Hanford Environmental Radiation Oversight Program

2016 Data Summary Report

DOH 320-120
December 2017

Hanford Environmental Radiation Oversight Program

2016 Data Summary Report

December 2017

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

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

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

Mike Elsen
Director, Office of Radiation Protection

Acknowledgements

Activities in the Hanford Environmental Radiation Oversight Program include sample schedule development, sample collection, radiochemical sample analyses, data entry, data quality assurance, laboratory reporting, contextual analysis of the data, writing and completing a technical review of the annual report, document preparation, database maintenance, and overall program management.

Office of Radiation Protection

Mike Elsen, Director, Office of Radiation Protection
Mike Priddy, Manager, Environmental Sciences Section

Written and Prepared by:

Scott Van Verst, PhD

Contributors:

Office of Radiation Protection

Lynn Albin
Megan Babcock
Eileen Kramer
Scott McDonald
Thomas Rogers
Scott Van Verst

Public Health Laboratory

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

Ben Clemence
Catherine Franklin
Richard Hinderer
Paul Marbourg
Josephine Pompey
Olivia Robbins
Lynn Skidmore
Hung Tran
Jose Caracamo (FERN)

Contents

Acronyms and Abbreviations

DOH	Department of Health (Washington State)
ERDF	Environmental Restoration Disposal Facility
LIGO	Laser Interferometer Gravitational-wave Observatory
LLD	Lower Limit of Detection
MAPEP	Mixed Analyte Proficiency Evaluation Program
MDA	Minimum Detectable Activity
MSA	Mission Support Alliance
OSL	Optically Stimulated Luminescence
PFP	Plutonium Finishing Plant
TLD	Thermoluminescent Dosimeters

Background

The Washington State Department of Health (Health) began monitoring environmental radiation in 1961. The focus of the early program was fallout from atmospheric testing of nuclear weapons. Health now monitors radiation at several state-licensed and federal facilities throughout the state, including the Hanford Site in eastern Washington. Health's purpose is to provide oversight to the environmental monitoring programs run by these facilities. Environmental samples are first divided into two parts: one going to Health, the other to the facility (split sampling). Each program assesses their split sample and Health compares the two results.

In 1985, Health began working with the U.S. Department of Energy (Energy) to collect environmental samples in and around the Hanford Site. Health's Hanford Environmental Radiation Oversight Program independently verifies the quality of Energy's environmental monitoring programs at Hanford. The program assesses the potential for public health risk, and addresses public concerns about environmental radiation at Hanford. Health typically monitors air, groundwater, surface water, riverbank seep water, drinking water, sediment, food and farm products, fish and wildlife, vegetation, and radiation levels in the surrounding area.

Summary

In this report, Health uses the categories of *good*, *fair*, and *poor* to describe how closely radioactivity measurements by Health and Energy agree. These data are not expected to be in exact agreement because of the random nature of radioactive decay, the fact that split samples collected from the field are not identical, and analytical methods may differ between programs. Health investigates and reports all unexpected discrepancies in split sample results.

Sections 3 and 4 of the report discuss the analytical results. Many environmental samples analyzed by Health have radioactivity concentrations either below detection limits or consistent with naturally occurring (background) radiation. Some samples have concentrations elevated above background. In most cases, however, the concentrations are consistent with historical trends. Generally, there is good to fair agreement between analytical results from samples split between Health and Energy. The Hanford Environmental Radiation Oversight Program met the program objectives and made the following conclusions:

- Health independently evaluated and verified Energy's monitoring program by conducting split sampling, and comparing the results. Health investigated any differences in results. The general *good* to *fair* agreement between the limited split data provides confidence that the remainder of the Energy's environmental data is valid.

- Health's oversight program finds Hanford-related radioactivity in the environment. However, Health's assessment of the data shows that public exposure to radioactivity from Hanford is far below regulatory limits.

- Health responds to any concerns the public has over radiation issues at Hanford. Health also participates in the Hanford Advisory Board, where the public can raise issues or express concerns. Health follows up on the issues raised in this forum.

1. Introduction

Chapter 70.98 of the Revised Code of Washington designates the Washington State Department of Health (Health) 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, Health conducts radiological monitoring throughout the state, placing emphasis on major nuclear facilities with known or potential radiological impacts associated with the facility operations, decommissioning, or cleanup. This report summarizes environmental radiation sampling results from the Department of Health's Hanford Environmental Radiation Oversight Program.

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

The primary objectives of the oversight program are:

- To independently verify the quality of the U.S. Department of Energy monitoring programs at the Hanford Site by conducting split, collocated, and independent sampling at locations having the potential to release radionuclides to the environment or locations which may be impacted by such releases.
- To independently assess impacts to the public, using Health's oversight data, to compare radionuclide concentrations in samples potentially impacted by Hanford with concentrations in background samples. With the primary role of oversight, Health's monitoring program is not intended to completely characterize environmental radiation from the Hanford Site, nor is it intended to find and report the highest environmental contaminant concentrations.
- To address public concerns related to environmental radiation at Hanford.

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

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

2. The Hanford Environmental Radiation Oversight Program Description

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

Split samples are prepared by dividing a sample into two parts. Collocated samples are those samples that are collected adjacent to the Energy contractor sample. In each case, Health's sample is sent to the Washington State Public Health Laboratory in Shoreline, Washington for radiochemical analysis. Results of Health's analyses are compared to the Energy 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 state laboratory 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 state laboratory'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

In 2016, the laboratory participated in three intercomparison programs: 1) The Department of Energy's Mixed Analyte Performance Evaluation Program (MAPEP) tests the laboratory's ability to correctly analyze multiple radionuclides covering four matrices: soil, air filter, vegetation, and water. This is a National Institute of Standards and Technology traceable proficiency-testing program. 2) The FDA/USDA Food Emergency Response Network proficiency testing program tests the laboratory's ability to correctly analyze for radioactivity in foodstuffs. The samples provided meet the requirements for NIST traceability. This work was conducted under contract with the US Food and Drug Administration. 3)Lastly, the laboratory participated in an exercise with fresh fission product performance testing material for testing food under emergency conditions provided by a certified reference laboratory . This work was also conducted under contract with the US Food and Drug Administration .

