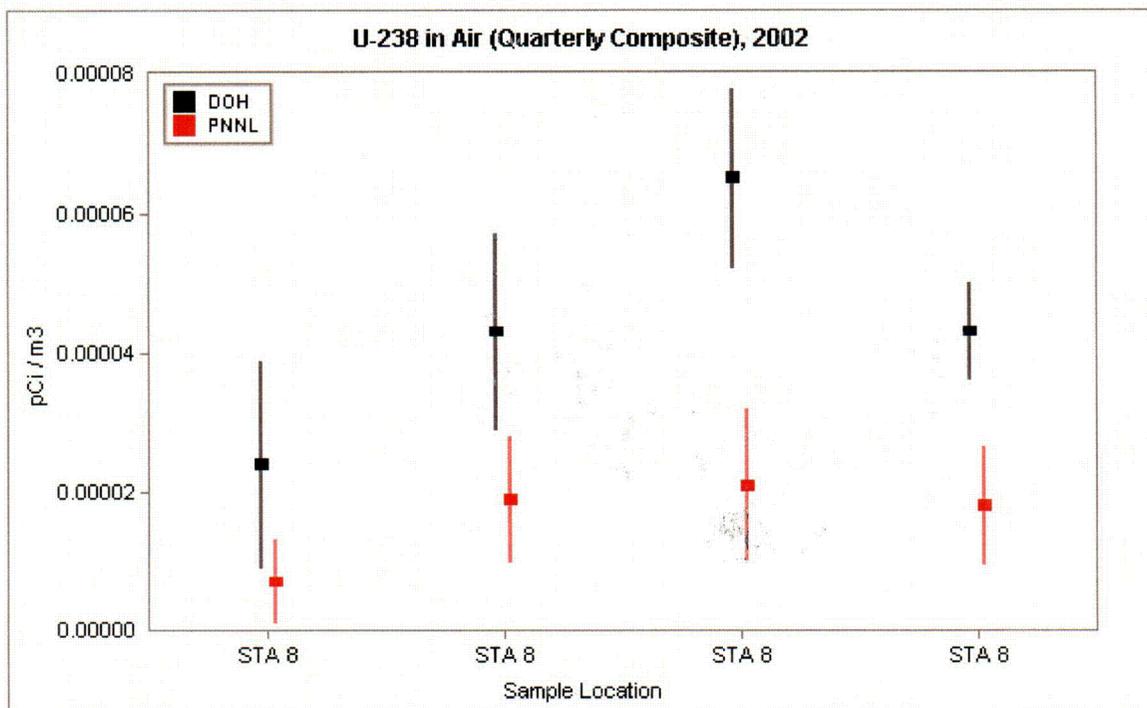


Figure 3.1.7 DOH and PNNL U-238 Concentrations in Air (2002)

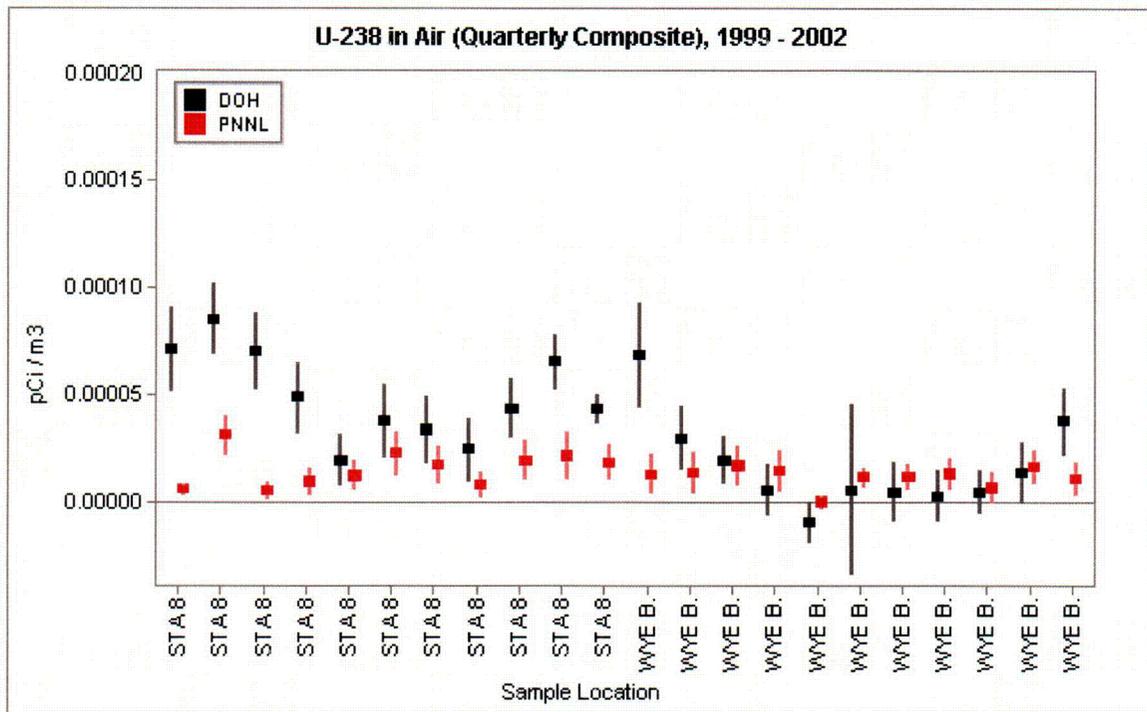


Figure 3.1.8 DOH and PNNL U-238 Concentrations in Air (1999-2002)

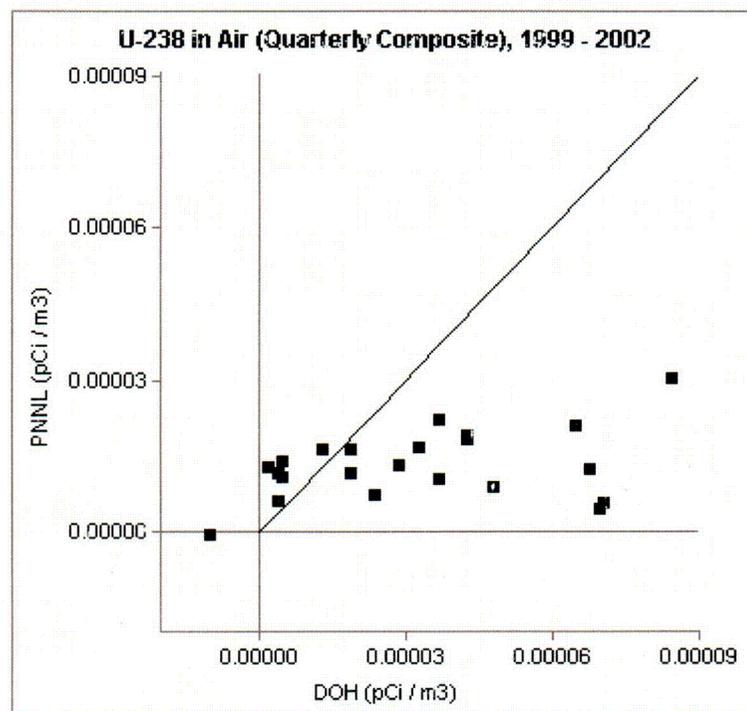


Figure 3.1.9 DOH and PNNL Scatter Plot for U-238 Concentrations in Air (1999-2002)

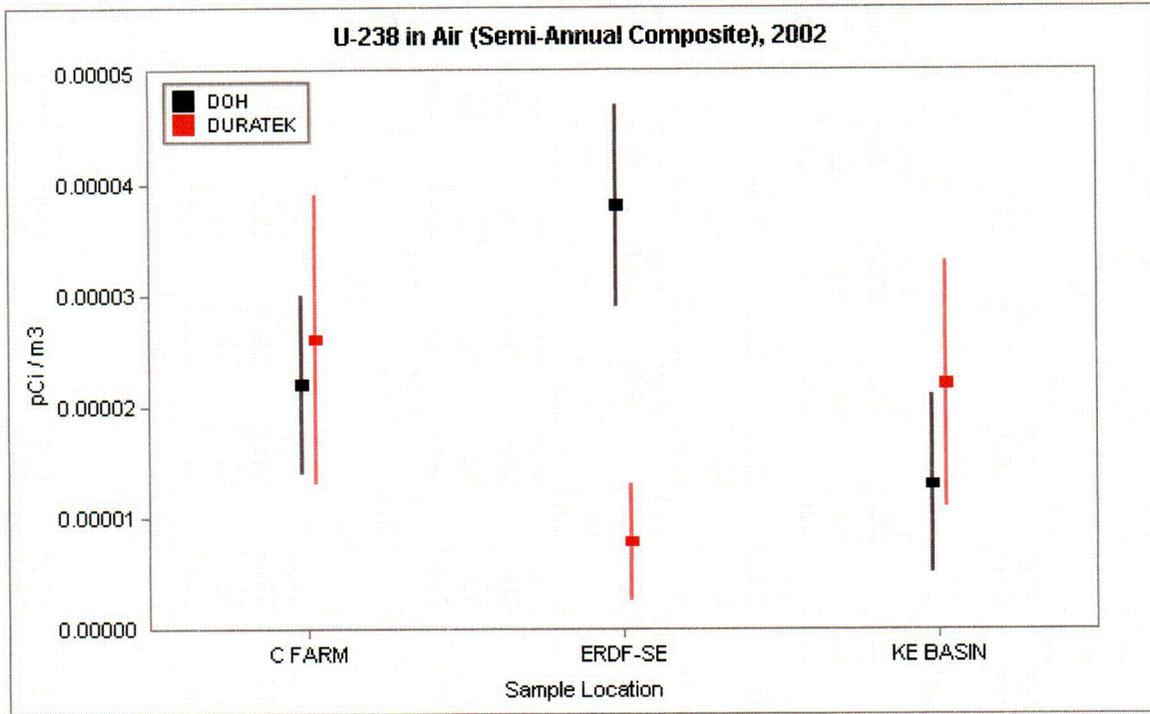


Figure 3.1.10 DOH and Duratek U-238 Concentrations in Air

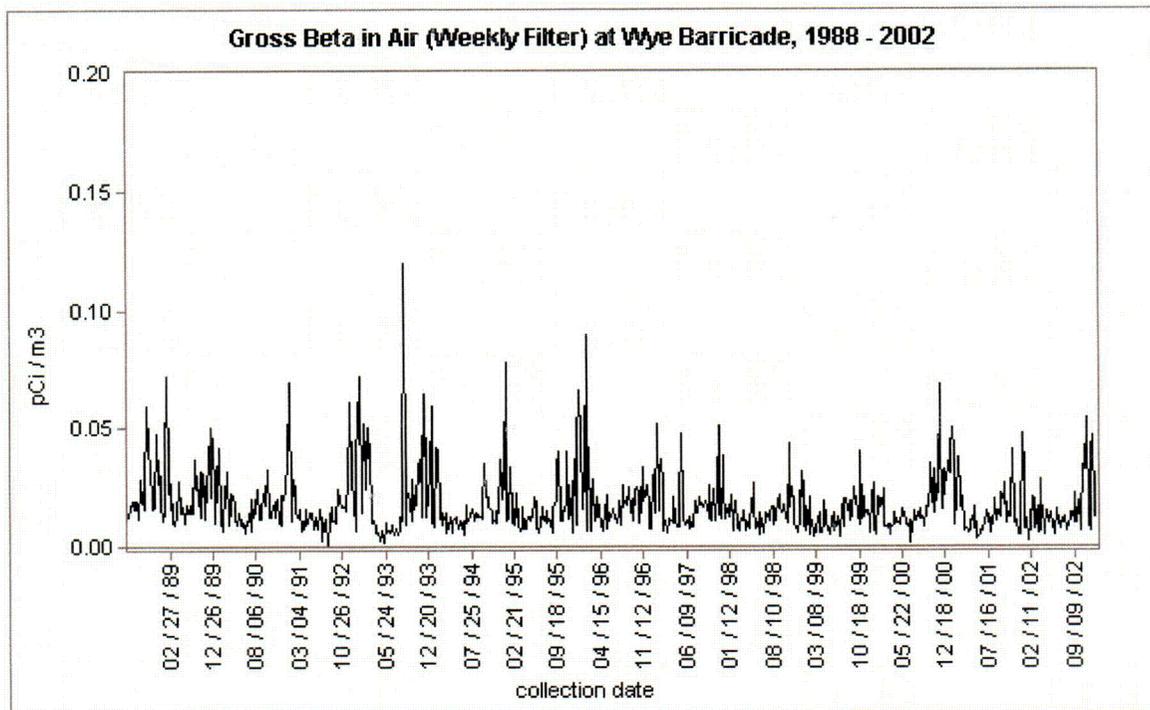


Figure 3.1.11 DOH Historical Gross Beta Concentrations in Air at Wye Barricade

3.2 Groundwater, Riverbank Seep, and Surface Water Monitoring

Major Findings:

- The DOH and PNNL split water results are in good agreement for Co-60, Cs-134, Cs-137, Sb-125, tritium (H-3), Sr-90, Tc-99, and isotopes of uranium. The agreement is fair for gross alpha and gross beta, and is poor for I-129. The DOH and WMFS split TEDF discharge water results are in good agreement.
- Water results in 2002 are consistent with historical data. Radionuclides were detected in groundwater in the vicinity of known groundwater plumes, and in riverbank seep water and Columbia River surface water in the vicinity of plumes known to be entering the Columbia River.
- Tritium was detected above the EPA drinking water standard in groundwater, riverbank seep water, and Columbia River surface water.
- I-129, Sr-90, Tc-99, and isotopes of uranium were detected above EPA drinking water standards in groundwater.
- Radionuclide concentrations in RFTF drinking water are below EPA drinking water standards.
- Radionuclide concentrations in TEDF discharge water are below limits set by the Department of Natural Resources.

3.2.1 Purpose and General Discussion

Operations at the Hanford Site have resulted in contaminated groundwater and Columbia River water. Radioactive contaminants have leached from waste sites in the soil to groundwater beneath the Site, and then have migrated with groundwater to the Columbia River. Occasionally, groundwater entering the Columbia River takes the form of riverbank seeps.

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

DOH collects groundwater, surface water, riverbank seep water, and drinking water samples that are split with PNNL. PNNL monitors radioactivity in water to track contaminant plumes in groundwater, and to evaluate impacts to the public and environment. While the DOH program does not sample enough groundwater wells to track groundwater plumes, the riverbank seep and Columbia River data is adequate to understand impacts to the public. In addition, DOH and Waste Management Federal Services NW (WMFS) split discharge water samples from an effluent treatment facility.

3.2.2 Monitoring Locations

Groundwater

DOH collected 24 split samples from 19 groundwater wells in 2002. Most well locations sampled are on the Hanford Site, either within contaminated plumes, near waste sites, or along the Columbia River shoreline. A few of the well locations are off the Hanford Site, located just south of Hanford in the northern part of Richland and just across the Columbia River in Franklin County. Figure 3.2.1 shows the locations of the DOH groundwater sampling sites.

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

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

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

The 400 Area is the location of the Fast Flux Test Facility, a liquid sodium cooled test reactor that ceased operation in 1993 and is currently being deactivated. Tritium (H-3) originating from the 200 Area is a common contaminant found in 400 Area groundwater. The primary objective of groundwater monitoring in this area is to assess impacts to the primary drinking water source for this area.

The 600 Area includes all the land outside the operational areas of the Hanford Site. Tritium (H-3) originating from the 200 Area is a common contaminant found in 600 Area groundwater. The major objective of sampling 600 Area groundwater is to assess the nature and extent of plumes originating in the 200 Area that may be moving offsite.

Riverbank Seeps

Groundwater enters the Columbia River through riverbank seeps. Historically, the predominant areas for discharge of riverbank seep water to the Columbia River were located at the 100N Area, the Old Hanford Townsite, and the 300 Area. In 2002, one

split riverbank seep sample was collected from each of three sites. The sites were located at the 100F and 100K Areas, and the Old Hanford Townsite (Spring 28.2). Figure 3.2.1 shows the locations of the DOH riverbank seep sampling sites.

Surface and Discharge Water

A total of 23 split surface water samples were collected from 12 sites. Ten of the sites were on the Columbia River - one at Priest Rapids Dam, four at the 100F Area, and 5 at the Old Hanford Townsite. Two of the sites were at irrigation canals, one located across the Columbia River at Riverview, and the other at the southern boundary of the Hanford Site at the Horn Rapids irrigation pumping station. Figure 3.2.1 shows the locations of the DOH surface water sampling sites.

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

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

The TEDF was constructed as part of a Tri-Party Agreement Milestone to cease discharges to the 300 Area Process Trenches. The facility began operation in December 1994 and effluent sampling has been conducted since that time. In 2002, DOH split 2 discharge samples from TEDF with WMFS.

Drinking Water

Drinking water for the 400 Area (the Fast Flux Test Facility, i.e. FFTF) comes from groundwater wells in the area. Drinking water for the 100N Area comes from the 100B Area pumphouse. In 2002, DOH and PNNL split one drinking water sample from FFTF and one from the 100N Area.

3.2.3 Monitoring Procedures

Groundwater

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

Riverbank Seeps

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

Surface and Discharge Water

Columbia River surface water is monitored by collecting samples at several points spanning the width of the river. This technique is known as transect sampling. Columbia River transect samples were collected during a joint sampling trip with PNNL. Samples were split in the field and analyzed unfiltered. All samples were analyzed for isotopes of uranium and tritium (H-3). Analyses for gross alpha, gross beta, gamma-emitting radionuclides, Sr-90, and Tc-99 were added where appropriate. In addition, the discharge samples from the 310 Treated Effluent Disposal Facility were analyzed for gross alpha, gross beta, gamma emitting radionuclides, and tritium.

Drinking Water

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

Summary

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

Water Matrix	DOE Contractor	Analytes	Number of Sample Sites	Number of Samples
Groundwater	PNNL	C-14, Co-60, Cs-134, Cs-137, gross alpha, gross beta, H-3, I-129, Sb-125, Sr-90, Tc-99, Total U, U-234, U-235, U-238	19	24
Riverbank Seep	PNNL	Co-60, Cs-137, gross alpha, gross beta, H-3, Sr-90, Tc-99, U-234, U-235, U-238	3	3
Surface Water	PNNL	Co-60, Cs-137, gross alpha, gross beta, H-3, Sr-90, Tc-99, U-234, U-235, U-238	12	23
Discharge Water	WMFS	Co-60, Cs-137, gross alpha, gross beta, H-3	1	2
Drinking Water	PNNL	gross alpha, gross beta, H-3, Sr-90	2	2

Table 3.2.1 Summary of Split Water Samples

3.2.4 Comparison of DOH and Contractor Data

In 2002, the DOH Hanford Oversight Program split groundwater, surface water, drinking water, and riverbank seep water samples with PNNL. Laboratory techniques to analyze all these different types of water samples are identical. Therefore, the regression analysis, which is used to quantify the degree of agreement between DOH and the DOE contractor, included all of the different types of water samples.

Regression analysis was carried out for gross alpha, gross beta, H-3, Sr-90, Tc-99, U-234, and U-238. The data for all other radionuclides measured in water samples did not meet the criteria for conducting regression analysis (see section 2.2.4.2), either because there were too few data points, or most of the data were below detection limits. For example, all results for the gamma emitting radionuclides Co-60, Cs-134, Cs-137, and Sb-125 were in good agreement, but all results were below the detection limit. Other radionuclides such as C-14 and I-129 did not have enough data points in 2002 for a statistical analysis. However, a regression analysis was carried out for historical I-129 results.

DOH vs. PNNL scatter plots for split water samples were generated for gross alpha, gross beta, H-3, Sr-90, Tc-99, and U-238. The scatter plots combine groundwater, surface water, riverbank seep water, and drinking water. A scatter plot for U-234 is not shown because it is similar to U-238. The x-coordinate of each point represents the DOH result, while the y-coordinate represents the PNNL result. Ideally, if the DOH and PNNL results were identical, all the points would fall on the straight line with slope equal to unity and y-intercept equal to zero (shown as the black line in the figures). Regression analysis was used to find the best straight-line fit to the data (blue dashed line), and the resulting slopes and y-intercepts quantify the agreement between DOH and PNNL results.

The DOH and PNNL gross alpha scatter plot for all water samples collected in 2002 is shown in Figure 3.2.2. Expanding the lower concentration results in the figure indicate a poor agreement between the DOH and PNNL data. Figure 3.2.3 shows all 2002 water samples with concentrations less than 20 pCi/L. The best straight-line fit to the data deviates from the ideal case, and clearly shows the systematic bias in which on average the PNNL results are approximately one-half of the concentrations reported by DOH. Figure 3.2.4 shows the gross alpha scatter plot for all water samples collected from 1999 through 2002. This figure shows that the systematic bias has existed historically, and extends to higher concentration data as well. DOH is currently investigating this discrepancy and will report its findings in a future annual report.

The split gross alpha groundwater data are shown in Figure 3.2.5. Even though the systematic bias is evident from the scatter plots, Figure 3.2.5 indicates that the DOH and PNNL data generally follow the same trends.

The DOH and PNNL gross beta scatter plot for all water samples collected in 2002 is shown in Figure 3.2.6. Expanding the lower concentration results in the figure indicate a poor agreement between some of the DOH and PNNL data. Figure 3.2.7 shows all 2002 water samples with concentrations less than 100 pCi/L. A regression analysis was not carried out because of the large scatter in the data. The figure shows that some of the

PNNL results are approximately one-half of the concentrations reported by DOH. Figure 3.2.8 shows the gross beta scatter plot for all water samples with concentrations less than 100 pCi/L collected from 1999 through 2002. This best straight-line fit to the data shows a systematic bias, which has existed historically, in which on average the PNNL results are approximately one-half of the concentrations reported by DOH. DOH is currently investigating this discrepancy and will report its findings in a future annual report.