These programs provide an independent check of laboratory proficiency for analyzing environmental samples. The laboratory quality assurance plan also includes analysis of standard reference samples as part of analysis of a batch of samples. Reference material is generally any environmental media containing known quantities of radioactive material in a solution or homogenous matrix.

2.2 Interpretation of Results

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

2.2.1 Uncertainty in Radioactivity Measurements

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

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

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

2.2.2 Detection Limits

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

For samples with very low radionuclide concentration, it is often difficult to determine if the radionuclide is actually detected. This also may lead to difficulty in comparing Health and Energy results. This situation often arises with semiannual air and soil/sediment samples.

When concentrations are very low, it is a challenge to compare Health and Energy results. 1) In some cases, both Health and Energy report concentrations below laboratory detection limits. In this situation, a comparison only determines if both parties agree that the concentrations are too small to detect. 2) In other cases, concentrations are reported as "detected"; however, the concentrations are usually very small and similar in value to the detection limit. In this situation, the comparison attempts to determine if one or both parties detects the contaminant. However, since Health and Energy contractor detection limits may differ, and since the concentrations are very near to the detection limit, it is often difficult to definitively make this determination. 3) Finally, in yet other cases, concentrations are "definitively detected" above the detection limit. In this situation, the number of detected results is typically too small for a meaningful quantitative comparison by a statistical analysis.

Health intends to measure to the lowest concentration practical and minimize the error of reporting a non-detectable contaminant concentration when the contaminant is actually present. Detection limits are set low to ensure that measurements can verify protection of public health and the environment.

Health has traditionally used the measured concentration, uncertainty, and minimum detectable activity (MDA) values to determine if a contaminant is present. The MDA represents the balance point between the probability functions that describe the likelihood of false-detection and false-rejection; it is not the point above which calculated activity can be considered to be positively detected. During the last few years, consensus among the environmental radioactivity measurements community has been building to move away from the use of the MDA to determine whether an analyte has been detected, precisely because of this ambiguity.

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

2.2.3 Laboratory Background and Negative Results

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

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

The net sample activity represents the best estimate of the true value of the sample activity. Therefore, to prevent biased reporting, Health 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 Health and Energy Contractor Data

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

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

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

3) For split samples, the non-homogeneous nature of environmental samples may result in the two splits containing different amounts of radioactivity, and the results are not expected to be identical.
4) The evaluation of uncertainty in Health and Energy contractor data is limited, whereas a rigorous quantitative approach requires a more complete characterization of uncertainty.

2.2.4.1 Qualitative Comparisons

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

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

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

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

2.2.4.2 Regression Analysis and Scatter Plots

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

Assuming there is a sufficient amount of data above the detection limit for a meaningful regression analysis, each of the split or collocated Health and Energy results for a given sample type and radionuclide are formed into an (x, y) pair. The x-value represents the Health result and the y-value represents the Energy result for a particular sample. The paired data for all samples of a given sample type and radionuclide are plotted on a two-dimensional scatter plot. The correlation coefficient R is then calculated for the set of (x, y) pairs. R can vary from

-1 to +1. A value near ±1 implies a strong correlation, while a value near 0 implies a weak or non-correlation.

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

If the results between Health and Energy 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 Health measures zero activity, then Energy also measures zero for the same sample. A non-zero y-intercept indicates an overall offset between Health and Energy results. The slope is simply the ratio of Health and Energy results.

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

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

2.2.5 Comparison of Current Health Results to Historical Results

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

2.2.6 Gamma Analysis

Concentrations of the gamma emitting radionuclides Co-60 and Cs-137 are reported, regardless of whether the concentrations are above or below a detection limit. Concentrations of other gamma emitting radionuclides are reported if they are detected.

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

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

3. Environmental Monitoring Results

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

The sub-sections which follow discuss each of these sample types. Note that the figures for each sub-section are located at the end of the sub-section.

3.1 Ambient Air Monitoring

Major Findings:

- Health and Energy biweekly air concentrations are in fair agreement for gross alpha and gross beta activity. The concentrations are similar and follow the same trends over time, but there is a systematic discrepancy between the Health and Energy data.
- Health and Energy semiannual composite air sample results are in fair agreement for Am-241, Pu-239/240, Sr-90, U-234, and U-238, and in good agreement for all other radionuclides.
- Health and Energy H-3 concentrations in atmospheric water vapor are in fair agreement.
- Most Health air concentrations are consistent with historical results. Pu-241 concentrations were anomalous in several semiannual composite air samples.

3.1.1 Purpose and General Discussion

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

Sources of Hanford-specific airborne emissions include resuspension of contaminated soil (caused by wind or cleanup activities, for example) and escape of radioactive particulates and gasses from facilities and operations. Sources of natural airborne radioactivity include natural radon gas and its decay products; resuspension of soil containing natural radionuclides such as U-234, U-238, and K-40; and radioactive atoms such as Be-7 and H-3 (tritium) that are generated in the atmosphere by interactions with cosmic radiation. Other sources of man-made airborne radioactivity include resuspension of fallout from historical atmospheric testing of nuclear weapons, including Sr-90, Cs-137 and Pu-239/240.

3.1.2 Sample Types and Monitoring Locations

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

Health collected air samples collocated with the Near Facilities and Operations program at eight locations, five of which are near facilities that have the potential to emit radionuclides to

the atmosphere. These locations include the Liquid Effluent Retention Facility (N499 LERF), the Environmental Restoration Disposal Facility (ERDF-SE), and the Plutonium Finishing Plant (PFP-N165, PFP N554, PFP N555, PFP N975), all in the 200 Area; the 100K East Area near the fuel storage basins (100K N576); and a burial ground in the 600 Area (618-10 BG N548). The eighth collocated site, which is not near any facility, is at the Wye Barricade.

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

Health also independently collects biweekly air samples at the LIGO facility in the 600 Area. This sampling location is not collocated with Energy.

Figure 3.1.1 shows some of Health's historical air sampling sites, indicating the general areas on the Hanford site targeted for sampling. Note that the map does not show all of the current sampling locations.

3.1.3 Monitoring Procedures

The air samplers work by continuously drawing air through a filter that traps airborne particulates. The filters are collected at each sample location every other week (biweekly), are stored for three days, and then analyzed for gross beta and gross alpha activity. The storage period allows naturally occurring short-lived radionuclides to decay that would otherwise obscure detection of radionuclides potentially present from Hanford Site emissions.

The amount of radioactive material collected on a filter in a two-week period is typically too small to accurately detect concentrations of individual radionuclides. In order to increase the sensitivity and accuracy, so that individual radionuclide concentrations can be determined, the biweekly filter samples for a three or six-month period are dissolved and combined into quarterly or semiannual composite samples.

Energy requested to discontinue the analysis of quarterly composite air samples because that time period is too short to accurately detect individual radionuclides. The semiannual composite samples are analyzed for gamma emitting radionuclides, and isotopes of strontium, americium, uranium, and plutonium. Note that the laboratories do not carry out analysis for all radionuclides at every sample location.

The Site-Wide and Offsite program also collects monthly atmospheric water vapor for tritium (H-3) analysis by continuously drawing air through samplers containing adsorbent silica gel. Health collects collocated samples from two locations for this analysis, the 300 Water Intake

and Battelle Complex, typically resulting in 24 collocated samples. Water is distilled from the silica gel of each sample and analyzed for its tritium content. Due to sample collection problems in 2016, Health collected only 15 of the 24 scheduled samples, and the time in the field for several of these samples did not match any corresponding Energy samples. Therefore, Health did not carry out analysis of collocated H-3 in air data this year, but Section 3.1.4 presents a discussion of Health's and Energy's individual data.

3.1.4 Comparison of Health and Energy Contractor Data

Table 3.1.1 summarizes the comparison of Health and Energy data (see Section 2.2). The first columns in the table list the analytes assessed in the laboratory sample analyses and the sample collection period. Then, for each analyte, the table lists the number of split or collocated results, the quality of agreement between the Health and Energy results (see Section 2.2.4.1), and the range of concentrations measured by Health. A concentration value prefaced by the "less than" symbol (<) indicates that the value is the detection limit and that some or all Health results are less than this value. Finally, the "Anomalous Data ?" column denotes whether any of the measured Health concentrations for the current year are anomalous compared to historical results (see Section 2.2.5).

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

Analyte	Collection Period	Number of Results	Quality of Agreement	Health's Data Range (pCi/m^3)	Anomalous Data ?
Gross Alpha	biweekly	334	**fair**	0.0002 to 0.009	no
Gross Beta	biweekly	334	**fair**	0.002 to 0.07	no
H-3	monthly	15		< 1 to 4	no
Am-241	semiannual	12	**fair**	< 0.00001 to 0.00007	no
Co-60	semiannual	27	good	< 0.0007	no
Cs-134	semiannual	27	good	< 0.0005	no
Cs-137	semiannual	27	good	< 0.0009	no
Eu-152	semiannual	27	good	< 0.001	no
Eu-154	semiannual	27	good	< 0.001	no
Eu-155	semiannual	27	good	< 0.001	no
Pu-238	semiannual	25	good	< 0.00001	no
Pu-239/240	semiannual	25	**fair**	< 0.000005 to 0.0001	no
Pu-241	semiannual	10	**poor**	< 0.0009 to 0.004	**yes**
Sr-90	semiannual	25	**fair**	< 0.00006 to 0.0002	no
U-234	semiannual	23	**fair**	< 0.00001 to 0.00002	no
U-235	semiannual	23	good	< 0.000005	no
U-238	semiannual	23	**fair**	< 0.00001 to 0.00006	no

Table 3.1.1 Summary of Air Samples Collocated with Energy

In the graphs for the semiannual data at the end of this section, note that the data for the first half of the year (January – June) followed by the data for the second half of the year (July – December) are shown for each site. For example, in Figure 3.1.11, each site is listed twice, and the first data point for each site is for the first half of the year while the second data point for each site is for the second half of the year.

Health and Energy gross alpha concentrations are in fair agreement. Figure 3.1.2 shows the collocated data at Prosser Barricade. The concentrations are similar and follow the same temporal trend, but the concentrations reported by Energy are systematically less than those reported by Health. The data at some locations do not show the same level of disagreement. For example, the Health and Energy concentrations at the 618-10 Burial Ground, shown in Figure 3.1.3, do not show the same systematic bias.

Figure 3.1.4 shows the scatter plot for gross alpha concentrations at all monitoring locations. There is significant scatter about the theoretical line in which Health and Energy concentrations are identical, with differences up to a factor of two being common. Regression analysis indicates that, on average, the concentrations reported by Energy are approximately 65% of the values reported by Health. These data are similar to historical results.