The split gross beta groundwater data for samples with concentrations less than 100 pCi/L are shown in Figure 3.2.9. Even though a historical systematic bias is evident from the scatter plots, Figure 3.2.9 indicates that the DOH and PNNL data generally follow the same trends.

The DOH and PNNL tritium (H-3) scatter plot for all water samples collected in 2002 (51 samples) is shown in Figure 3.2.10. The slope of 0.88 and the relatively small y-intercept value of 95 pCi/L in the regression analysis indicates that the DOH and PNNL data are in good agreement. On average, the difference in concentrations reported by DOH and PNNL are less than approximately 10%. Also shown in Figure 3.2.11 are the split tritium data in groundwater. As can be seen, most of the data are in good agreement. Historically, the DOH and PNNL split H-3 results in water are in good agreement.

The DOH and PNNL Sr-90 scatter plot for all water samples collected from 1999 through 2002 is shown in Figure 3.2.12. A scatter plot for 2002 data only (29 samples) was not generated because most of the data were below the detection limit. The slope of 0.94 in the regression analysis indicates that the DOH and PNNL data are historically in good agreement. On average, the difference in concentrations reported by DOH and PNNL are less than approximately 5%. Most of the data in this figure are below the detection limit of approximately 0.7 pCi/L. Figure 3.2.13 shows the 2002 split Sr-90 results for groundwater. As can be seen, the data are in good agreement.

The DOH and PNNL Tc-99 scatter plot for all water samples collected in 2002 (11 samples) is shown in Figure 3.2.14. The slope of unity and the small y-intercept in the regression analysis indicates that the DOH and PNNL data are in good agreement. Figure 3.2.15 shows the 2002 split Tc-99 results for groundwater. As can be seen, the data are in good agreement. Historically, the DOH and PNNL split Tc-99 results in water are in good agreement.

The DOH and PNNL U-238 scatter plot for all water samples collected in 2002 (30 samples) is shown in Figure 3.2.16. The slope of unity in the regression analysis indicates that the DOH and PNNL data are in good agreement. The U-234 data and regression analysis are similar to those for U-238. Historically, the DOH and PNNL split U-238 results in water are in good agreement, at least for results less than approximately 50 pCi/L (see scatter plot in Figure 3.2.17). However, for higher concentrations, the agreement is poor, with the PNNL results approximately twice the concentrations reported by DOH (see Figure 3.2.18). The higher concentration results in Figure 3.2.18 were collected in 1999.

Figure 3.2.19 shows the 2002 split U-238 results for groundwater. As can be seen, the data are in good agreement. DOH and PNNL results for U-234 in groundwater are similar to those for U-238, and are also in good agreement.

The historical DOH and PNNL I-129 scatter plot for 1999 - 2002 is shown in Figure 3.2.20. All samples are from groundwater. For samples where the results are above the detection limit, the agreement is poor. The I-129 discrepancy is significant, as most of the results are above the EPA drinking water maximum contaminant level of 1 pCi/L. DOH is currently investigating this discrepancy and will report its findings in a future annual report.

All the split Co-60, Cs-134, Cs-137, and Sb-125 data are in good agreement, but are below the detection limit of 2 pCi/L. The split U-235 results are in good agreement, although most results are below the detection limit of 0.06 pCi/L. One split C-14 sample appears to be in poor agreement. The DOH result was below the detection limit of 150 pCi/L and PNNL detected C-14 at a concentration of 180 pCi/L. However, similar to historical data, the PNNL C-14 result is near the value of the DOH detection limit, so it is not clear that the DOH and PNNL results are significantly different. The uncertainties of the PNNL C-14 data are ten times smaller than the uncertainties of the DOH data, indicating different laboratory protocols. DOH will investigate the significance of these different protocols and report its findings in a future annual report.

Summary

There is good agreement between DOH and PNNL split results for Co-60, Cs-134, Cs-137, Sb-125, and U-235, although most of these results are below detection limits. Tritium (H-3), Sr-90, Tc-99, U-234, and U-238 results in 2002 are also in good agreement. The agreement between DOH and PNNL results for gross alpha and gross beta is only fair, as the data indicate a systematic bias in which the PNNL results are approximately one-half the concentrations reported by DOH. The DOH and PNNL I-129 results and the single C-14 result are in poor agreement.

The DOH and WMFS results for the two discharge water samples at TEDF are in good agreement for all analyzed radionuclides (Co-60, Cs-137, gross alpha, gross beta, and H-3).

3.2.5 Discussion of Results

All DOH C-14, Co-60, Cs-134, Cs-137, and Sb-125 concentrations in water samples were below detection limits (2 pCi/L, except 150 pCi/L for C-14). In addition to the split water samples discussed above, DOH also analyzed two groundwater samples from the 100K Area and two from the 300 Area for Pu-238 and Pu-239/240. All plutonium results were below the detection limit of approximately 0.08 pCi/L. The results in 2002 for these radionuclides are similar to historical data.

DOH routinely detects H-3, I-129, 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 2002, all measured concentrations for these radionuclides were consistent with historical DOH results.

DOH detected tritium (H-3) at concentrations above the EPA drinking water standard of 20,000 pCi/L in groundwater wells 199-K-109A, 199-N-14, 699-26-33, 699-35-70, 699-60-60 (see Figure 3.2.11); in riverbank seep water at river mile 28.2 near the Old Hanford Townsite; and in Columbia River surface water near river mile 28. The maximum tritium concentration of 335,000 pCi/L was measured in groundwater well 699-35-70, and historical DOH results for this well are shown in Figure 3.2.21. Historical riverbank seep water results at river mile 28.2 are shown in Figure 3.2.22 (2002 result of 72,000 pCi/L). A Columbia River surface water sample collected at river mile 28 had a tritium concentration of 21,000 pCi/L.

Tritium was detected in 400 Area drinking water at a concentration of 3,300 pCi/L, which is below the drinking water standard and is consistent with historical results as shown in Figure 3.2.23. The maximum tritium concentration detected in TEDF discharge water was 90 pCi/L.

DOH detected I-129 at concentrations above the EPA drinking water standard of 1 pCi/L in groundwater well 699-35-70, with a maximum concentration of 12 pCi/L. This well is in the vicinity of a known I-129 plume in the 200 Area. Historical I-129 results at well 699-35-70 are shown in Figure 3.2.24.

DOH detected Sr-90 at concentrations above the EPA drinking water standard of 8 pCi/L in groundwater wells 199-F5-1, 199-K-109A, and 199-N-14 (see Figure 3.2.13). The maximum Sr-90 concentration of 2,000 pCi/L was detected in well 199-K-109A in a sample that was not split with PNNL. Historical Sr-90 concentrations at groundwater well 199-N-14 are shown in Figure 3.2.25. Strontium-90 results for drinking water, Columbia River surface water, and riverbank seep water were all below the detection limit of 0.7 pCi/L. In 2002, DOH did not analyze surface water or seep water from near the 100N Area, where elevated Sr-90 concentrations are typically found.

DOH did not detect Tc-99 at concentrations above the EPA drinking water standard of 900 pCi/L for any water samples collected in 2002. The maximum Tc-99 concentration of 140 pCi/L was detected in groundwater well 699-60-60 (see Figure 3.2.15). Historical Tc-99 concentrations for this well are shown in Figure 3.2.26. A concentration of 55 pCi/L was detected in riverbank seep water at river mile 28.2 near the Old Hanford Townsite (historical data shown in Figure 3.2.27). Technetium-99 was not detected above the detection limit of 4 pCi/L in Columbia River surface water samples. Drinking water and discharge water samples were not analyzed for Tc-99.

DOH detected isotopic uranium concentrations above the EPA drinking water standard of 21 pCi/L (total uranium) in groundwater well 399-1-17A, with a maximum total uranium concentration of 42 pCi/L (see Figure 3.2.19). This well is in the vicinity of a known uranium plume in the 300 Area. Historical results for this well are shown in Figure 3.2.28. Concentrations are declining at this site since discharge to the nearby process trenches was discontinued in 1997. A total uranium concentration of 5 pCi/L was

detected in riverbank seep water from the 100K Area. Total uranium concentrations in Columbia River surface water were similar to background values of approximately 0.4 pCi/L. Drinking water and discharge water samples were not analyzed for uranium.

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 from both the Sr-90 and the daughter Y-90).

Summary

Radionuclides detected in groundwater wells include gross alpha, gross beta, H-3, I-129, Sr-90, Tc-99, and isotopes of uranium. Radionuclides in groundwater that exceed drinking water standards include gross alpha, gross beta, H-3, I-129, Sr-90, and uranium. Radionuclide concentrations in 2002 were similar to historical data, and were detected in the vicinity of known groundwater plumes.

Radionuclides detected in riverbank seep water include gross alpha, gross beta, tritium, Tc-99, and isotopes of uranium. Tritium entering the Columbia River near the Old Hanford Townsite was the only radionuclide detected above drinking water standards.

Most radioactivity concentrations in Columbia River surface water samples were either below detection limits or were similar to background concentrations detected at Priest Rapids Dam upstream of the Hanford Site. The only exception includes tritium, at a concentrations slightly above the drinking water standard, in near-shore Columbia River surface water collected near the Old Hanford Townsite.

All radionuclides detected in drinking water samples were below EPA drinking water standards.

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

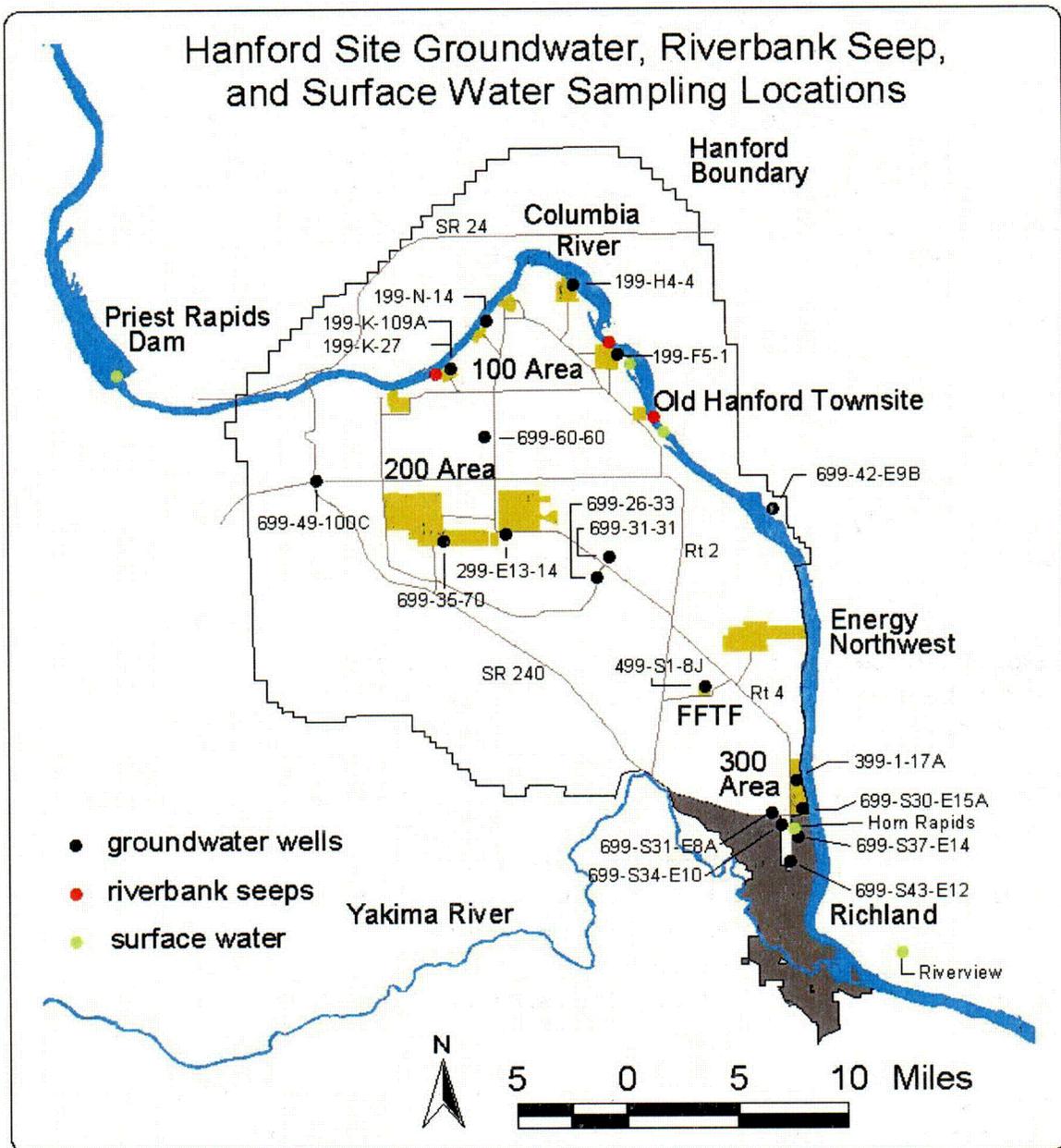


Figure 3.2.1 Water Monitoring Locations

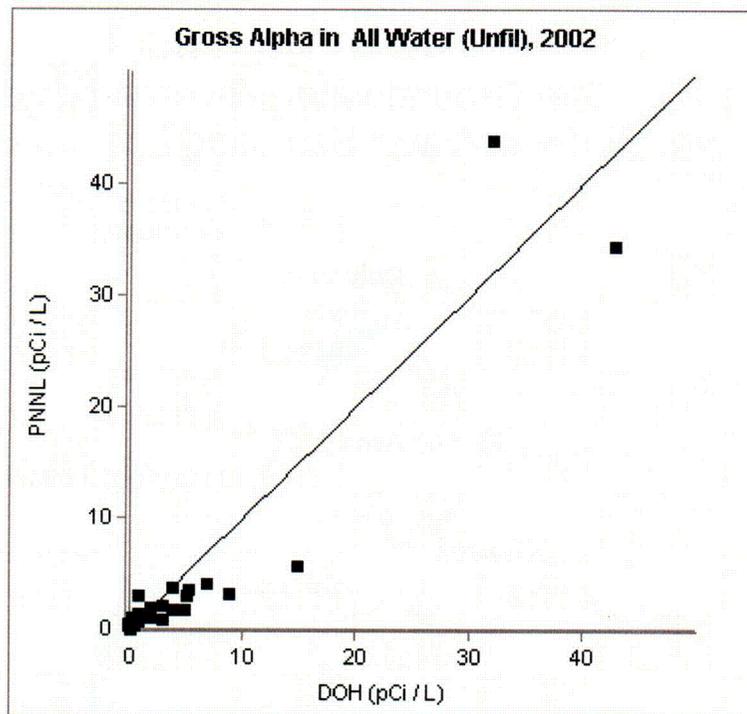


Figure 3.2.2 DOH and PNNL Scatter Plot for Gross Alpha Concentrations in Water Samples

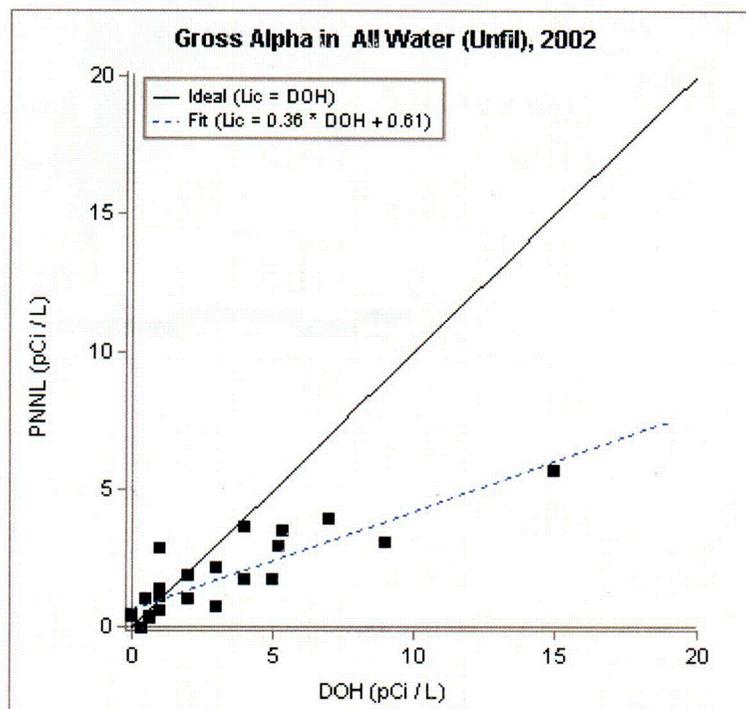


Figure 3.2.3 DOH and PNNL Scatter Plot for Low Activity Gross Alpha in Water Samples

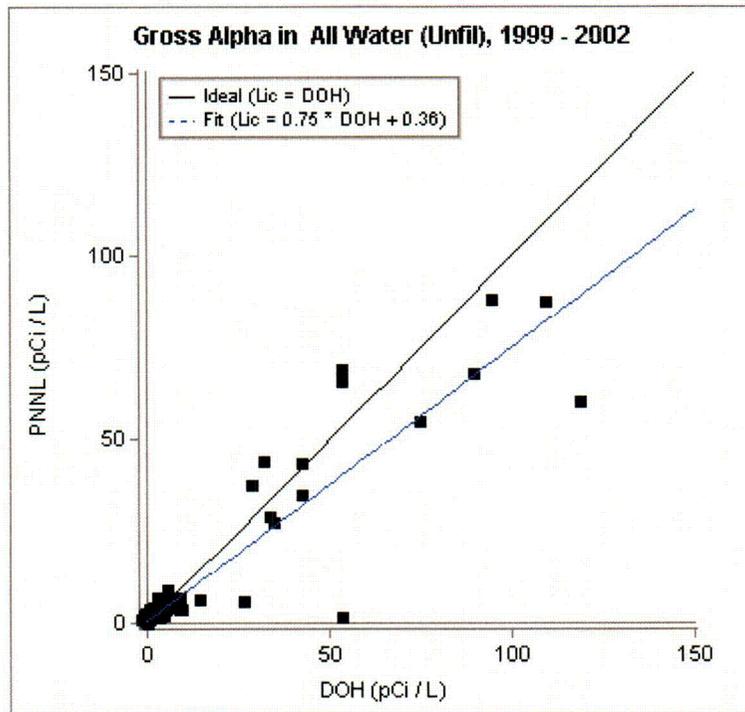


Figure 3.2.4 DOH and PNNL Scatter Plot for Historical Gross Alpha in Water Samples

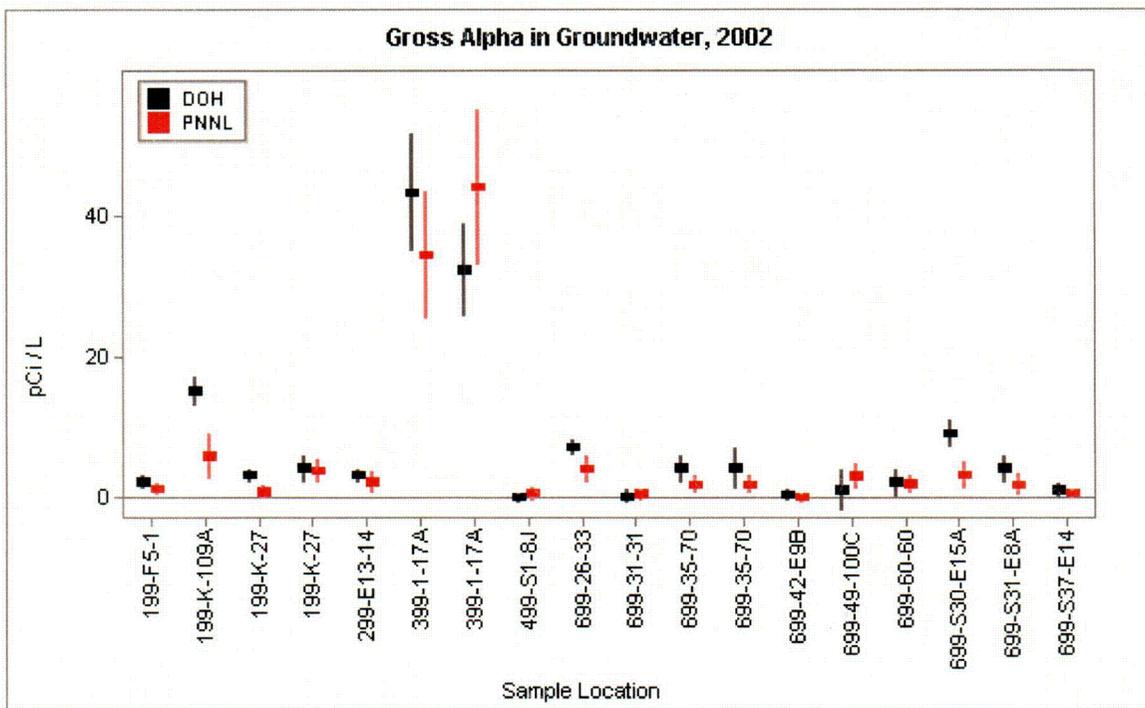


Figure 3.2.5 DOH and PNNL Gross Alpha Concentrations in Groundwater

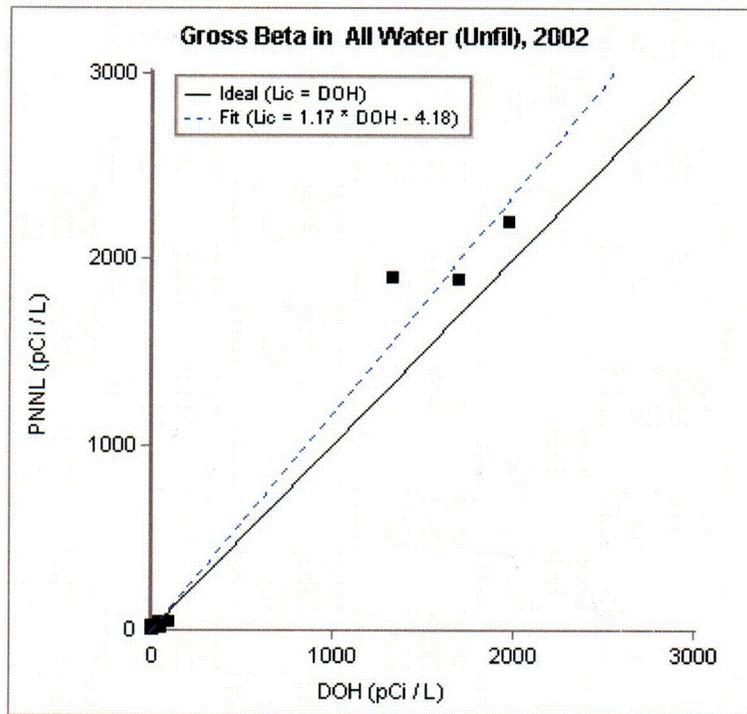


Figure 3.2.6 DOH and PNNL Scatter Plot for Gross Beta Concentrations in Water Samples