Health and Energy gross beta concentrations are in fair agreement. Figure 3.1.5 shows the collocated data at 618-10 Burial Ground. The concentrations are similar and follow the same temporal trend, but the concentrations reported by Energy are systematically greater than those reported by Health. The data at some locations do not show the same level of disagreement. For example, the Health and Energy concentrations at PFP-N165, shown in Figure 3.1.6, do not show the same systematic bias.

Figure 3.1.7 shows the scatter plot for gross beta concentrations at all monitoring locations. There is significant scatter about the theoretical line in which Health and Energy concentrations are identical, with differences up to a factor of two being common. Data analysis indicates that, on average, the concentrations reported by Energy are approximately 0.005 pCi/m^3 greater than the values reported by Health. These data are similar to historical results.

In April of 2016, at the 100K East Area (100K N576), Health measured gross alpha and gross beta concentrations significantly higher than Energy. Figures 3.1.8 and 3.1.9 show these results.

Due to problems discussed in Section 3.1.3, there is no comparison of collocated H-3 in atmospheric water vapor data this year. Health's data ranged in concentrations from below the detection limit to 4 pCi/m^3, while Energy's data ranged from below the detection limit to 17 pCi/m^3. Historically, the agreement between Health and Energy H-3 (tritium) concentrations is poor. Figure 3.1.10 shows the scatter plot of historical data up through year 2015 from all sites, where it can be seen that Energy typically reports concentrations higher than those reported by Health.

Heath and Energy Am-241 concentrations in semiannual air samples are in fair agreement. Both Health and Energy detected Am-241 in a few of the samples. Concentrations range from below the detection limit of 0.00001 pCi/m^3 to 0.00007 pCi/m^3. Figure 3.1.11 shows the Am-241 data. The large error bars for some of Energy's data render the y-axis scale too large to show the low concentrations of the results, and therefore the results without the large error bars are shown in Figure 3.1.12. For several samples, Health reports higher concentrations than Energy.

In 2015, Health measured an Am-241 concentration at the 618-10 Burial Ground that is several times greater than concentrations typically detected in air samples. The results in 2016 are consistent with historical Am-241 concentrations in air. Historical results at the 618-10 Burial Ground are shown in Figure 3.1.13.

All Health and Energy Co-60, Cs-134, Cs-137, Eu-152, Eu-154, and Eu-155 concentrations in semiannual air samples are in good agreement, and all concentrations are below detection limits.

Historically, Cs-137 is occasionally detected in air samples. When it is detected, the concentrations reported by Energy are typically one-half the concentration value reported by Health. This can be seen in Figures 3.1.14 and 3.1.15, which show scatter plots for historical Cs-137 concentrations in air for lower concentration and higher concentration data, respectively.

All Health and Energy Pu-238 concentrations in semiannual air samples are in good agreement, and all concentrations are below Health's detection limit of 0.00001 pCi/m^3 (see Figure 3.1.16).

Plutonium-238, produced in historical reactor operations in small quantities and with a relatively short half-life of 88 years, is generally not detected in Hanford environmental air samples. However, Health occasionally detects Pu-238 at small concentrations just a few times greater than the detection limit. This was the case in 2015 for two samples collected at the 618-10 Burial Ground, however, all results in 2016 samples are below the detection limit.

The Health and Energy Pu-239 concentrations in semiannual air samples are in fair agreement, with concentrations ranging from below the detection limit of 0.000005 pCi/m^3 to 0.0001 pCi/m^3. Figure 3.1.17 shows the higher concentration data, while Figure 3.1.18 shows the data for lower concentrations. When Pu-239/240 is detected, Health often reports higher concentrations than Energy. Plutonium-239/240 may be detected at small concentrations in environmental air samples, as it was produced from historical atmospheric testing of nuclear weapons, as well as from Hanford operations.

The Health and Energy Pu-241 concentrations in semiannual air samples are in poor agreement. Concentrations measured by Health are below the detection limit of 0.0009 pCi/m^3 for all of the first half semiannual samples, while concentrations range from 0.002 pCi/m3 to 0.004 pCi/m^3 for all of the second half semiannual samples. All of Energy's results are below the detection limit. Figure 3.1.19 shows these data.

The Health and Energy Sr-90 concentrations in semiannual air samples are in fair agreement, and Health's results ranged from below the detection limit of 0.00006 pCi/m^3 to 0.0002 pCi/m^3. Figure 3.1.20 shows the results for locations where Health detected Sr-90, and in these cases, Energy did not detect Sr-90 in their samples. Similar to Pu-239, Sr-90 is often detected at small concentrations in environmental samples, as it was produced from historical atmospheric testing of nuclear weapons, as well as from Hanford operations.

The Health and Energy U-235 concentrations are in good agreement, and all concentrations are below the detection limit of 0.000005 pCi/m^3.

The U-234 and U-238 concentrations are in fair agreement. Figure 3.1.21 shows the U-234 results (U-238 data are similar). The Health and Energy results follow the same trend, as seen in the figure, but in several cases, the results display a non-systematic disagreement. Historically, there is a systematic discrepancy between Health's and Energy's isotopic uranium results, with Health typically reporting concentrations significantly greater than Energy, as can be seen in Figure 3.1.22 which shows the scatter plot for U-238.

The Health and Energy H-3 concentrations in water vapor from air samples are in fair agreement. Health's results range from concentrations below the detection limit of 1 pCi/m^3 to 4 pCi/m^3, while Energy's results range from below their detection limit of 5 pCi/m^3 to 16 pCi/m^3. Figure 3.1.23 shows the H-3 data.

3.1.5 Other Discussion

Radioactivity in air data shows a trend of higher concentration during the winter months, typically October through February. The gross beta data clearly show this trend. Higher concentrations are attributed to increased concentrations of radon decay products due to decreased atmospheric mixing during the winter months when there is decreased atmospheric heating. The annual cycle of increased gross beta activity in the winter months is seen in Figure 3.1.24, which shows historical gross beta activity at Wye Barricade.

In addition to the collocated samples, Health also independently collects biweekly air samples at the LIGO facility in the 600 Area. The gross alpha, gross beta, Sr-90, and isotopic uranium concentrations in 2016 at this site are consistent with historical data. All other radionuclides were not detected.

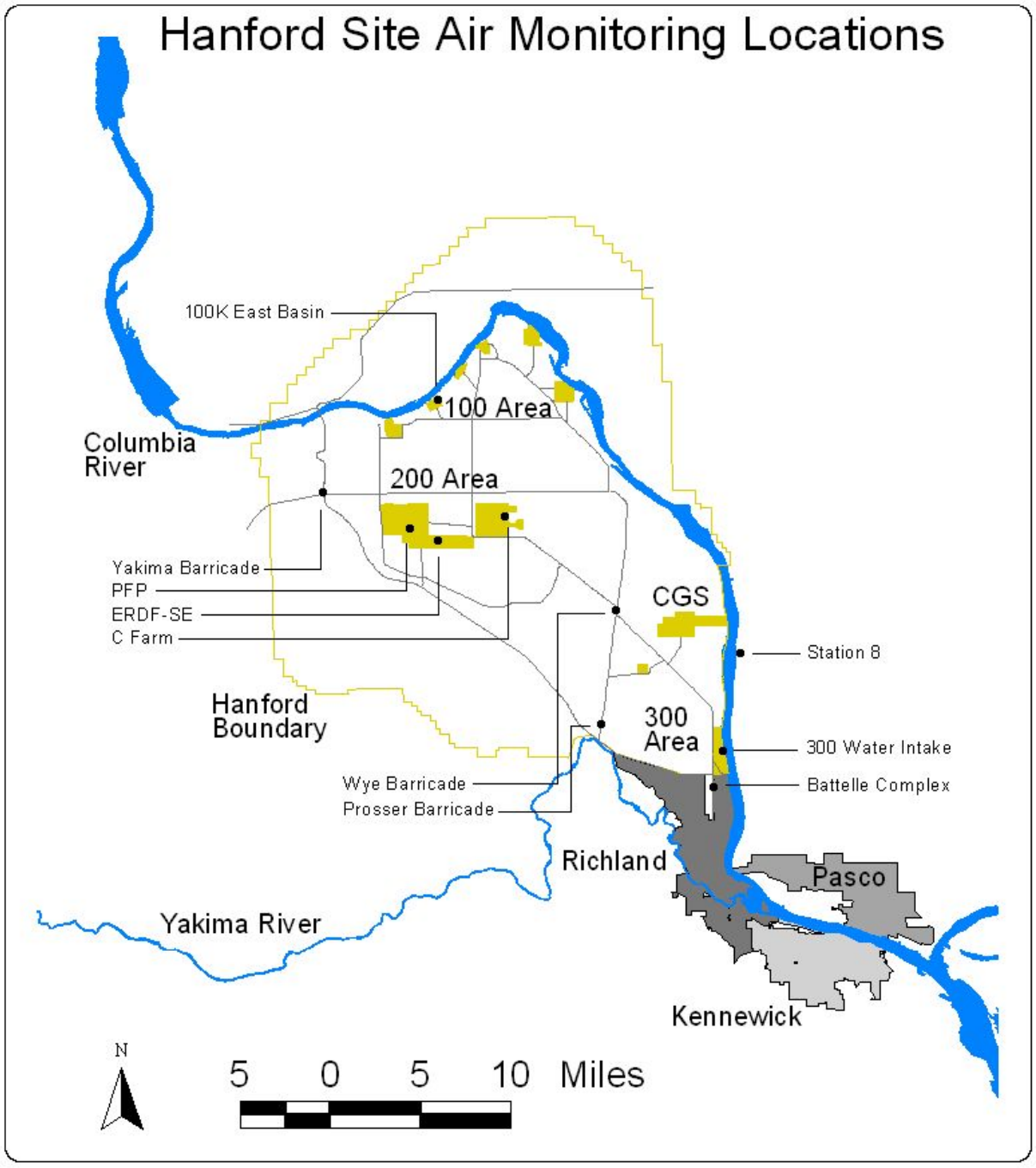

Figure 3.1.1 Hanford Area Air Monitoring Locations

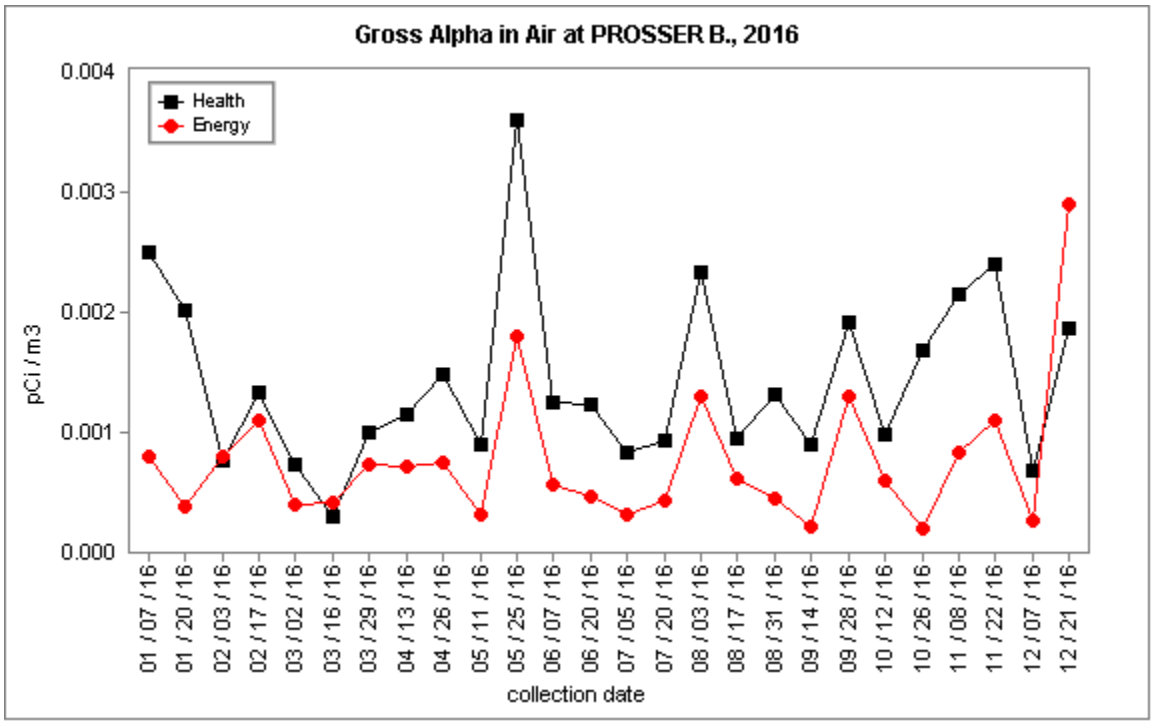

Figure 3.1.2 Health and Energy Gross Alpha Concentrations in Air at Prosser Barricade

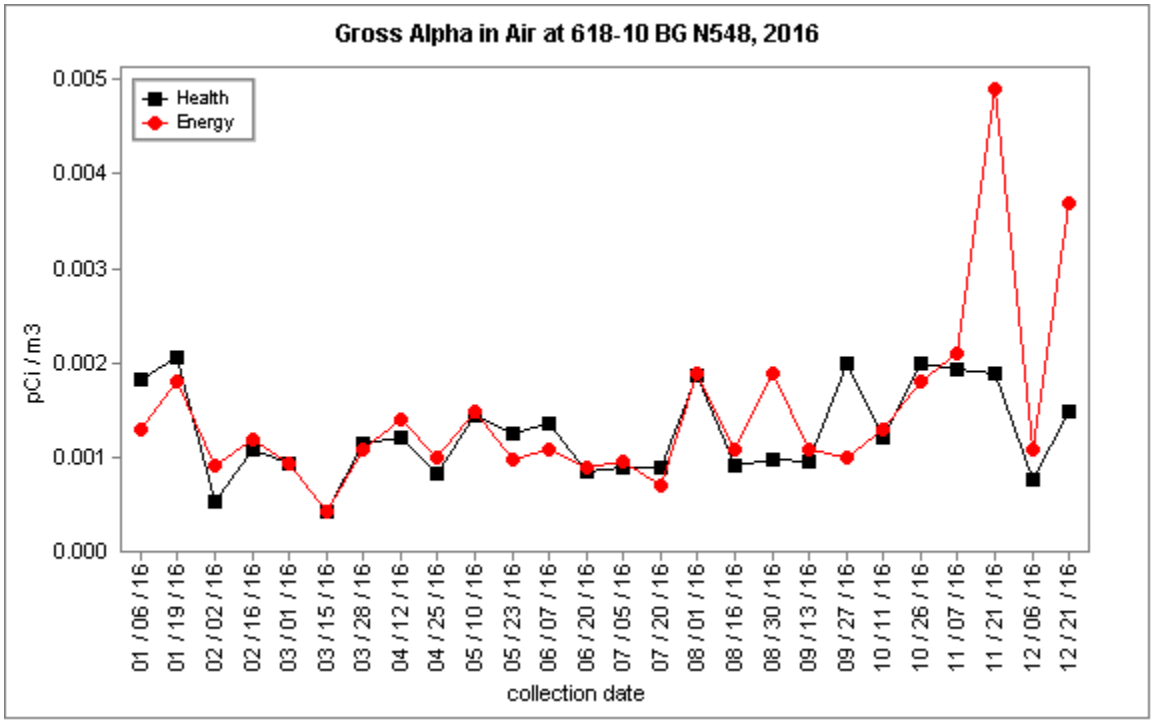

Figure 3.1.3 Health and Energy Gross Alpha Concentrations in Air at 618-10 Burial Ground