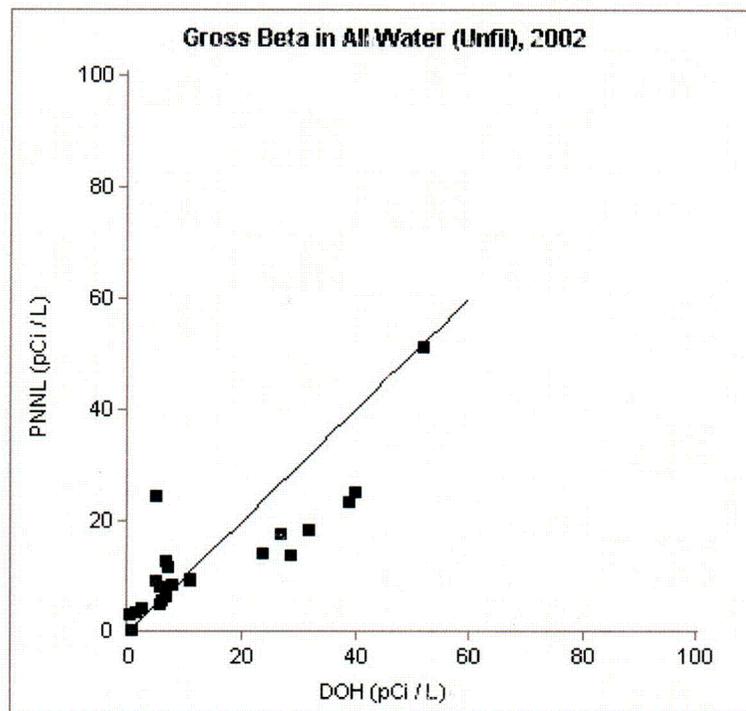


Figure 3.2.7 DOH and PNNL Scatter Plot for Low Activity Gross Beta in Water Samples

C10

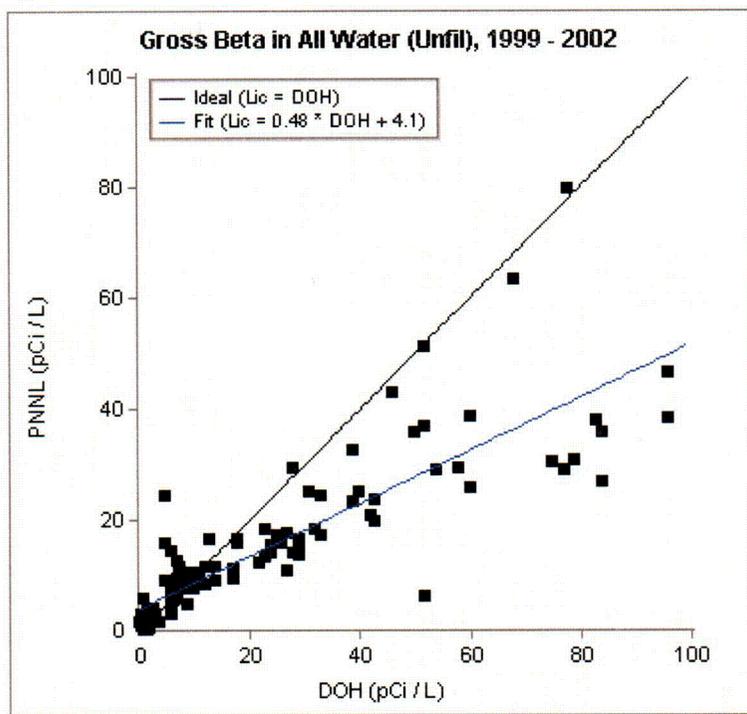


Figure 3.2.8 DOH and PNNL Scatter Plot for Historical Low Activity Gross Beta in Water

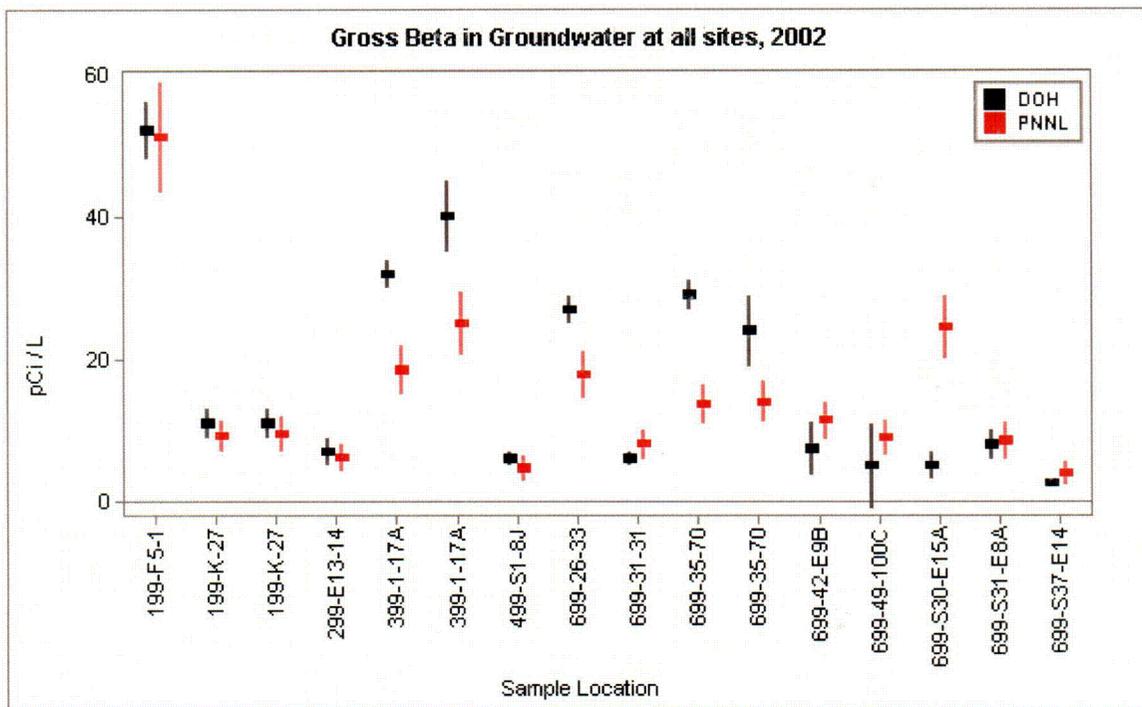


Figure 3.2.9 DOH and PNNL Low Activity Gross Beta Concentrations in Groundwater

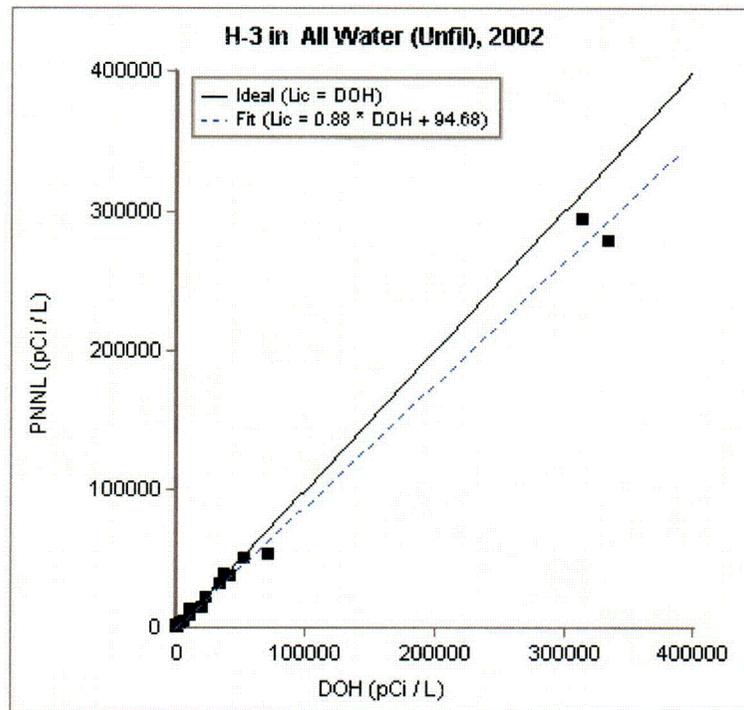


Figure 3.2.10 DOH and PNNL Scatter Plot for H-3 Concentrations in Water Samples

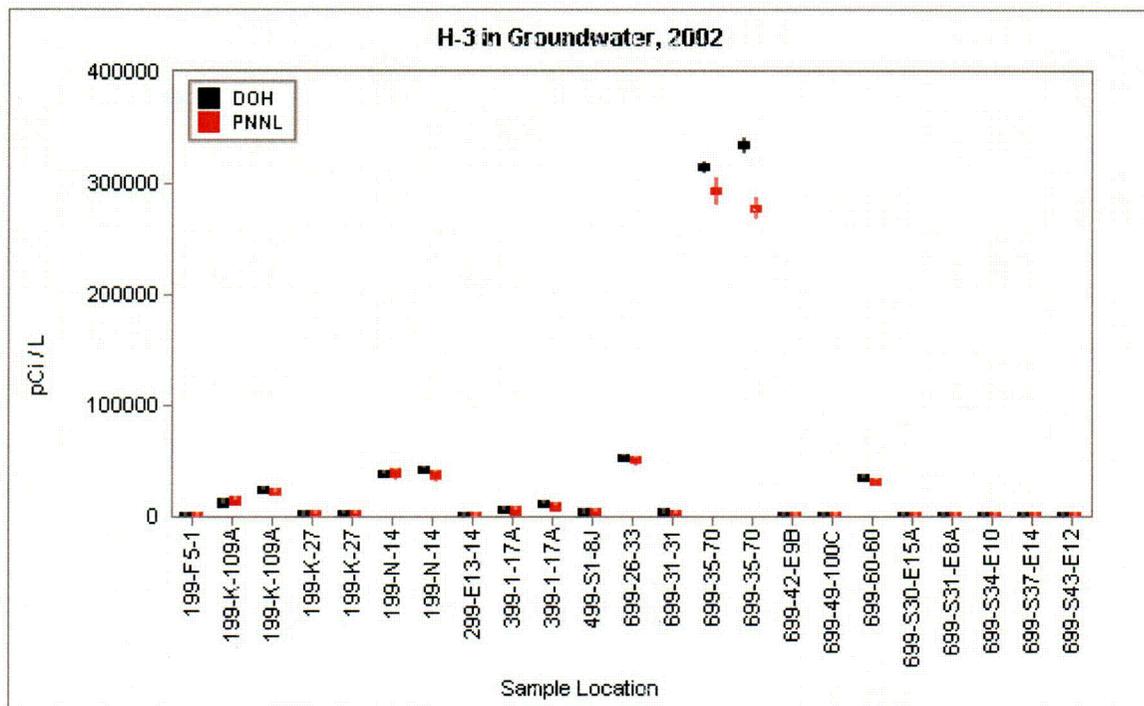


Figure 3.2.11 DOH and PNNL H-3 Concentrations in Groundwater

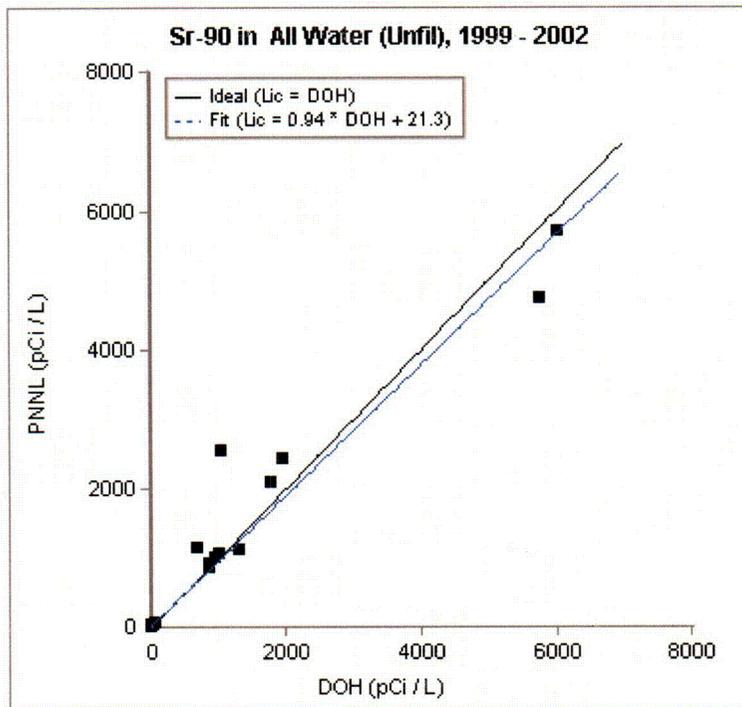


Figure 3.2.12 DOH and PNNL Scatter Plot for Historical Sr-90 in Water Samples

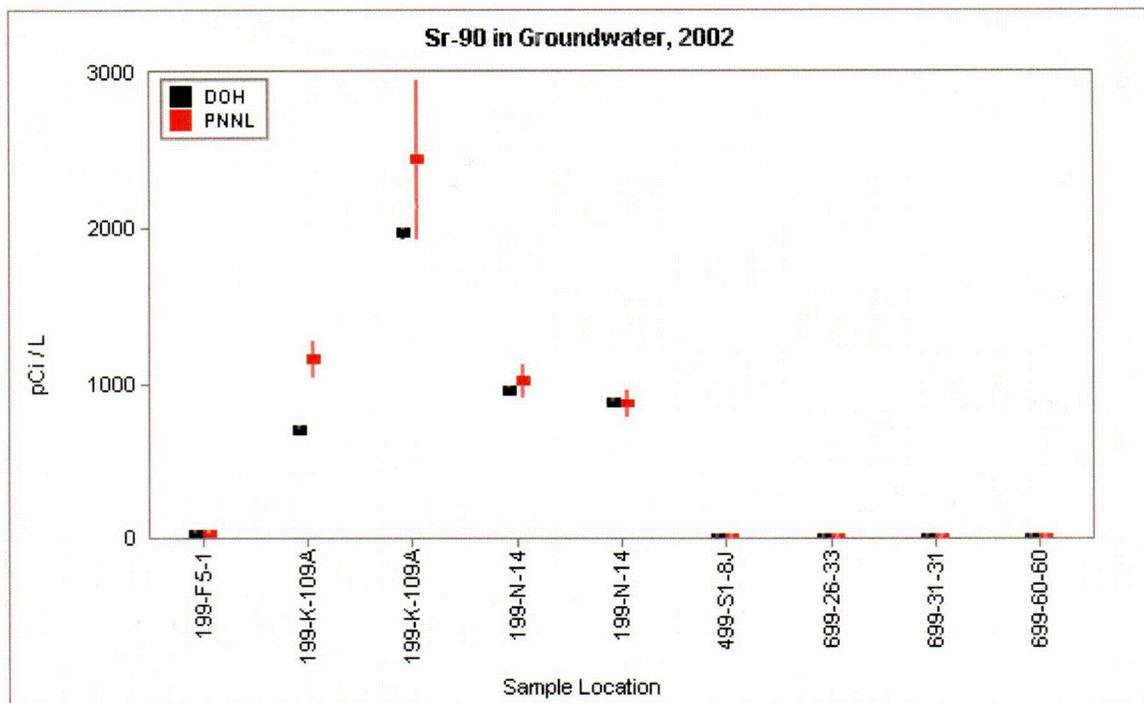


Figure 3.2.13 DOH and PNNL Sr-90 Concentrations in Groundwater

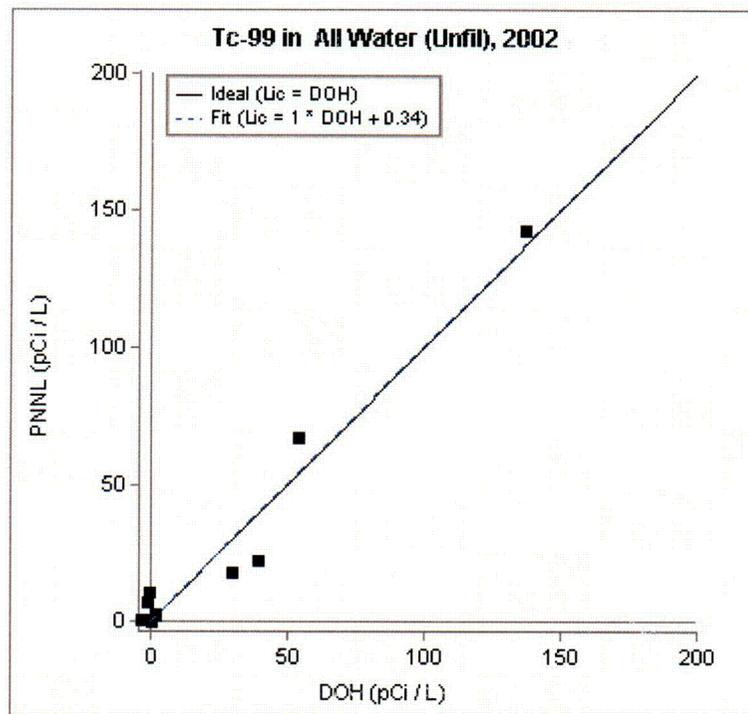


Figure 3.2.14 DOH and PNNL Scatter Plot for Tc-99 Concentrations in Water Samples

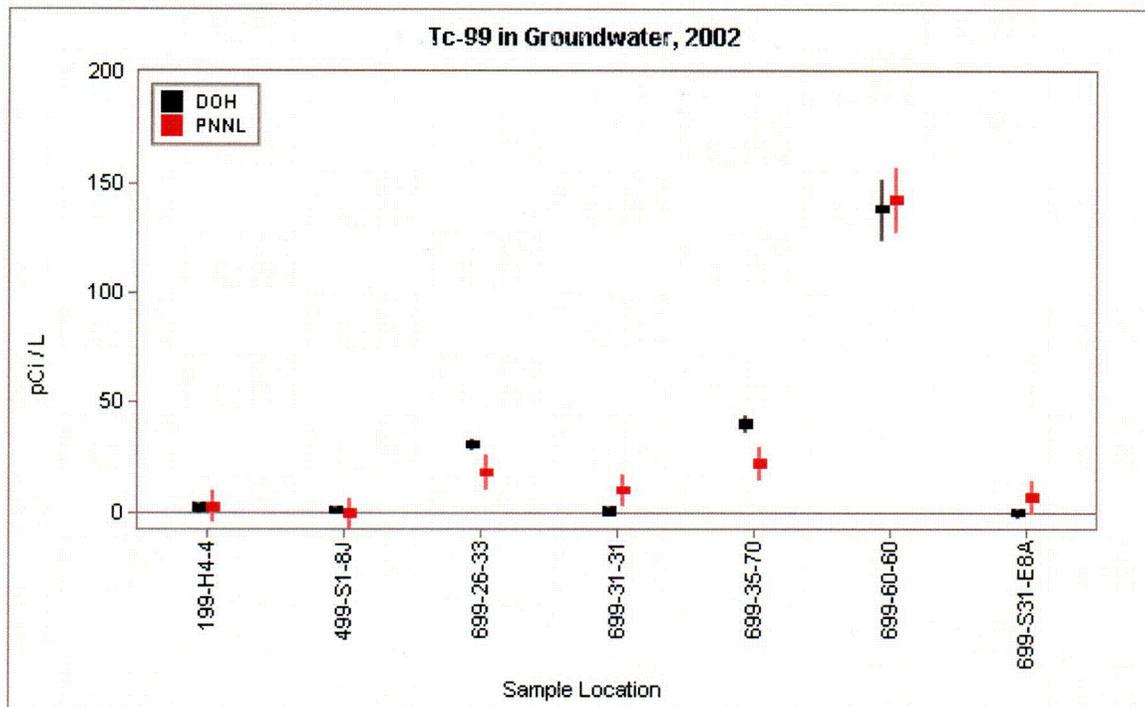


Figure 3.2.15 DOH and PNNL Tc-99 Concentrations in Groundwater

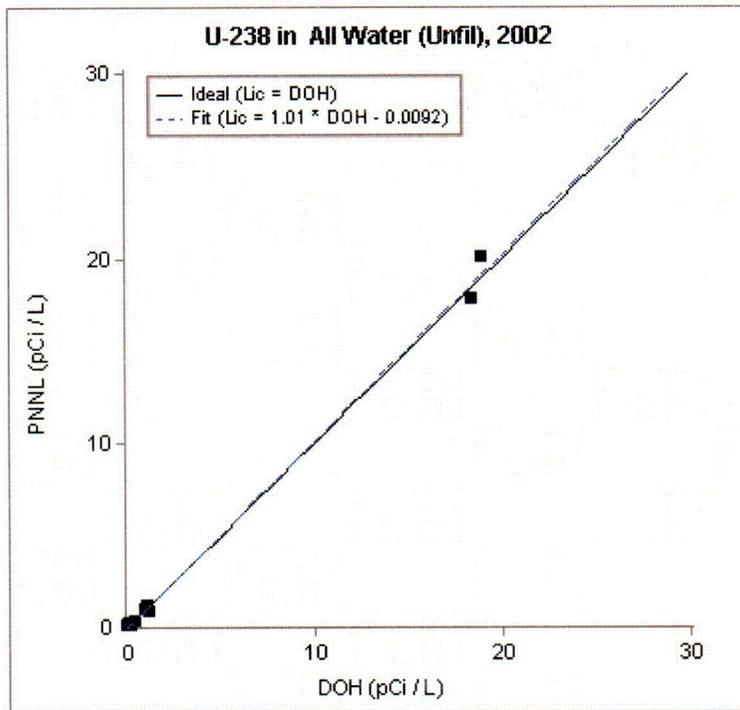


Figure 3.2.16 DOH and PNNL Scatter Plot for U-238 Concentrations in Water Samples