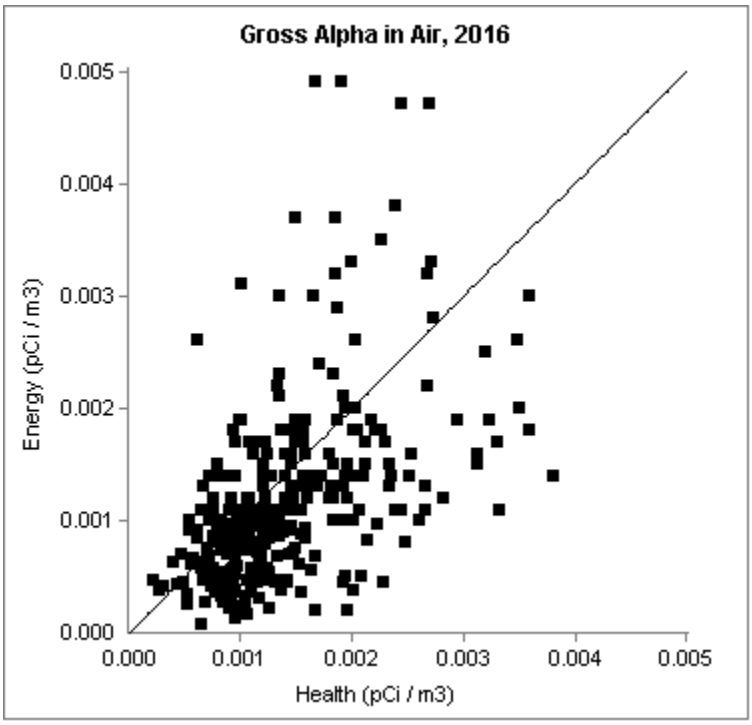

Figure 3.1.4 Health and Energy Scatter Plot for Gross Alpha Concentrations in Air