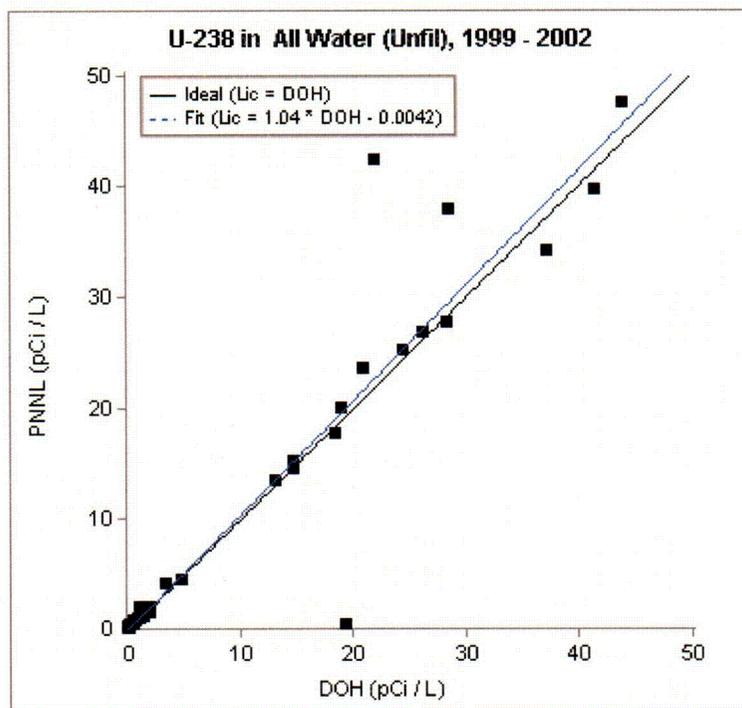


Figure 3.2.17 DOH and PNNL Scatter Plot for Historical U-238 (< 50 pCi/L) in Water

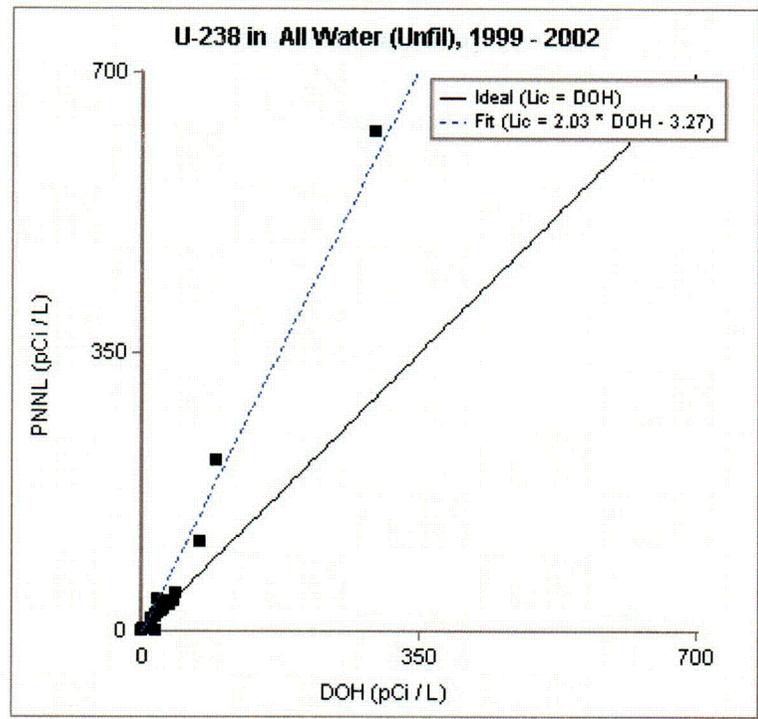


Figure 3.2.18 DOH and PNNL Scatter Plot for Historical U-238 in Water Samples

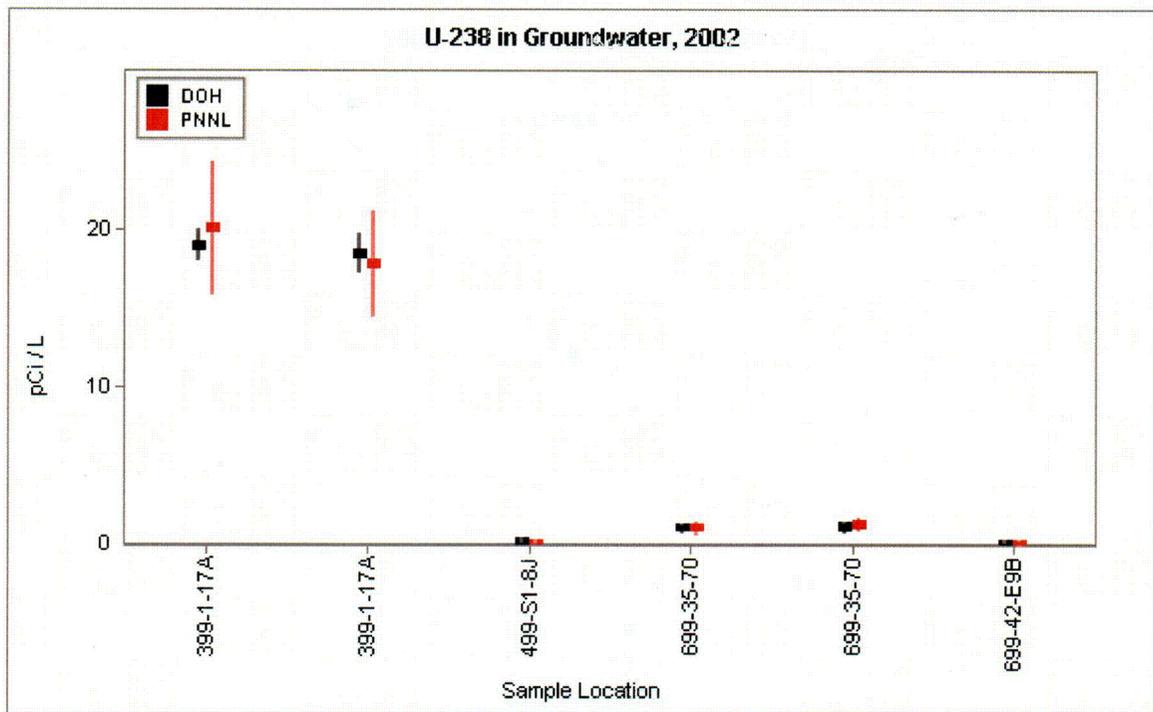


Figure 3.2.19 DOH and PNNL U-238 Concentrations in Groundwater

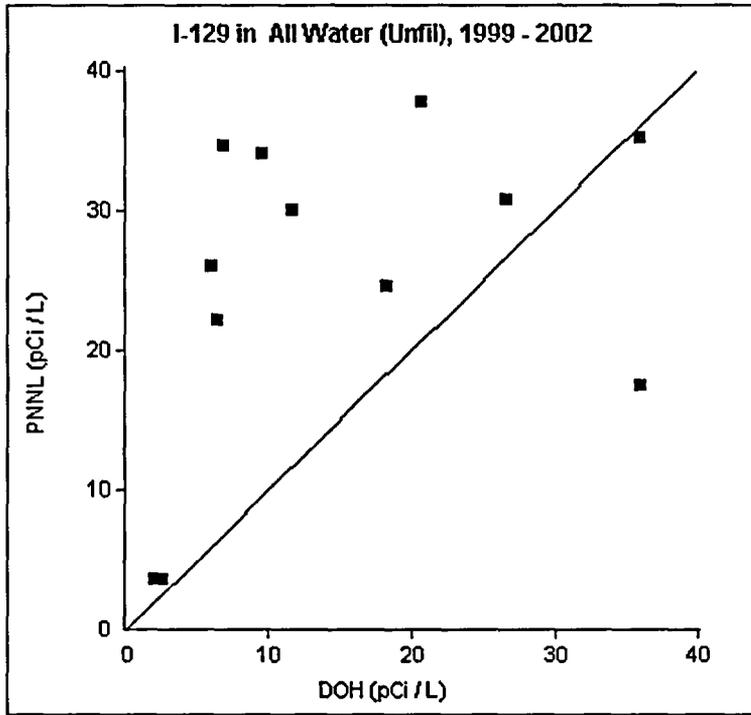


Figure 3.2.20 DOH and PNNL Scatter Plot for Historical I-129 Concentrations in Water

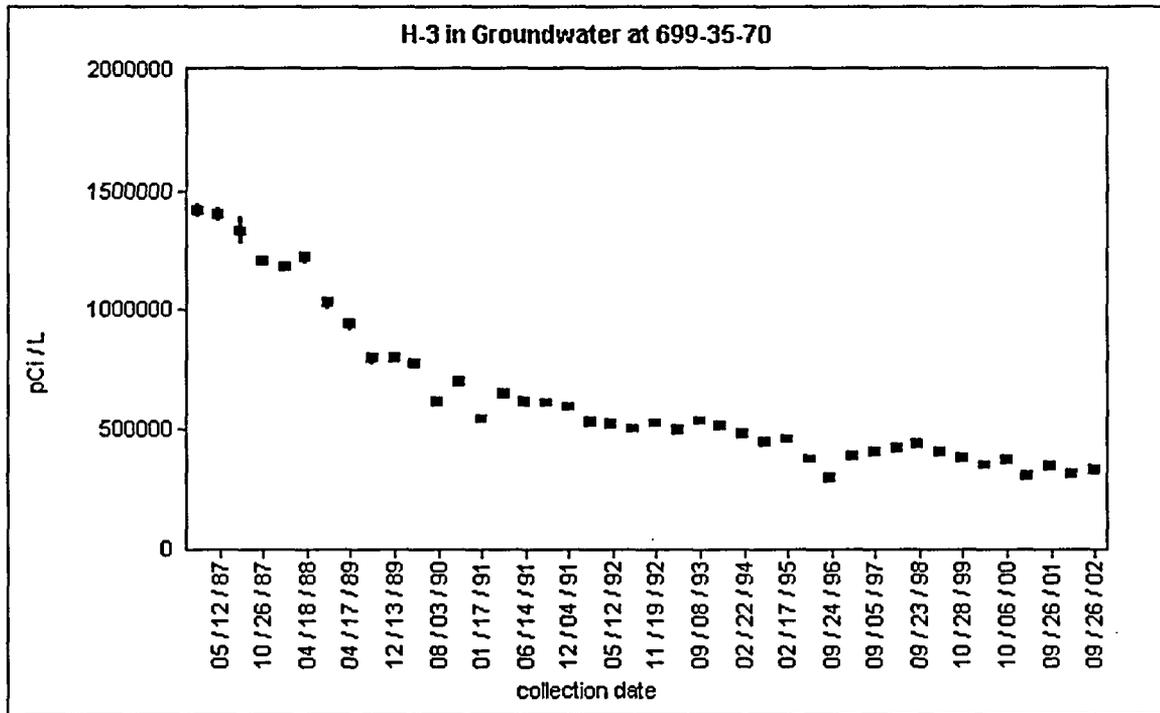


Figure 3.2.21 Historical DOH Tritium Concentrations in Groundwater Well 699-35-70

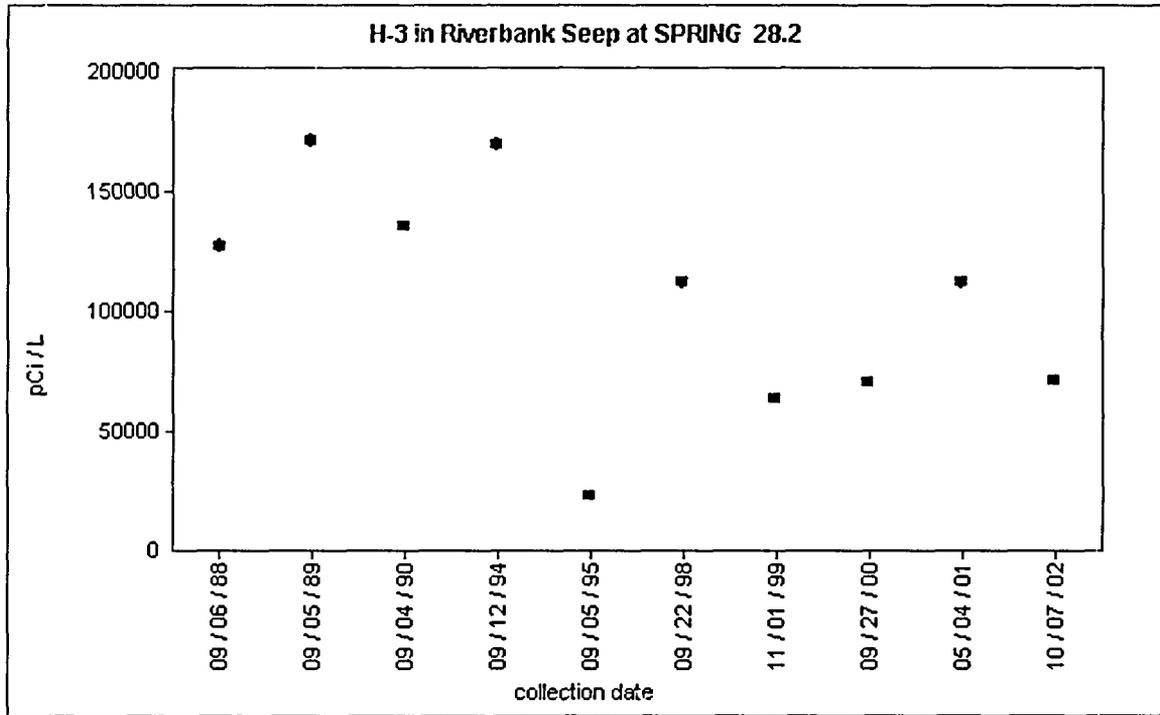


Figure 3.2.22 Historical DOH Tritium Concentrations in Riverbank Seep Water at Spring 28.2

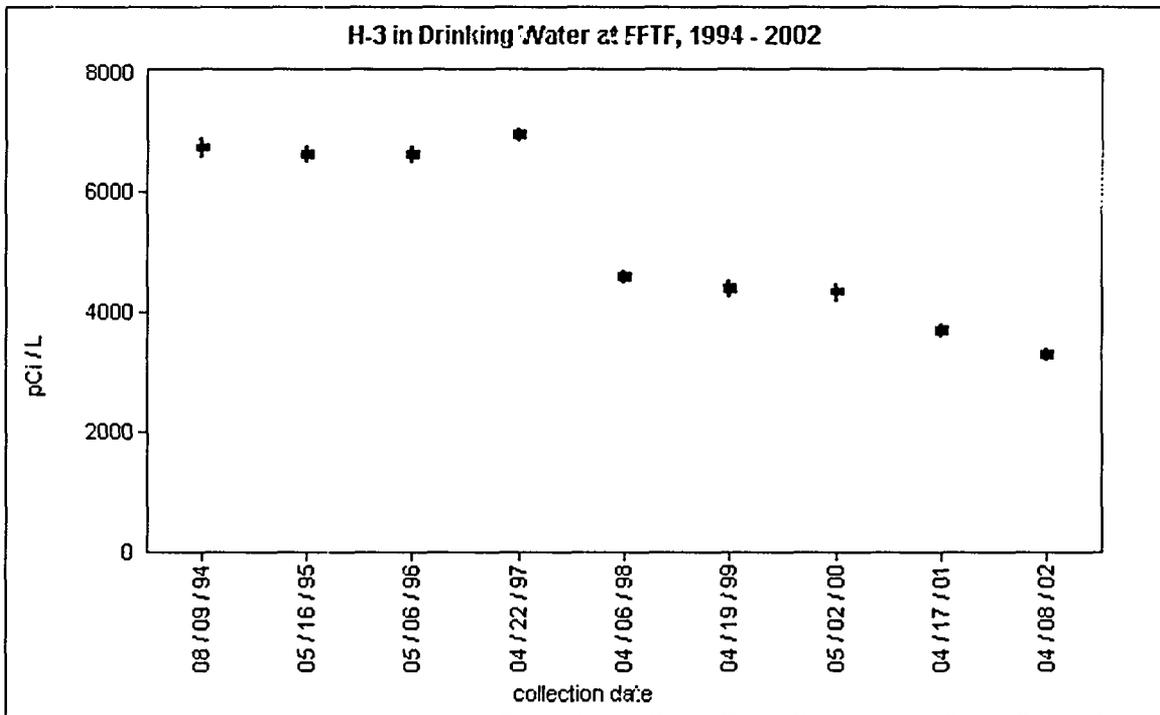


Figure 3.2.23 Historical DOH Tritium Concentrations in Drinking Water at FFTF

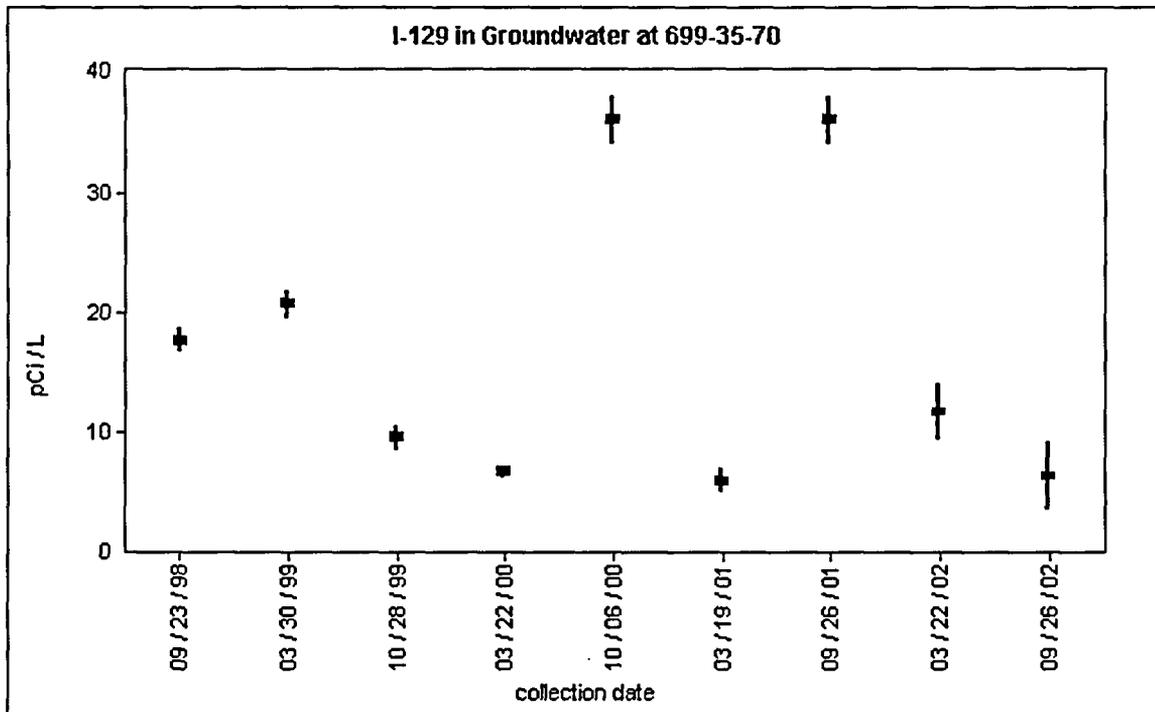


Figure 3.2.24 Historical DOH I-129 Concentrations in Groundwater Well 199-N-14

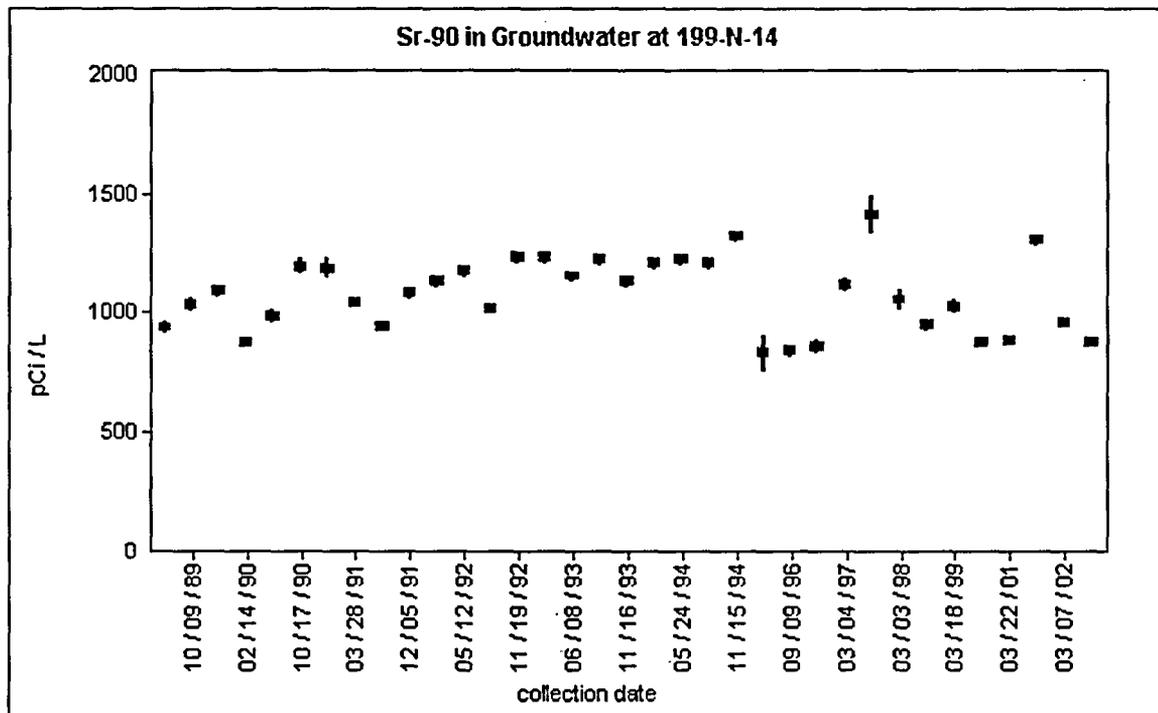


Figure 3.2.25 Historical DOH Sr-90 Concentrations in Groundwater Well 199-N-14

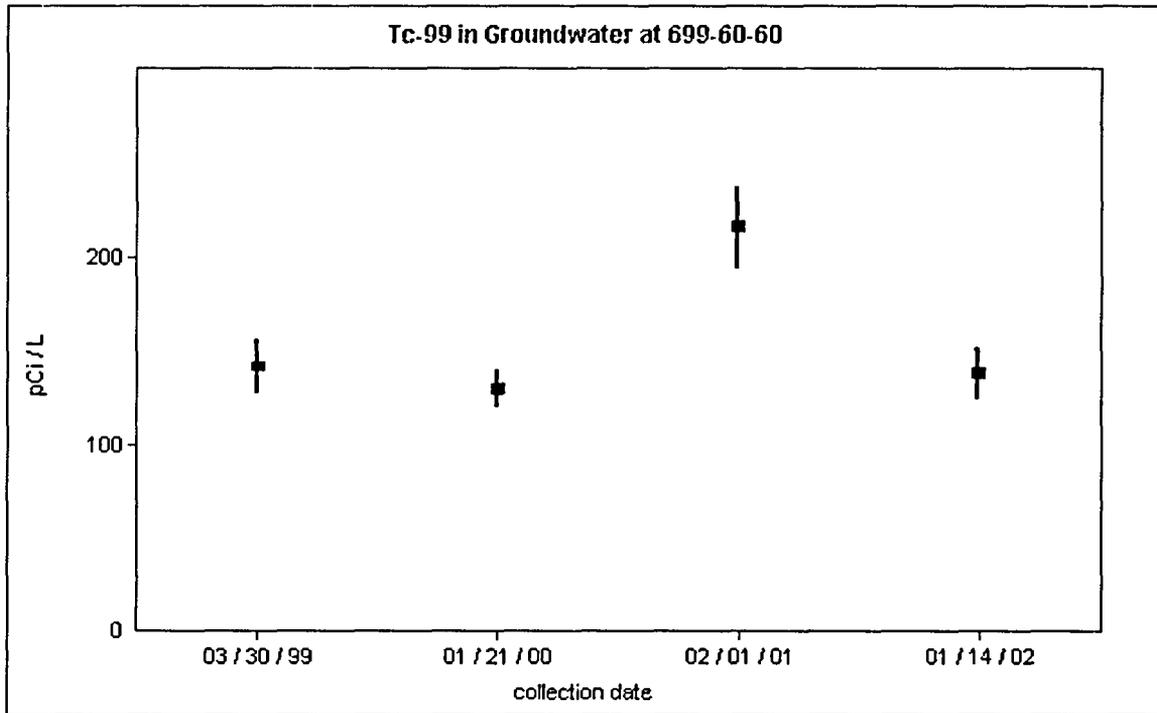


Figure 3.2.26 Historical DOH Tc-99 Concentrations in Groundwater Well 699-60-60

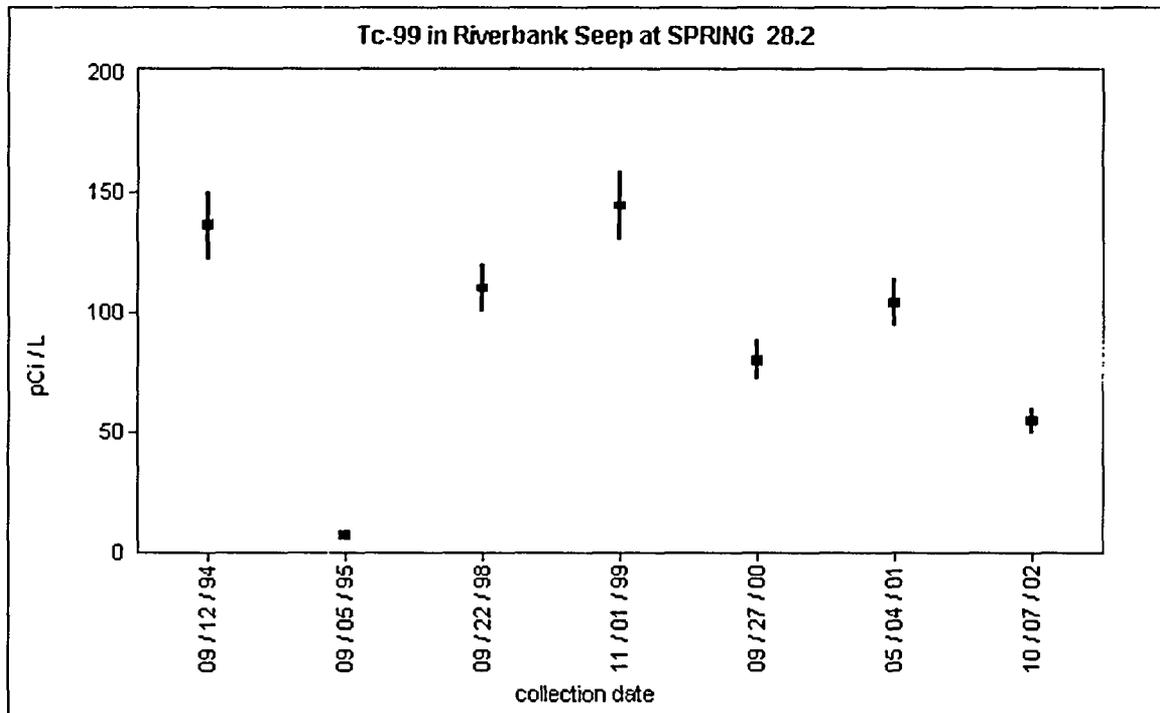


Figure 3.2.27 Historical DOH Tc-99 Concentrations in Riverbank Seep Water at Spring 28.2

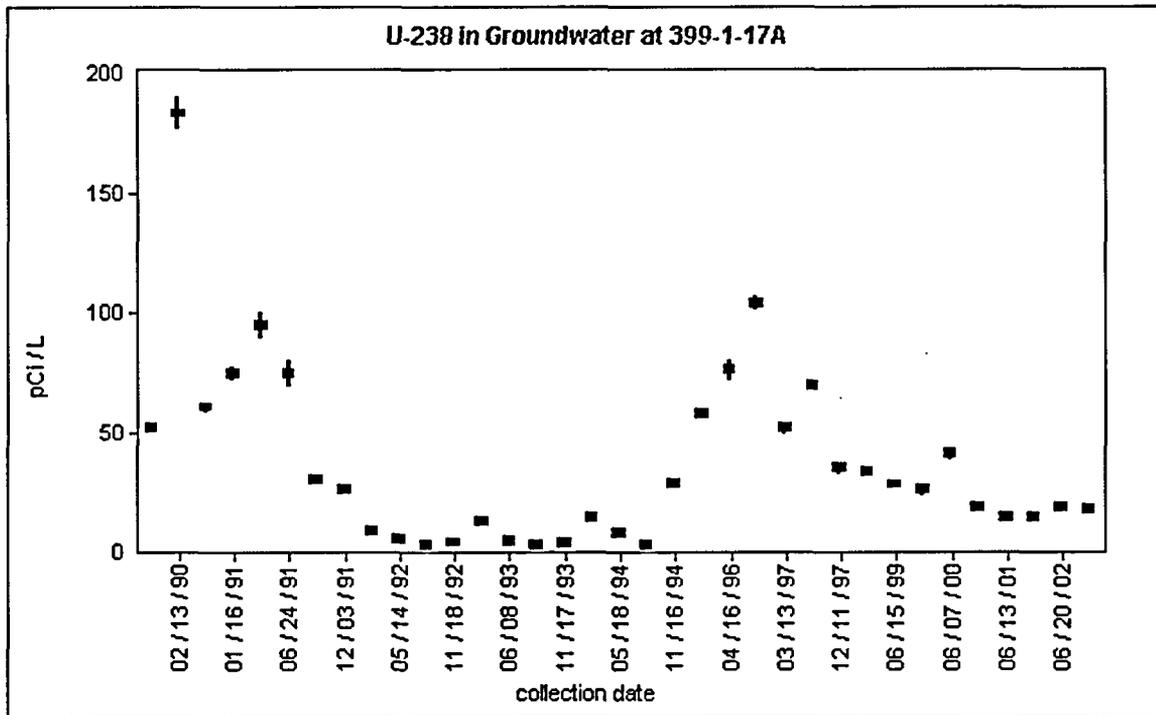


Figure 3.2.28 Historical DOH U-238 Concentrations in Groundwater Well 399-1-17A

3.3 External Gamma Radiation Monitoring

Major Findings:

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

3.3.1 Purpose and General Discussion

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

3.3.2 Monitoring Locations

In 2002, DOH operated 24 ambient gamma radiation monitoring sites under the Hanford Environmental Oversight Program, 5 of which are co-located with Duratek, and 19 of which are co-located with PNNL. The site locations are shown in Figure 3.3.1. Thirteen of the TLD sites are located near Hanford operational or contaminated facilities. Three sites (Yakima and Wye Barricades, and Ligo Facility) are located on the Hanford Site, but away from contaminated areas. Five of the sites (Stations 4, 6, and 8; Byers Landing; and Benton County Shops) are located just outside the Hanford Site perimeter. The remaining three sites (Othello, Toppenish, and Yakima Airport) are significantly distant from the Hanford Site. Many of the TLD sites are co-located with air monitoring sites.

3.3.3 Monitoring Procedures

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

3.3.4 Comparison of DOH and Contractor Data

The DOH and Duratek TLD results for the 5 co-located sites are shown in Figure 3.3.2, and the DOH and PNNL TLD results for the 19 co-located sites are shown in Figure 3.3.3 and 3.3.4 (Byers Landing data is not shown in the figure because there was only 4th quarter data collected). Each of these figures show the 1st, 2nd, and 4th quarter results for each site. An error in the analysis for all of the 3rd quarter DOH TLDs has rendered those data unreliable, and therefore the 3rd quarter results are not shown. As can be seen, there is good agreement between the DOH and DOE contractor data.

DOH vs. Duratek TLD scatter plot results for the combined co-located sites are shown in Figure 3.3.5 and the DOH vs. PNNL TLD scatter plot results are shown in Figure 3.3.6. The x-coordinate of each point represents the DOH result, while the y-coordinate represents the contractor result. Ideally, if the DOH and contractor results were identical, all the points would fall on the straight line with slope equal to unity and y-intercept equal to zero (shown as the solid black line in the figure). The scatter plots indicate good agreement between the DOH and DOE contractor data.

3.3.5 Discussion of Results

The average of the quarterly external radiation exposure rates at each location on the Hanford Site near contaminated or impacted areas ranged from 0.20 to 0.30 mR/day. The average of the quarterly exposure rates for all the perimeter locations was 0.24 mR/day, and for all the distant locations was 0.20 mR/day. The exposure rates at the distant locations are slightly lower than the perimeter locations, most likely due to different concentrations of naturally occurring radioactivity at the distant locations.

The highest exposure rates of 0.3 mR/day, measured at 313 Building, 100N-1, and WRAP, are slightly higher than the average perimeter exposure rate of 0.24 mR/day. A person spending 365 days at one of these locations would receive 22 mR greater than the annual exposure at the Site perimeter. An exposure rate of 22 mR/year, or approximately 22 mrem/year, is well below radiation exposure limits for workers, and is also below the DOE limit of 100 mrem/yr to the public from DOE operations. There is no public access to these locations on the Hanford Site.

Historical DOH TLD data were examined for all of the TLD sites to determine if any new trends are present. All sites, except 100N-1, show consistent exposure rates over time. The historical data for site 100N-1 is shown in Figure 3.3.7. Exposure rates at this site continue to decrease over time, in part due to the decay of Co-60 (half life = 5 years) surface contamination at 100 N Area.