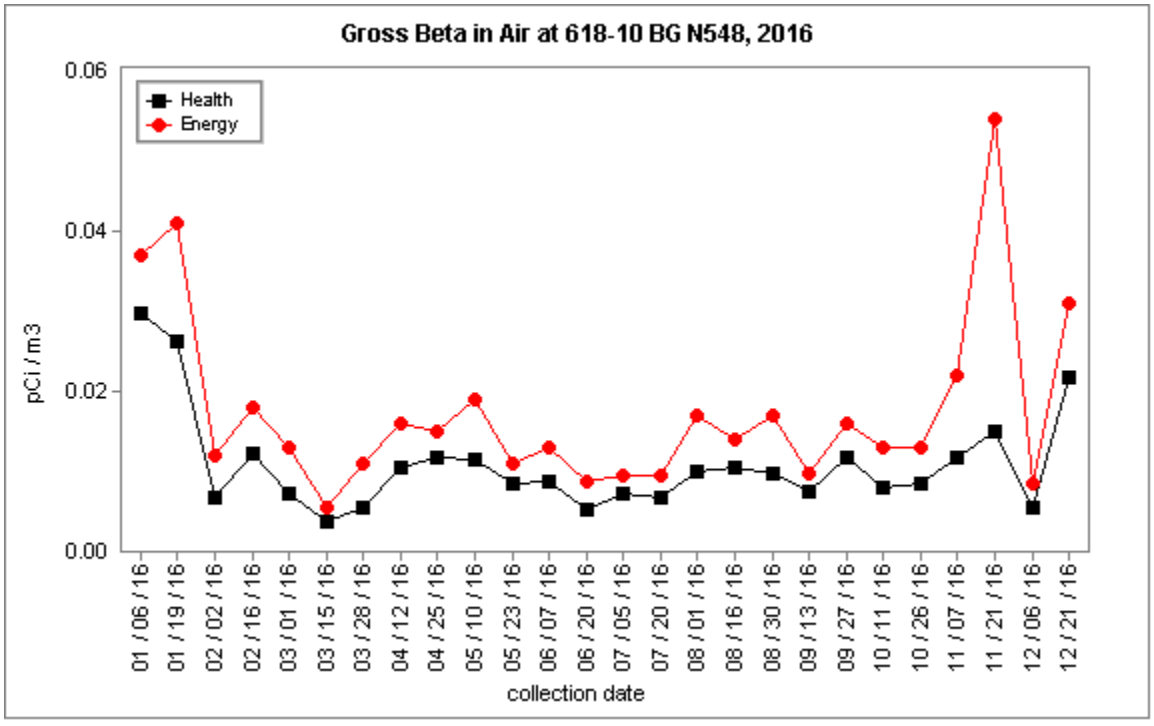

Figure 3.1.5 Health and Energy Gross Beta Concentrations in Air at Station 8

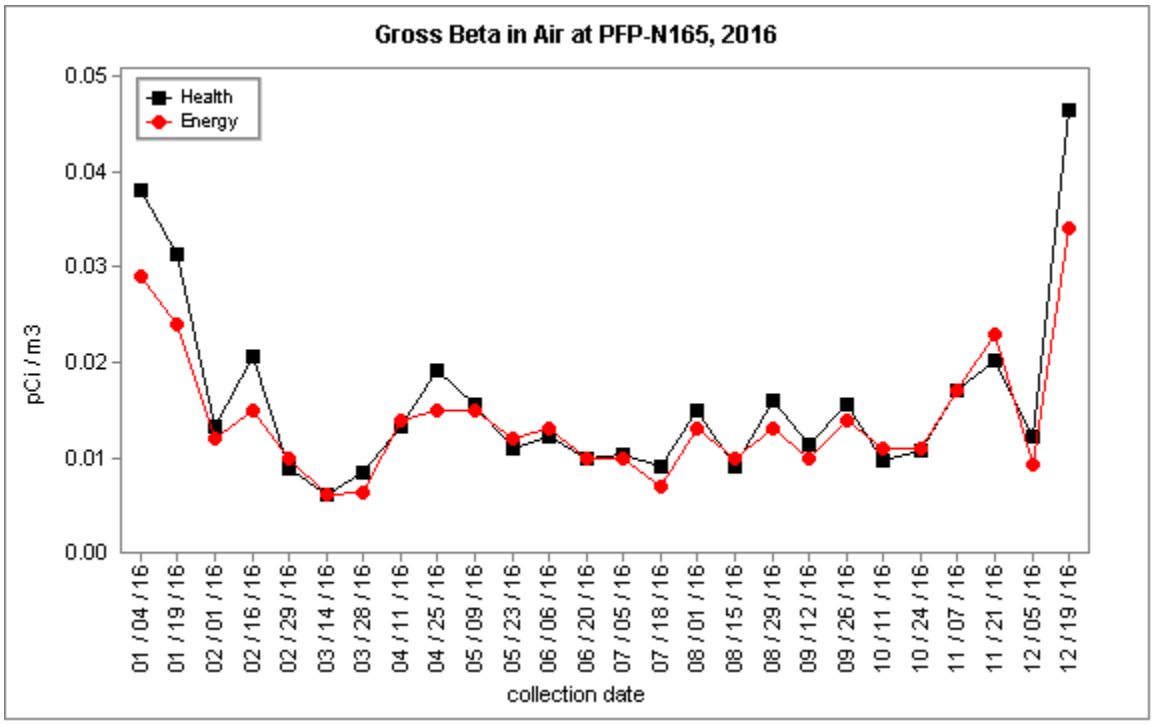

Figure 3.1.6 Health and Energy Gross Beta Concentrations in Air at ERDF SE