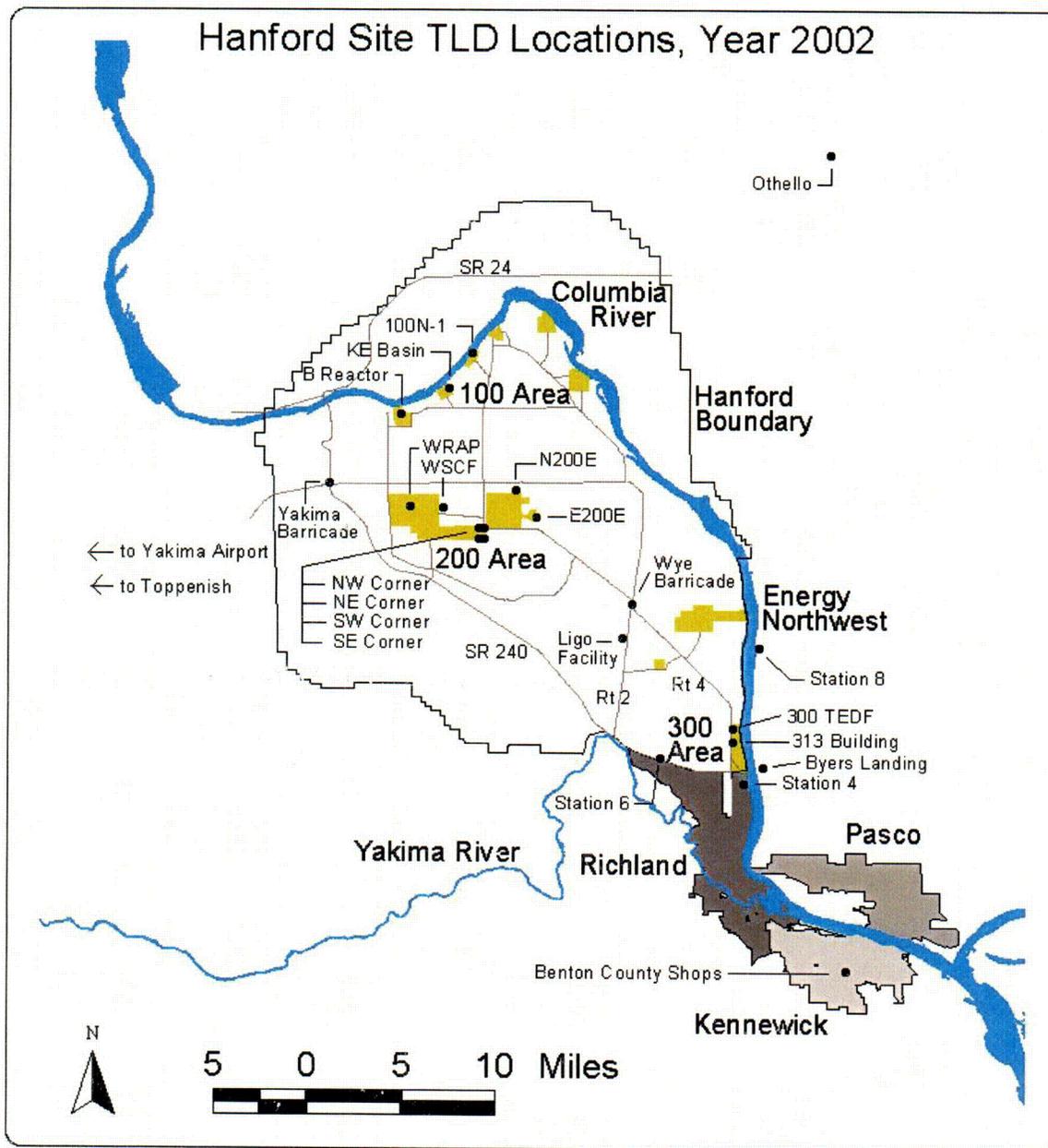


Figure 3.3.1 External Radiation Monitoring (TLD) Locations

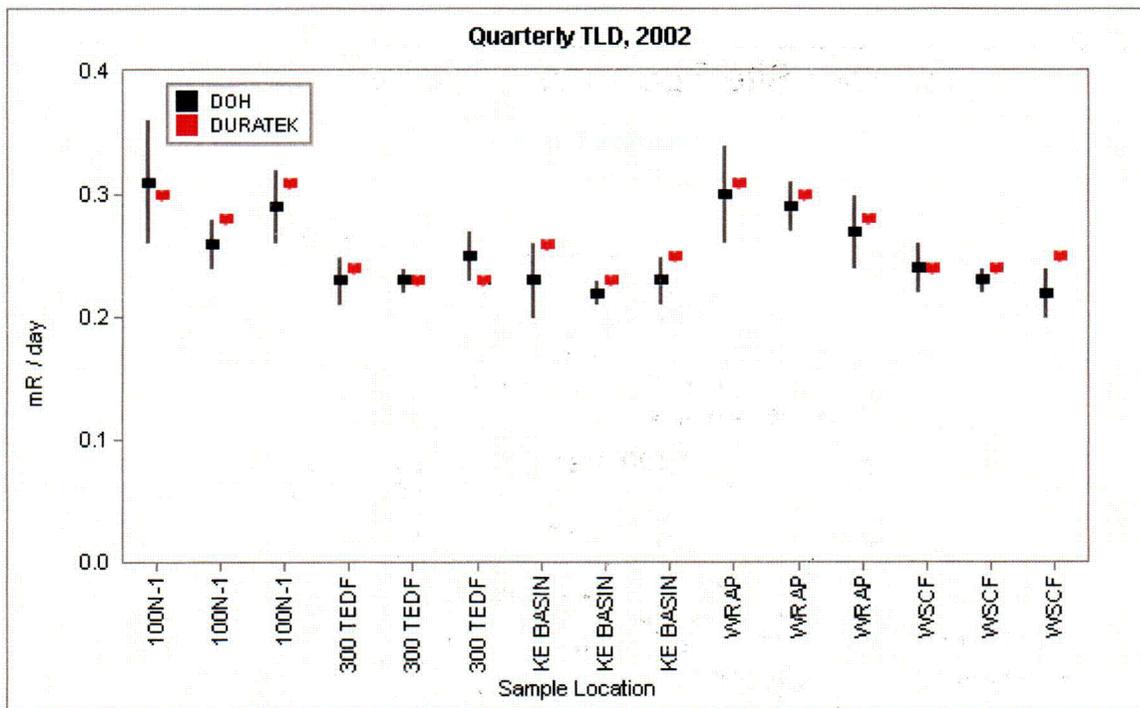


Figure 3.3.2 DOH and Duratek Quarterly TLD Results

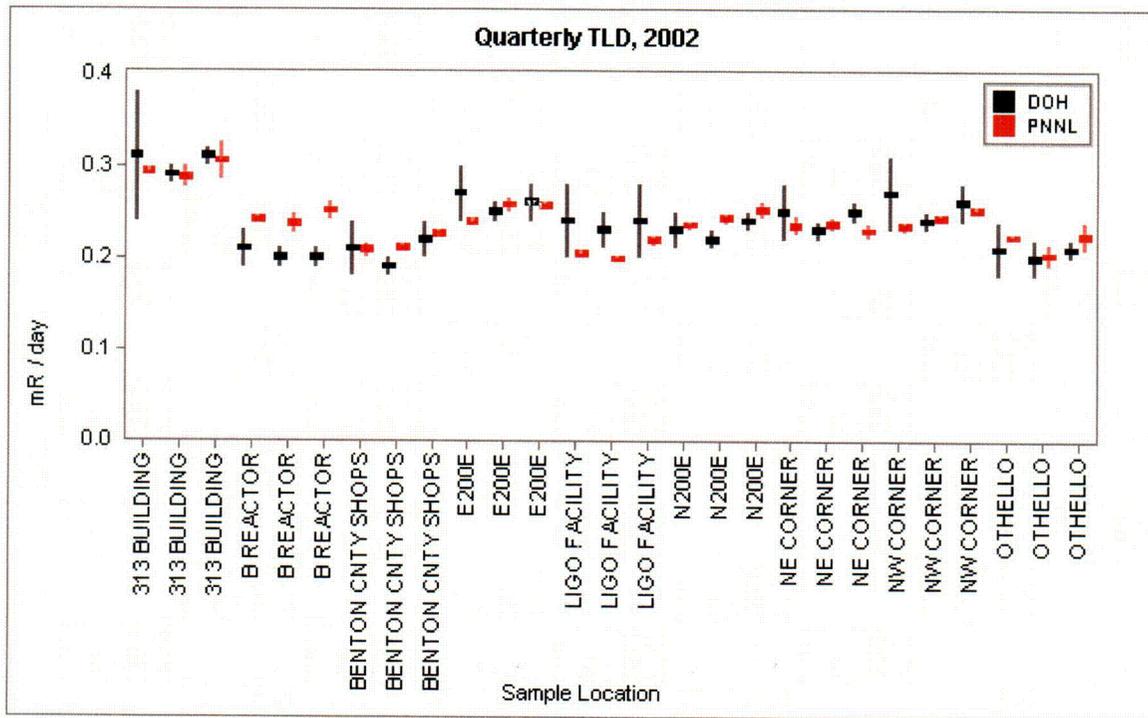


Figure 3.3.3 DOH and PNNL Quarterly TLD Results

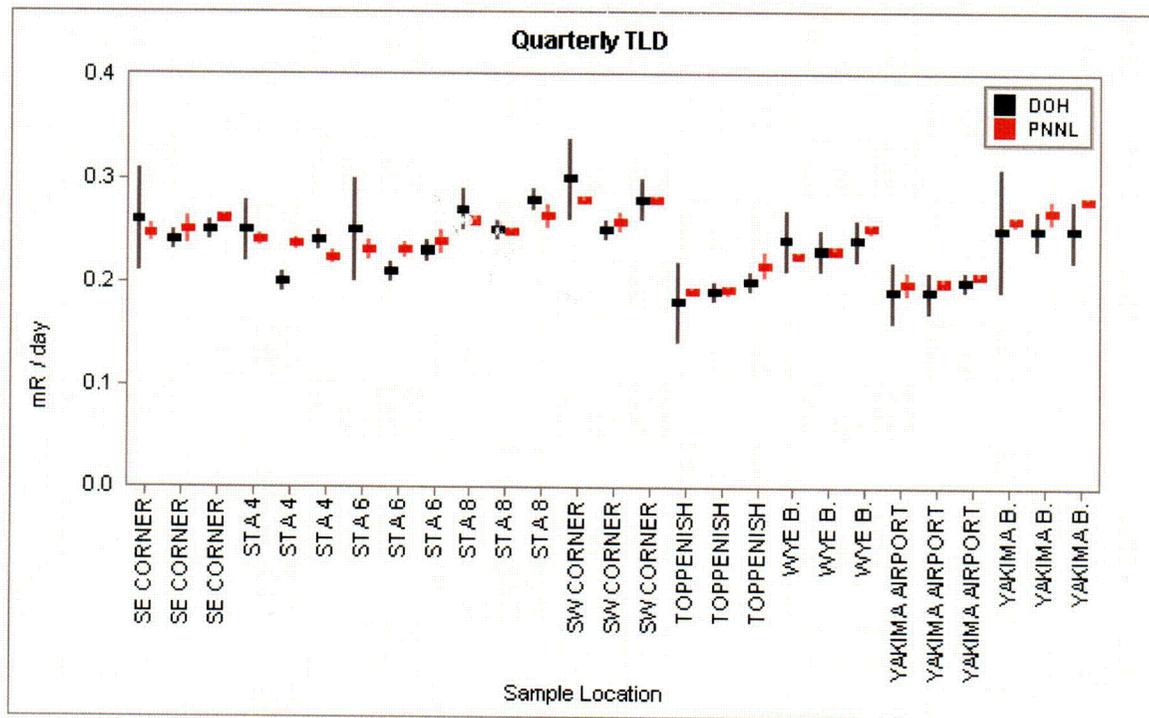


Figure 3.3.4 DOH and PNNL Quarterly TLD Results (Continued)

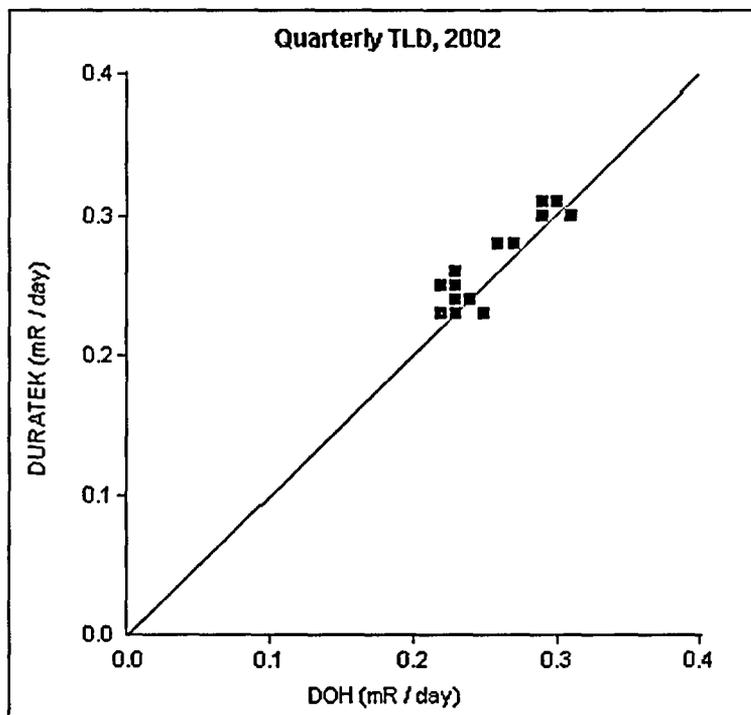


Figure 3.3.5 DOH vs. Duratek Scatter Plot for TLD Results

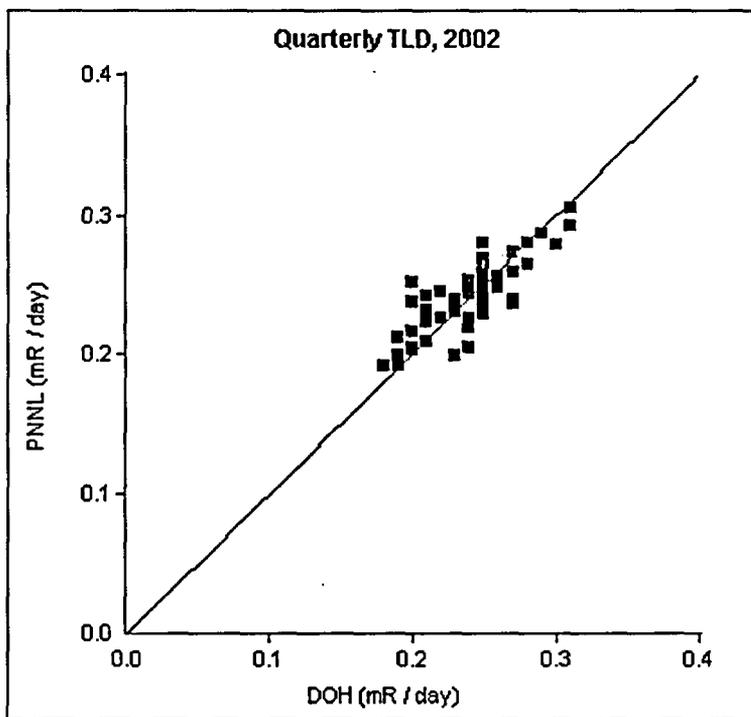


Figure 3.3.6 DOH vs. PNNL Scatter Plot for TLD Results

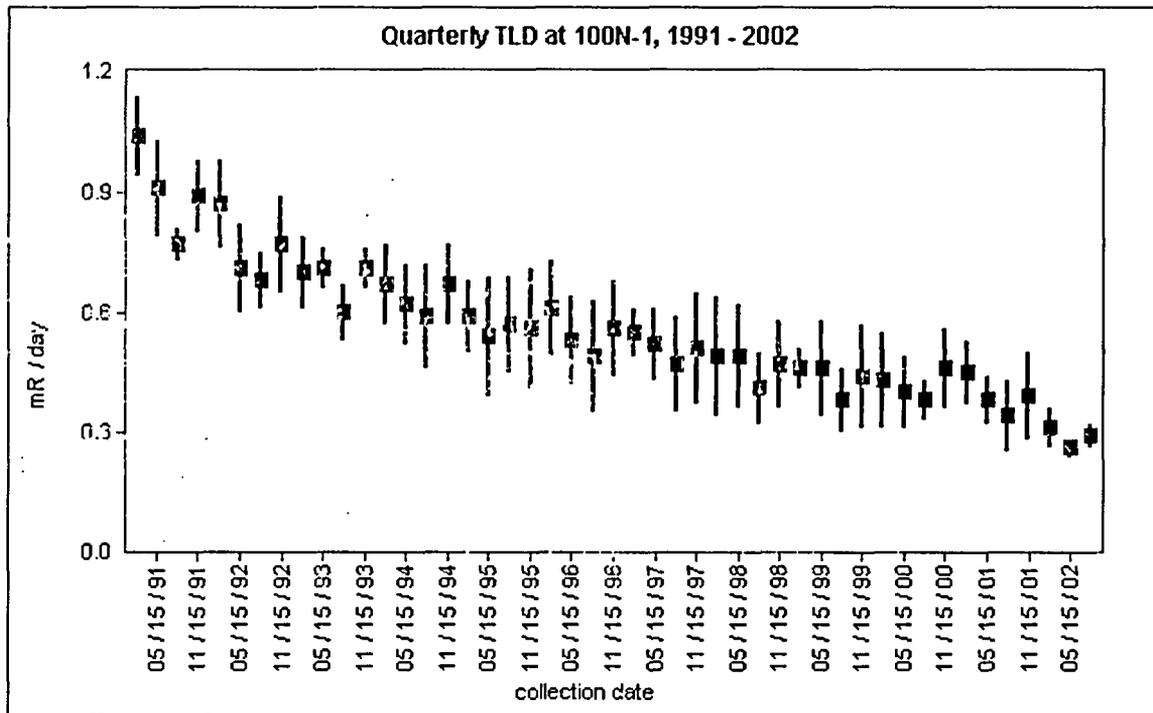
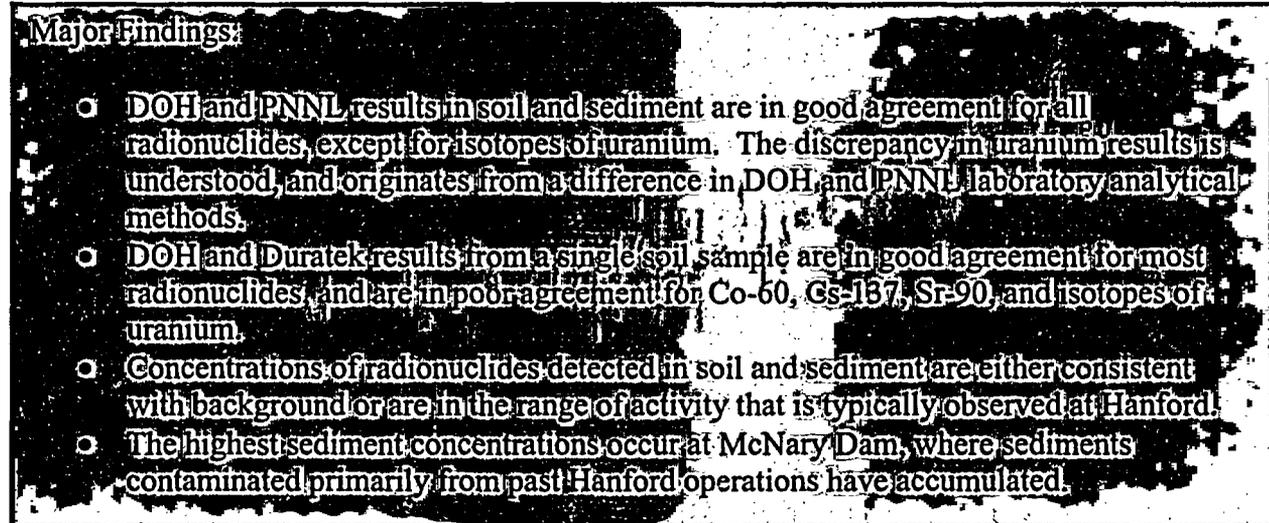


Figure 3.3.7 Historical DOH TLD Results at Location 100N-1 in the 100 N Area

3.4 Soil and Sediment Monitoring



3.4.1 Purpose and General Discussion

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

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

In 2002, DOH split soil samples with Duratek and PNNL, and split Columbia River sediment samples with PNNL. Duratek monitors surface soils throughout the Hanford Site to determine pre-operational baseline concentrations at new facilities and to verify that residual radioactivity at remediated sites meets clean-up criteria. PNNL monitors soil and Columbia River sediments to evaluate Hanford's impact on the environment. DOH splits soil and sediment samples with these contractors to provide oversight of the DOE monitoring program.

3.4.2 Monitoring Locations

Soil samples were collected from three locations in 2002; one sample collected near the 100N Springs was split with Duratek, and two samples collected near Energy Northwest were split with PNNL.

Sediment samples were collected from eight Columbia River locations; two upstream of the Hanford Site at Priest Rapids Dam, three from Hanford's 100 Area shoreline, one near the Old Hanford Townsite at Spring 28.2, and two downstream of the Hanford Site at McNary Dam. Priest Rapids Dam is upstream from the Hanford Site and is considered a background location. McNary Dam prohibits sediment transport further downstream, therefore this site is used to assess radionuclide accumulation. Sediment locations within the Hanford boundary change from year to year and are chosen to monitor areas where contaminants may be discharged into the river, areas where deposits could accumulate, or areas where the public may gain access to the shoreline. Soil and sediment locations are shown in Figure 3.4.1.

3.4.3 Monitoring Procedures

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

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

3.4.4 Comparison of DOH and DOE Contractor Data

The DOH and PNNL split soil results for the two samples collected in 2002 are in good agreement for Am-241, Co-60, Cs-137, Pu-238, Pu-239/240, and Sr-90. The results for isotopes of uranium are in poor agreement, as they display a systematic bias in which DOH consistently reports higher concentrations than PNNL. The split results for U-238 in soil for the years 1999 through 2002 are shown in Figure 3.4.2. The data for year 2002 in the figure are those for sites ENW-3 and ENW-7. On average, the PNNL U-238 soil concentrations are five times lower than those reported by DOH.

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

The DOH and Duratek split soil results for the one sample collected in 2002 are in good agreement for Eu-152, Eu-154, Eu-155, Pu-238, and Pu-239/240. The results for isotopes of uranium are in poor agreement, and the magnitude and origin of the discrepancy are the same as for the DOH and PNNL results described above.

In addition, the DOH and Duratek split soil results for the one sample are in poor agreement for Co-60, Cs-137, and Sr-90, with the Duratek concentrations between 5% and 20% of the DOH concentrations. The discrepancy with the gamma results (Co-60 and Cs-137) are anomalous compared to historical data, as typically DOH and Duratek gamma concentrations are in good agreement, as seen in Figure 3.4.3 (the 2002 result is the second set of data at 100N Springs). On the other hand, DOH and Duratek results for Sr-90 have historically been in poor agreement, as shown in Figure 3.4.4 (the 2002 result is the second set of data at 100N Springs).

The DOH and PNNL split sediment results are in good agreement for Co-60, Cs-137, Pu-239/240, and Sr-90. As an example, the split results for Pu-239/240 in sediment are shown in Figure 3.4.5. In addition to the sample concentrations, the figure also shows the minimum detectable activity (MDA), i.e. the detection limit, reported by DOH for each sample.

The DOH and PNNL split sediment results for isotopes of uranium are in poor agreement. The discrepancy in the uranium sediment results has the same origin as the discrepancy in soil discussed above. On average, the PNNL U-238 sediment concentrations are two times lower than those reported by DOH. A similar discrepancy is seen in the U-235 and U-234 sediment results.

3.4.5 Discussion of Results

Radionuclides consistently identified by DOH in the three soil samples collected in 2002 include Cs-137 (0.1 to 0.8 pCi/g), Sr-90 (0.014 to 0.14 pCi/g), U-234 (0.56 to 0.71 pCi/g), and U-238 (0.58 to 0.7 pCi/g). All results for these radionuclides are consistent with historical results measured by DOH. The Cs-137 and Sr-90 results are attributed to world-wide fallout as a result of past nuclear weapons testing, and the uranium results are attributed to natural background. Uranium-235 concentrations were near the detection limit of approximately 0.02 pCi/g. Other isotopes of uranium were not detected.

One soil sample had a Co-60 concentration of 1.1 pCi/g and a Pu-239/240 concentration of 0.017 pCi/g. The Co-60 result is anomalously high, and was not corroborated by the split Duratek result. The Pu-239/240 result is in the range of historical concentrations measured from soil samples on the Hanford Site. All other results, including Pu-238 and isotopes of europium, were less than detection limits.

Radionuclides consistently identified by DOH in the eight sediment samples collected in 2002 include Cs-137 (0.09 to 0.63 pCi/g) and U-234, 238 (0.5 to 1.5 pCi/g). Uranium-235 concentrations were near the detection limit of approximately 0.02 pCi/g. Other

isotopes of uranium, including U-233 (lower limit of detection approximately 0.1 pCi/g), were not detected.

Other radionuclides identified in some of the sediment samples include Co-60 (maximum concentration 0.03 pCi/g), Eu-152 (maximum concentration 0.15 pCi/g), Pu-238 (maximum concentration 0.01 pCi/g), Pu-239/240 (maximum concentration 0.01 pCi/g), and Sr-90 (maximum concentration 0.02 pCi/g). For most of the detected radionuclides, the highest concentrations were observed at McNary WA Shore.

The concentrations of uranium isotopes found in sediment samples are consistent with background concentrations. The concentrations of most other radionuclides detected in 2002 are consistent with those historically observed by DOH. In particular, concentrations of all detected radionuclides in sediment at McNary WA Shore in 2002 are consistent with historical concentrations at that site. The only 2002 result not consistent with historical DOH results is the detection of Pu-238 at McNary Oregon (0.01 pCi/g). Typically, Pu-238 results at all locations are below the detection limit of 0.005 pCi/g.

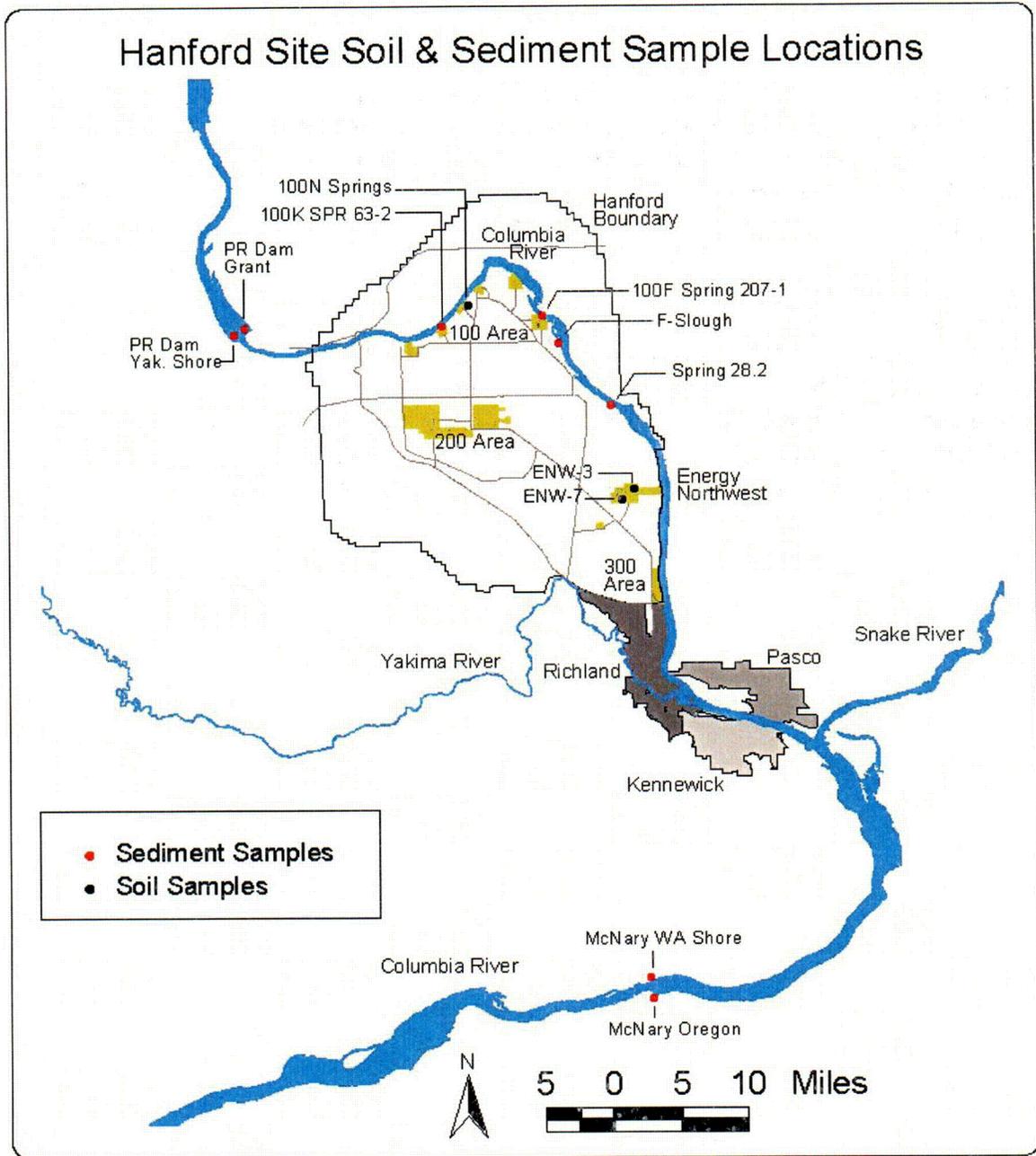


Figure 3.4.1 Soil and Sediment Monitoring Locations

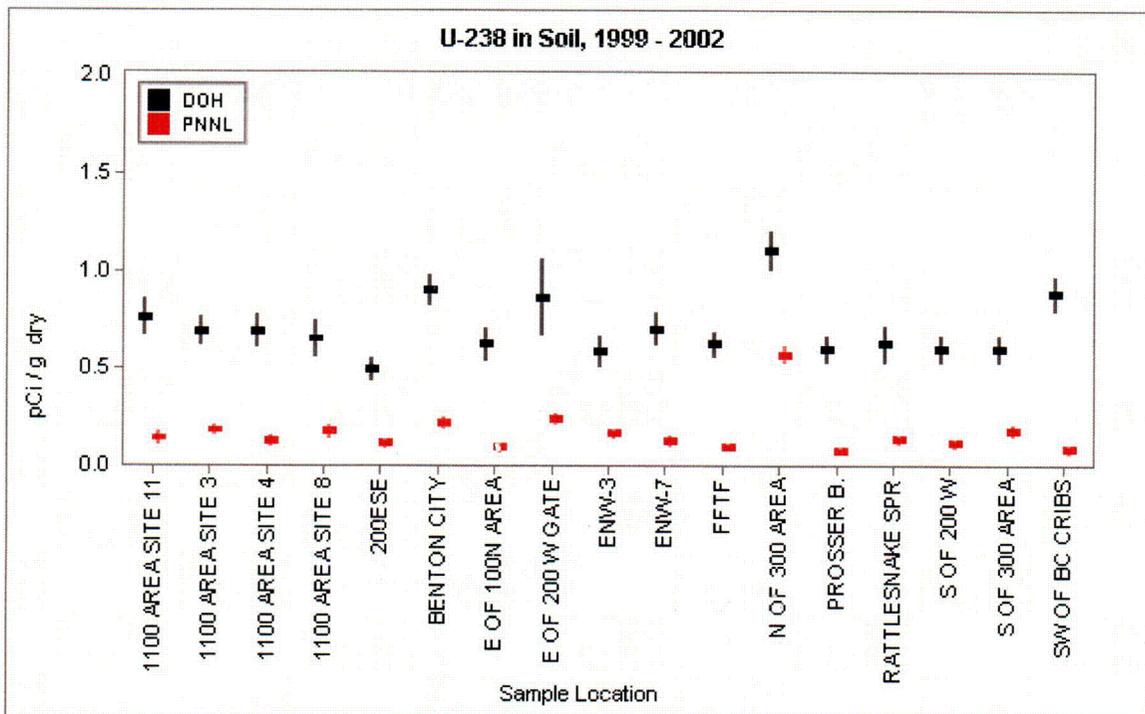


Figure 3.4.2 DOH and PNNL U-238 Concentrations in Soil, 1999-2002

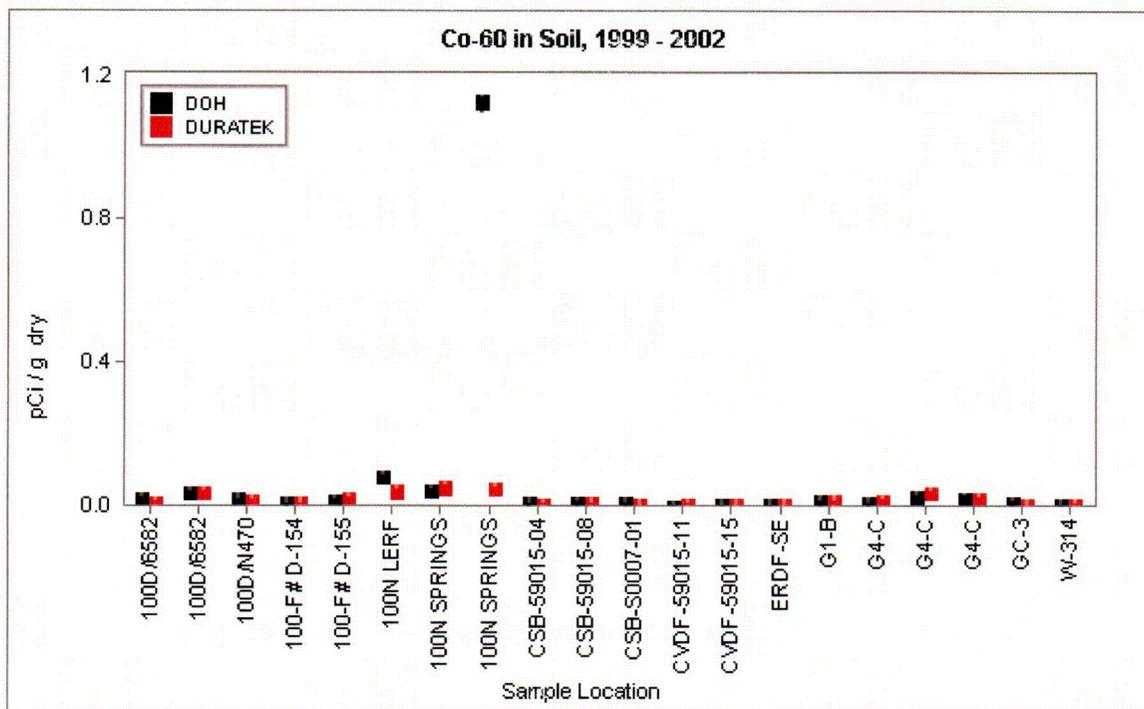


Figure 3.4.3 DOH and Duratek Co-60 Concentrations in Soil, 1999-2002

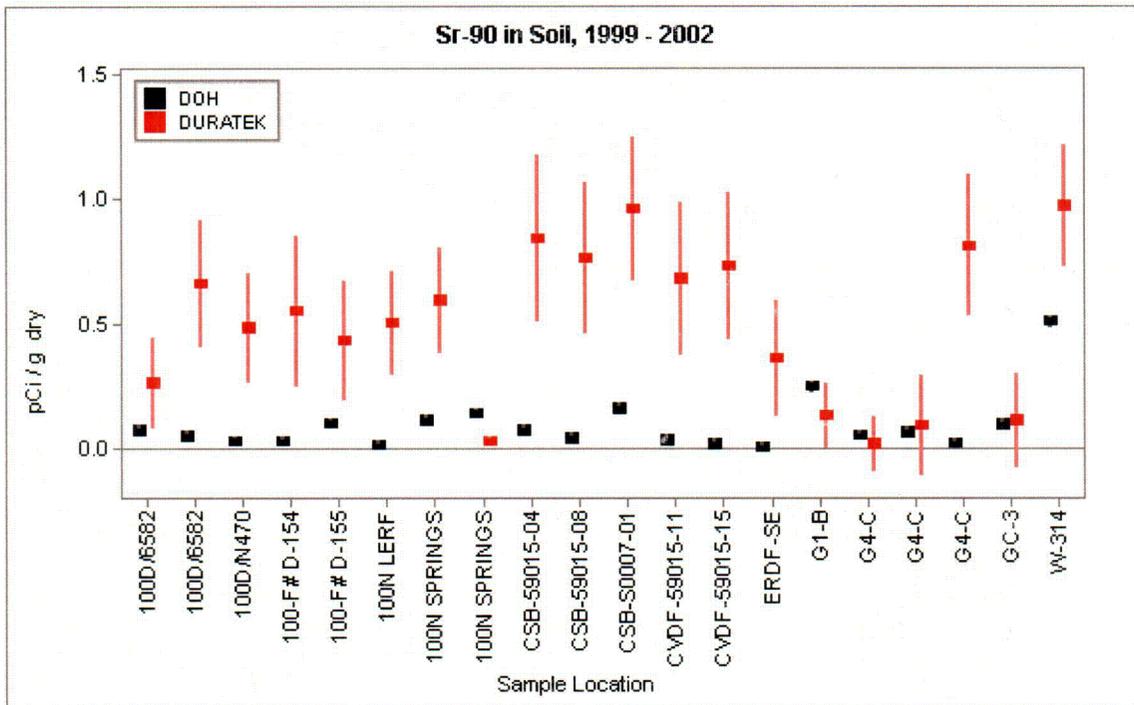


Figure 3.4.4 DOH and Duratek Sr-90 Concentrations in Soil, 1999-2002

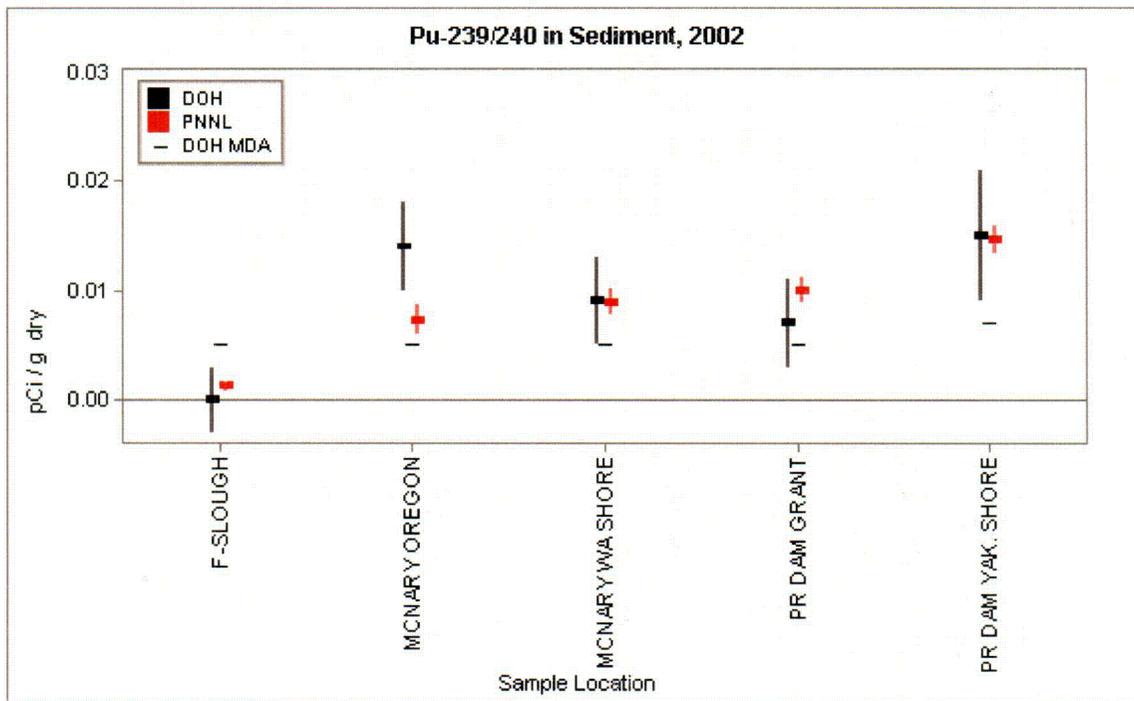


Figure 3.4.5 DOH and PNNL Pu-239/240 Concentrations in Sediment

3.5 Food and Farm Products Monitoring

Major Findings:

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

3.5.1 Purpose and General Discussion

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

Food Product	Analyte	Number of Samples
Cherries	Co-60, Cs-137, Sr-90	4
Leafy Vegetables	Co-60, Cs-137, Sr-90	2
Potato	Co-60, Cs-137, Sr-90	3
Tomato	Co-60, Cs-137, H-3, Sr-90	1
Red Wine	Co-60, Cs-137, H-3	2
White Wine	Co-60, Cs-137, H-3	2

Table 3.5.1 Analytes Monitored in Food and Farm Products

3.5.2 Monitoring Locations

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

3.5.3 Monitoring Procedures

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

3.5.4 Comparison of DOH and Contractor Data

Most of the DOH and PNNL split results in food and farm products are in good agreement. As an example, Sr-90 results in cherry samples are shown in Figure 3.5.1. Of the 43 food and farm product results, only three of the results show a discrepancy. For one of the leafy vegetable samples, DOH measured Cs-137 and Sr-90 concentrations of 0.04 and 0.07 pCi/g, respectively, while PNNL did not detect these radionuclides. The Sr-90 concentrations in leafy vegetables are shown in Figure 3.5.2. In one of the white wine samples, PNNL detected tritium at 115 pCi/L while DOH did not detect tritium. Since most of the results are below detection limits, a regression analysis is not carried out for food and farm product data.

3.5.5 Discussion of Results

Most of the radioactivity concentrations measured by DOH are below detection limits. Only three results were above detection limits. Cs-137 and Sr-90 were detected in one leafy vegetable sample at 0.04 and 0.07 pCi/g wet weight, respectively; and H-3 was detected in one red wine sample at 125 pCi/L (see Figure 3.5.3).

DOH occasionally detects small concentrations of Sr-90 in farm products around the Hanford Site, and it is not uncommon to detect small concentrations of H-3 in wine. Historical concentrations of H-3 in red wine are shown in Figure 3.5.4. The food and farm product results for all radionuclides analyzed in 2002 are consistent with historical DOH results.

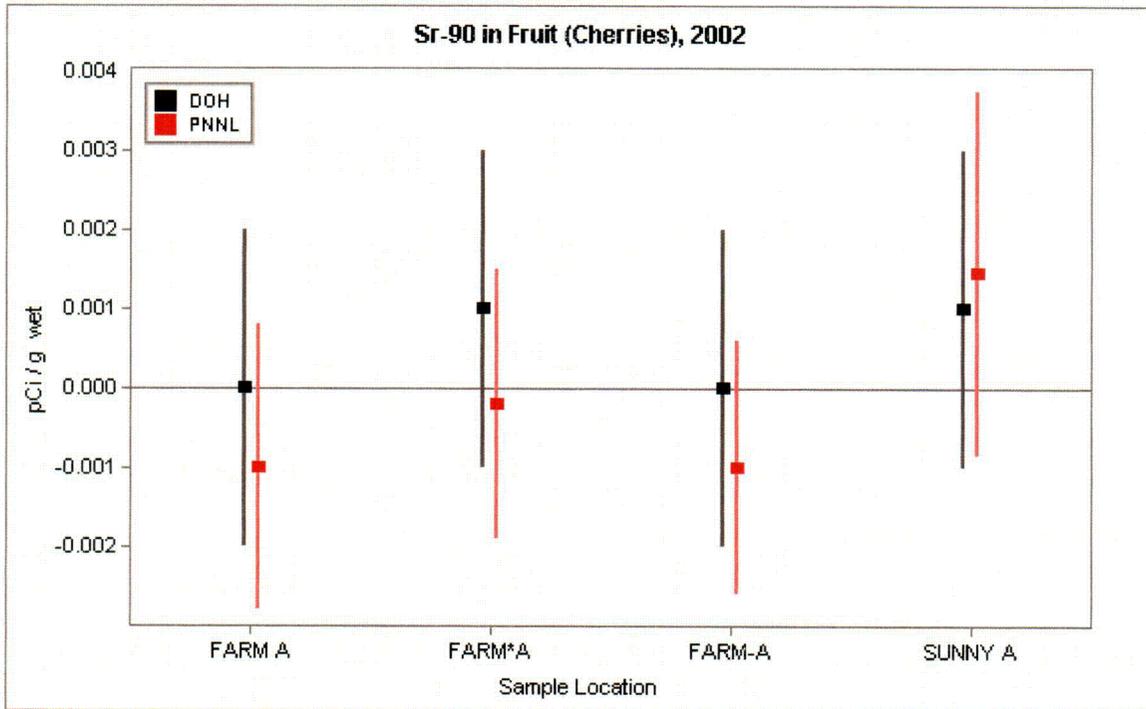


Figure 3.5.1 DOH and PNNL Sr-90 Concentrations in Off-Site Cherries

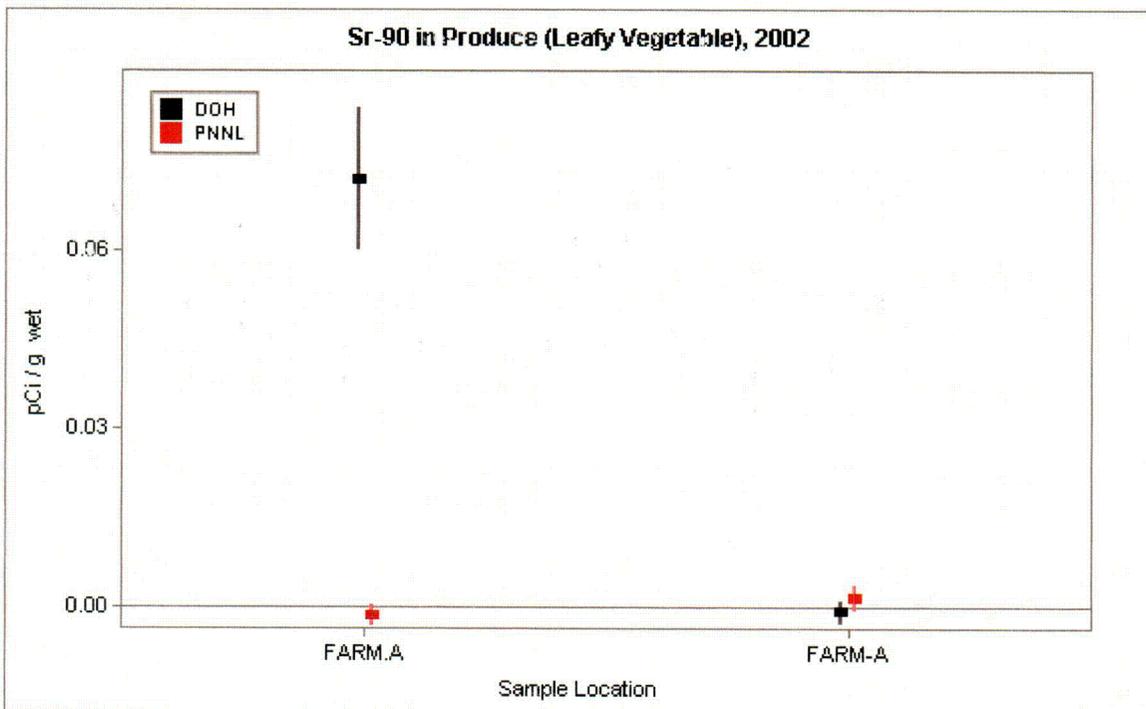


Figure 3.5.2 DOH and PNNL Sr-90 Concentrations in Off-Site Cherries

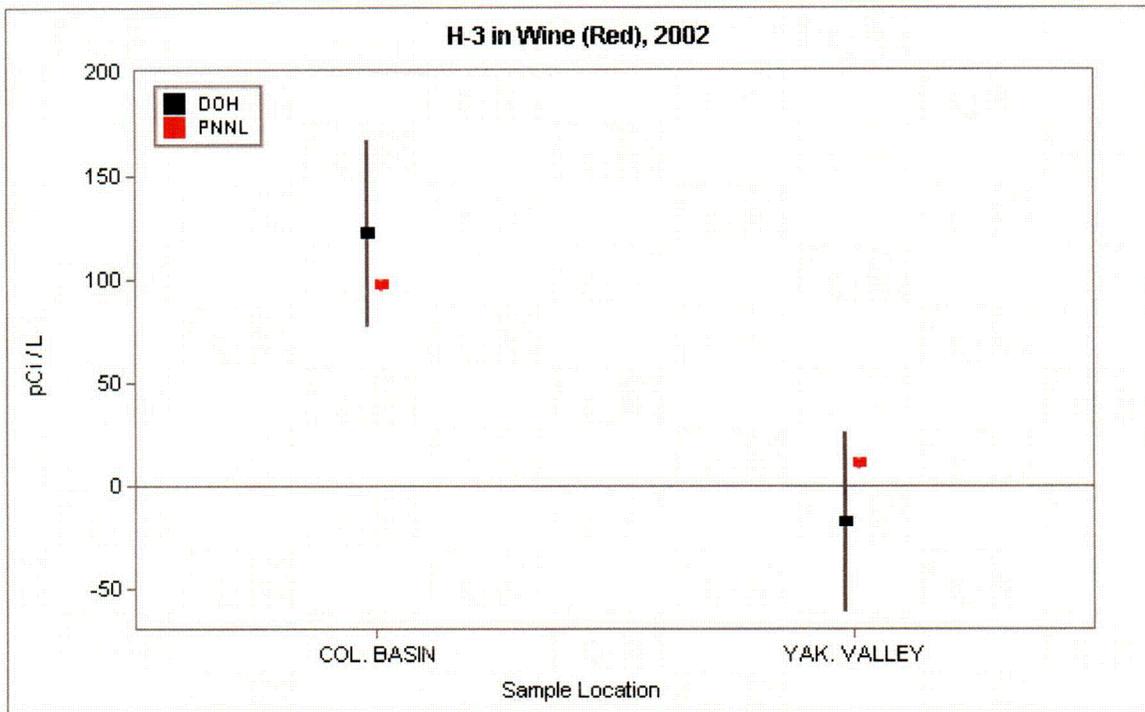


Figure 3.5.3 DOH and PNNL H-3 Concentrations in Red Wine

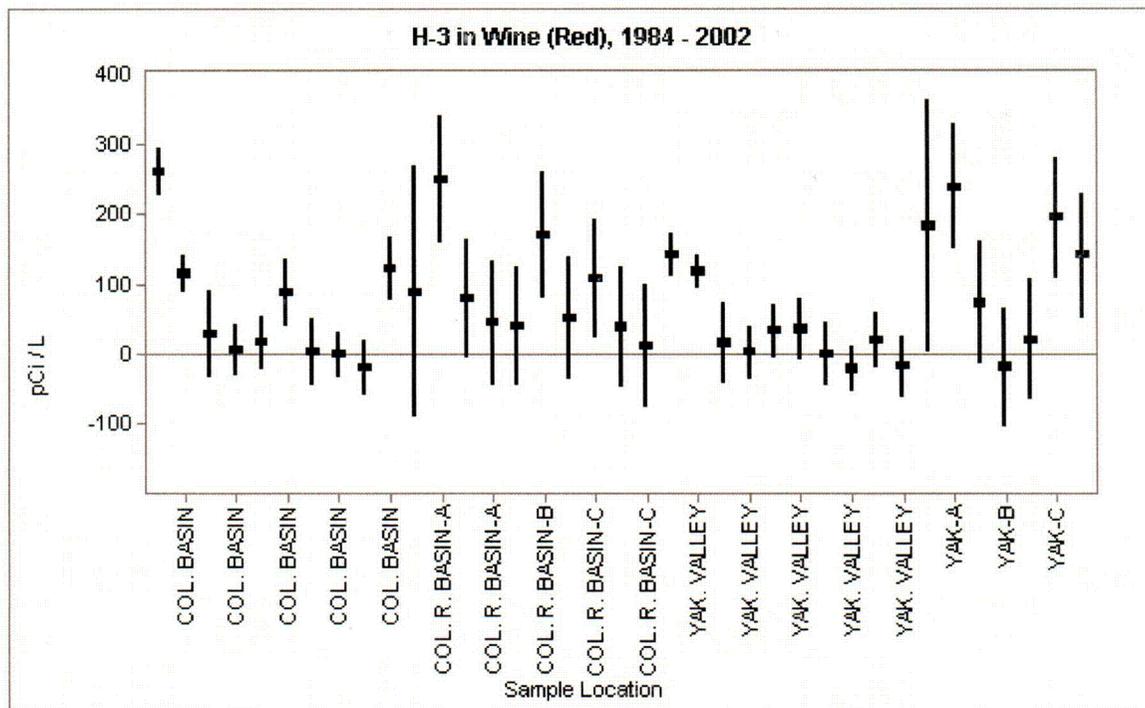


Figure 3.5.4 Historical DOH Tritium (H-3) Concentrations in Red Wine

3.6 Fish and Wildlife Monitoring

Major Findings:

- DOH and PNNL results are in good agreement for Co-60 and Cs-137, and are in poor agreement for Sr-90.
- The Co-60 and Cs-137 results are all below detection limits. Sr-90 was not detected by DOH in Columbia River fish and 100 Area game bird samples, but was detected in deer samples. The highest Sr-90 concentration was from the deer collected at the background location in Olympia.

3.6.1 Purpose and General Discussion

The Department of Health and DOE contractors monitor fish and wildlife to determine if contaminants have migrated into the food chain. Contaminants in fish arise from fish swimming in contaminated water and ingesting contaminated sediments. Contaminants in wildlife arise from ingestion of contaminated soil and vegetation. In 2002, DOH split two deer samples, two fish samples, and two game bird samples with PNNL. The type of samples, monitored analytes, and number of samples are listed in Table 3.6.1.

Sample Type	Analyte	Number of Samples
Deer Bone	Sr-90	2
Deer Meat	Co-60, Cs-137	2
Carp Carcass	Sr-90	2
Carp Meat	Co-60, Cs-137	2
Quail Bone	Sr-90	2
Quail Meat	Co-60, Cs-137	2

Table 3.6.1 Analytes Monitored in Fish and Wildlife

3.6.2 Monitoring Locations

One deer sample was collected from the 100N Area and another was collected from a background location in Olympia. The carp samples were collected from the Columbia River near the 100N Area and the 300 Area. The quail samples were collected from the 100D and 100H Areas. No background fish or game bird samples were collected in 2002.

3.6.3 Monitoring Procedures

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

3.6.4 Comparison of DOH and Contractor Data

DOH and PNNL split results for fish and wildlife are in good agreement for Co-60 and Cs-137. All Co-60 and Cs-137 split results were below the DOH detection limits of 0.008 and 0.006 pCi/g, respectively. DOH and PNNL split results for Sr-90 in deer and quail bone are shown in Figure 3.6.1 for samples collected in 2002. The DOH and PNNL Sr-90 results are in poor agreement for the two deer samples. DOH reports concentrations two to three times greater than those reported by PNNL. Historically, DOH and PNNL Sr-90 results in fish and wildlife range from good to fair to poor agreement. Figure 3.6.2 shows Sr-90 concentrations in wildlife for samples collected from 1999 to 2002.

3.6.5 Discussion of Results

The DOH Co-60 and Cs-137 results are all below detection limits. Strontium 90, which originates from worldwide fallout as well as Hanford operations, was not detected by DOH in the two carp and two quail samples, but was detected in the two deer bone samples (Figure 3.6.1). The Sr-90 concentration from the deer collected at the background location in Olympia, 1.9 pCi/g, was higher than the concentration from the deer collected at Hanford's 100N Area, 0.6 pCi/g.

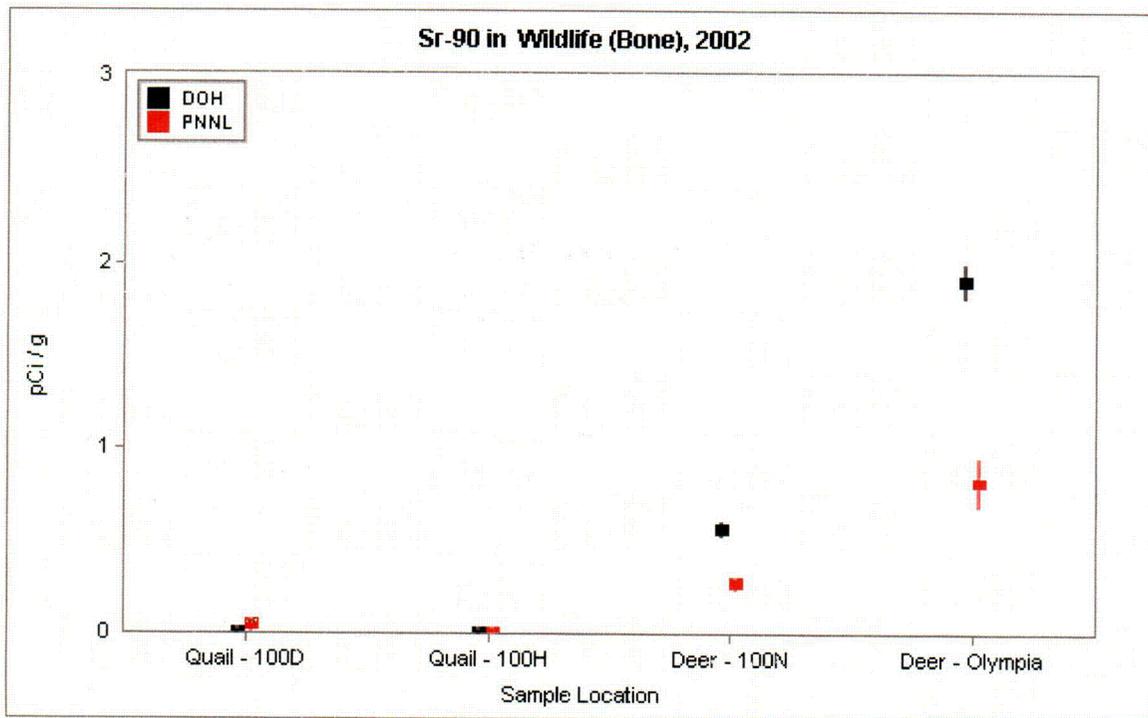


Figure 3.6.1 DOH and PNNL Sr-90 Concentrations in Wildlife

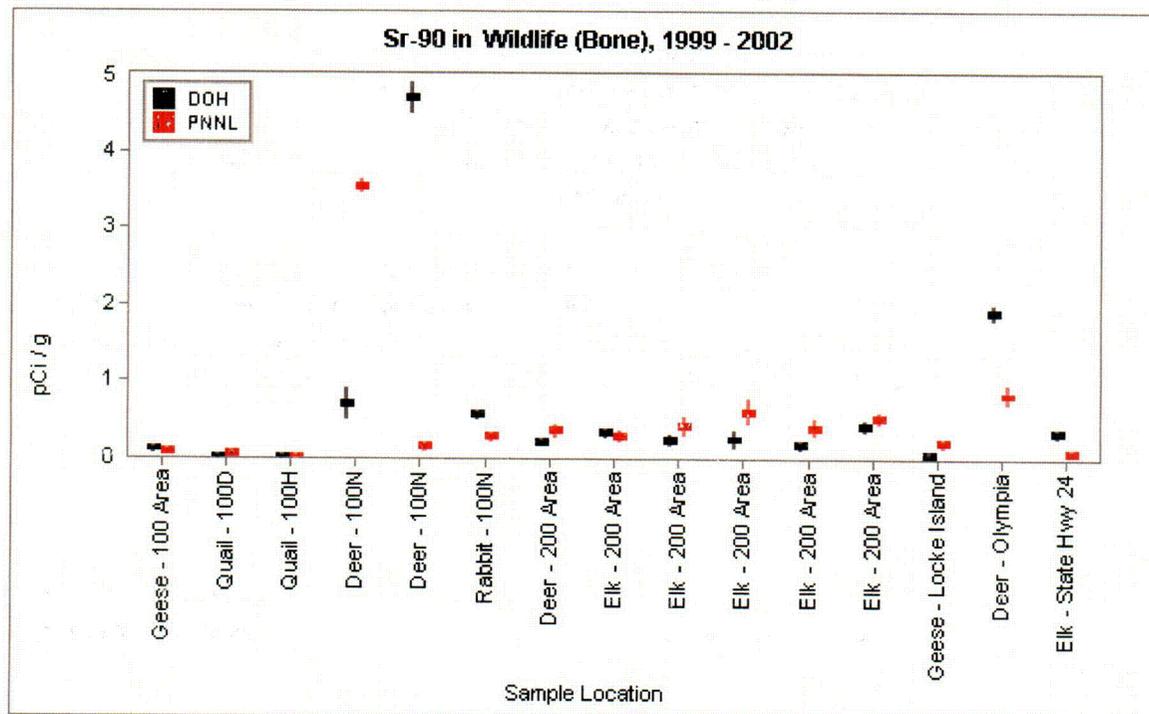


Figure 3.6.2 DOH and PNNL Historical Sr-90 Concentrations in Wildlife

4. Summary of Discrepancies Between DOH and DOE Contractor Results

The DOH and PNNL co-located bi-weekly gross beta results in air samples are in fair agreement. The data follow the same trends, but there is a small systematic discrepancy between the two data sets. At the lower end of the range of reported concentrations, PNNL consistently reports higher values than DOH. At the upper end of the range of concentrations, DOH consistently reports higher values than PNNL. In most cases, the discrepancy is less than a factor of two. This discrepancy observed in 2002 is also evident in historical DOH and PNNL results.

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

The DOH and PNNL split gross alpha and gross beta results in water samples are in fair agreement. A systematic discrepancy is observed between the two data sets. PNNL typically reports gross alpha and gross beta concentrations that are approximately one-half the values reported by DOH. This discrepancy observed in 2002 is also evident in historical DOH and PNNL results.

The DOH and PNNL split I-129 results in water samples are in poor agreement. There appears to be no correlation between the two data sets. This discrepancy observed in 2002 is also evident in historical DOH and PNNL results.

The DOH and PNNL split uranium results in soil and sediment samples are in poor agreement. 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 discrepancy, which is observed in historical DOH and PNNL data, results from different laboratory procedures.

The DOH and Duratek split Co-60, Cs-137, Sr-90, and uranium results in the single soil sample are in poor agreement, with the Duratek concentrations significantly lower than the results reported by DOH. The uranium discrepancy, which is observed historically, results from different laboratory procedures. The discrepancy with the gamma results (Co-60 and Cs-137) is anomalous compared to historical results, as typically DOH and Duratek gamma results are in good agreement. The discrepancy with Sr-90 is evident in historical DOH and Duratek results.

The DOH and PNNL split Sr-90 results in fish and wildlife samples are in poor agreement. In 2002, DOH reported concentrations two to three times greater than those reported by PNNL. Historically, DOH and PNNL results range from good to fair to poor agreement.

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

Appendix A - Radiation Tutorial

A.1 Radiation and Radioactivity

Radioactivity from natural sources is found throughout nature, including in air, water, soil, within the human body, and animals. Naturally occurring radioactivity originates from the decay of primordial terrestrial sources such as uranium and thorium. Other sources are continually produced in the upper atmosphere through interactions of atoms with cosmic rays. These naturally occurring sources of radiation produce the background levels of radiation to which humans are unavoidably exposed.

Radioactivity is the name given to the phenomena of matter emitting ionizing radiation. Radiation emitted from the nucleus of an atom is termed nuclear radiation. Atoms that emit radiation are termed radioactive. The three most common types of radiation are:

- Alpha – A particle consisting of two protons and two neutrons emitted from the nucleus of an atom. These charged particles lose their energy very rapidly in matter and are easily shielded by small amounts of material, such as a sheet of paper or the surface layer of skin. Alpha particles are only hazardous when they are internally deposited.
- Beta – An electron emitted from the nucleus of an atom. These charged particles lose their energy rapidly in matter, although less so than alpha radiation. Beta radiation is easily shielded by thin layers of metal or plastic. Beta particles are generally only hazardous when they are internally deposited.
- Gamma – Electromagnetic radiation, or photons, emitted from the nucleus of an atom. Gamma radiation is best shielded by thick layers of lead or steel. Gamma energy may cause an external or internal radiation hazard. (X-rays are similar to gamma radiation but originate from the outer shell of the atom instead of the nucleus).

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

Radioisotope and radionuclide are interchangeable terms used to refer to radioactive isotopes of an element. Elements are delineated by their chemical names followed by their atomic number, which is the sum of its number of protons and neutrons. For example, carbon-12, which is the most naturally abundant form of carbon, consists of six protons and six neutrons for a total of twelve. Carbon-13 and carbon-14, which consist of six protons and seven and eight neutrons respectively, are also found in nature. These

forms of carbon are called isotopes of carbon. If an isotope is radioactive it is called a radioisotope. In the example given, carbon-12 and carbon-13 are non-radioactive isotopes of carbon. Carbon-14 is radioactive, and therefore a radioisotope of carbon.

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

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

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

A.2 Radiological Units and Measurement

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

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

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

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

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

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

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

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

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

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

Appendix B - Laboratory a priori Lower Limits of Detection

Air Cartridge (pCi/m³)

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

Air Filter (pCi/m³)

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

Quarterly Composite Air Filter (pCi/m³)

	Nuclide	Volume (m ³)	Method	Standard LLD (400 min.)
Gamma	Be-7	5200	INGe	8.00E-02
	Co-60	5200	INGe	1.00E-03
	Cs-134	5200	INGe	2.00E-03
	Cs-137	5200	INGe	1.00E-03

Standard LLD (1000 min.)

Alpha	Nat U	5200	Alpha Spec	2.50E-05
	U-234	5200	Alpha Spec	2.50E-05
	U-235	5200	Alpha Spec	1.00E-05
	U-238	5200	Alpha Spec	2.50E-05

Semi-Annual Composite Air Filter (pCi/m³)

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

Semi-Annual Composite Air Filter (pCi/m³) Continued

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

Food (pCi/g)

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

Milk (pCi/L)

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

Meat (pCi/g)

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

Shellfish (pCi/g)

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

Soil/Sediment (pCi/g)

	Nuclide	Mass (g)	Method	Standard LLD (1000 min.)
Alpha	Nat U	1	Alpha Spec	4.00E-02
	U-234	1	Alpha Spec	3.00E-02
	U-235	1	Alpha Spec	2.00E-02
	U-238	1	Alpha Spec	3.00E-02
	Pu-238	10	Alpha Spec	5.00E-03
	Pu-239	10	Alpha Spec	4.00E-03
	Th-230	1	Alpha Spec	4.00E-02
	Th 232	1	Alpha Spec	4.00E-02
	Am-241	10	Alpha Spec	4.00E-03
	Ra - 226	1	$\alpha\beta$ Cntr	1.00E-01
	Ra-226(DA)	600	INGe	2.00E-02

Standard (100 min.)

Alpha	Gross	0.1	$\alpha\beta$ Cntr	4.00E+01
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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	$\alpha\beta$ Cntr	1.50E+00

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

	Nuclide	Mass (g)	Method	Standard LLD (1000 min.)
Alpha	Nat U	10	Alpha Spec.	8.00E-03
	U-234	10	Alpha Spec.	6.00E-03
	U-238	10	Alpha Spec.	6.00E-03
	Pu-238	10	Alpha Spec.	5.00E-03
	Pu-239	10	Alpha Spec.	4.00E-03
	Am-241	10	Alpha Spec.	4.00E-03
Gamma	K-40	100	INGe	3.00E-01
	Mn-54	100	INGe	4.00E-02
	Co-60	100	INGe	4.00E-02
	Zn-65	100	INGe	1.50E-01
	Zr-95	100	INGe	2.00E-01
	Ru-106	100	INGe	4.00E-01
	Cs-137	100	INGe	4.00E-02
	I-131	100	INGe	4.00E-02
	Am-241(GA)	100	INGe	2.00E-01
				Standard LLD (100 min.)
Beta	Gross	0.4	.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)				Standard LLD	Standard LLD
	Nuclide	Volume (L)	Method	(1000 min.)	(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	$\alpha\beta$ Cntr		2.00E-01
	Pu-238	0.5	Alpha Spec	8.00E-02	
	Pu-239	0.5	Alpha Spec	6.10E-02	
	Th-230	0.5	Alpha Spec	1.00E-01	
	Th 232	0.5	Alpha Spec	1.00E-01	
	Am-241	0.5	Alpha Spec	8.00E-02	

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

Water (pCi/L) Continued

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

*LLD for Air Cartridge is 3 days

METHOD

Preparation Methods

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

Counting Methods

INGe = Intrinsic Germanium Detector
 αβ Cntr = alpha, beta counter
 Alpha Spec = Alpha Spectrometry
 LS = Liquid Scintillation
 LEP = Low Energy Photon Detector

Formulas

A. Random Uncertainty

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

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

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

C. Lower Limit of Detection (LLD)

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

D. Definitions

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

Appendix C - Glossary of Terms

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

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

Half-life	The time in which half the atoms of a particular radioactive substance disintegrate to another nuclear form. Measured half-lives vary from millionths of a second to billions of years. Also called physical half-life.
ICRP	International Commission on Radiation Protection
Ionizing radiation	Any radiation capable of displacing electrons from atoms or molecules, thereby producing ions. Examples: alpha, beta, gamma, x-rays and neutrons.
Isotope	One of two or more atoms with the same number of protons, but different numbers of neutrons, in the nuclei.
Lower limit of detection (LLD)	The smallest amount or concentration of a radioactive element that can be reliably detected in a sample.
NCRP	National Council for Radiation Protection
PHL	Public Health Laboratory
pCi (picocurie)	10^{-12} curies (one trillionth of a curie)
PNNL	Pacific Northwest National Laboratory
QATF	Quality Assurance Task Force
Quality assurance	All those planned and systematic actions necessary to provide adequate confidence that a facility, structure, system or component will perform satisfactorily and safely in service.
Quality control	A component of Quality Assurance; comprises all those actions necessary to control and verify that a material, process or product meets specified requirements.

Quality Factor (Q)	A numerical factor assigned to describe the average effectiveness of a particular kind (and sometimes energy) of radiation in producing biological effects in the human.
Rad	The special unit of absorbed dose. It is a measure of the energy absorbed per mass of material. One rad is equal to an absorbed dose of 0.01 J kg^{-1} (1 rad = 0.01 gray).
Radioactivity	The process of undergoing spontaneous transformation of the nucleus, generally with the emission of alpha or beta particles, often accompanied by gamma rays. The term is also used to designate radioactive materials.
Radioisotope	A radioactive isotope; i.e. an unstable isotope that undergoes spontaneous transformation, emitting radiation. Approximately 2500 natural and artificial radioisotopes have been identified.
Radionuclide	A radioactive nuclide.
Rem	The special unit of dose equivalent. The dose equivalent in rem 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 is analyzed by the same laboratory.
Roentgen	A unit of exposure to ionizing radiation. It is that amount of gamma or x-rays required to produce ions carrying 1 electrostatic unit of electrical charge in 1 cubic centimeter of dry air under standard conditions. Named after Wilhelm Roentgen, German scientist who discovered x-rays in 1895.
Split Sample	A sample from one location that is divided into 2 samples and analyzed by different laboratories.

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

Appendix D - List of Analytes

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