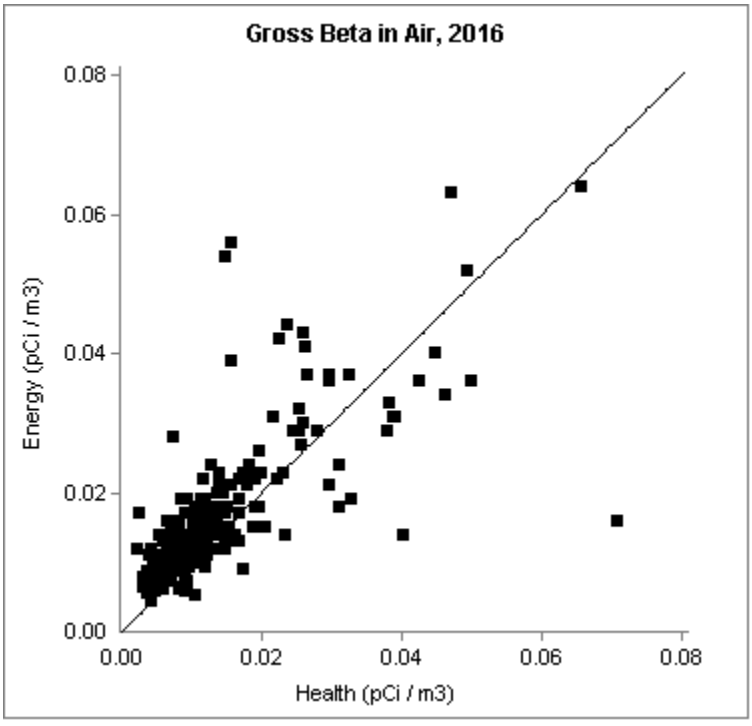

Figure 3.1.7 Health and Energy Scatter Plot for Gross Beta Concentrations in Air

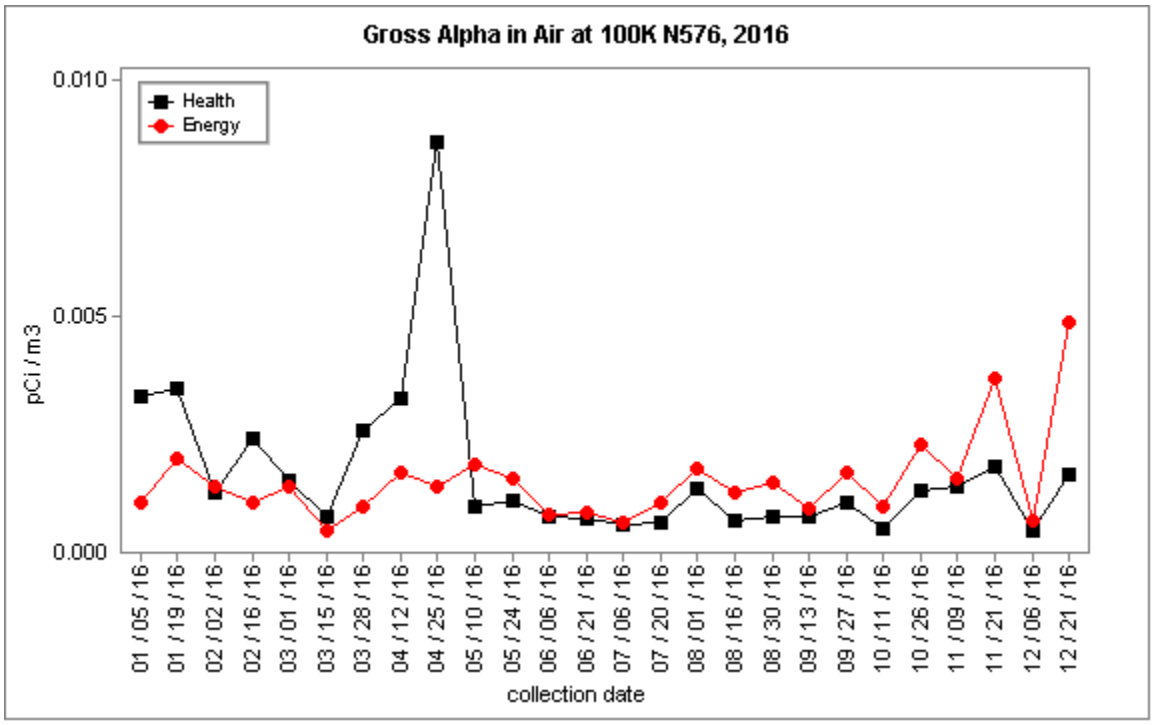

Figure 3.1.8 Health and Energy Gross Alpha Concentrations in Air at 100K N576

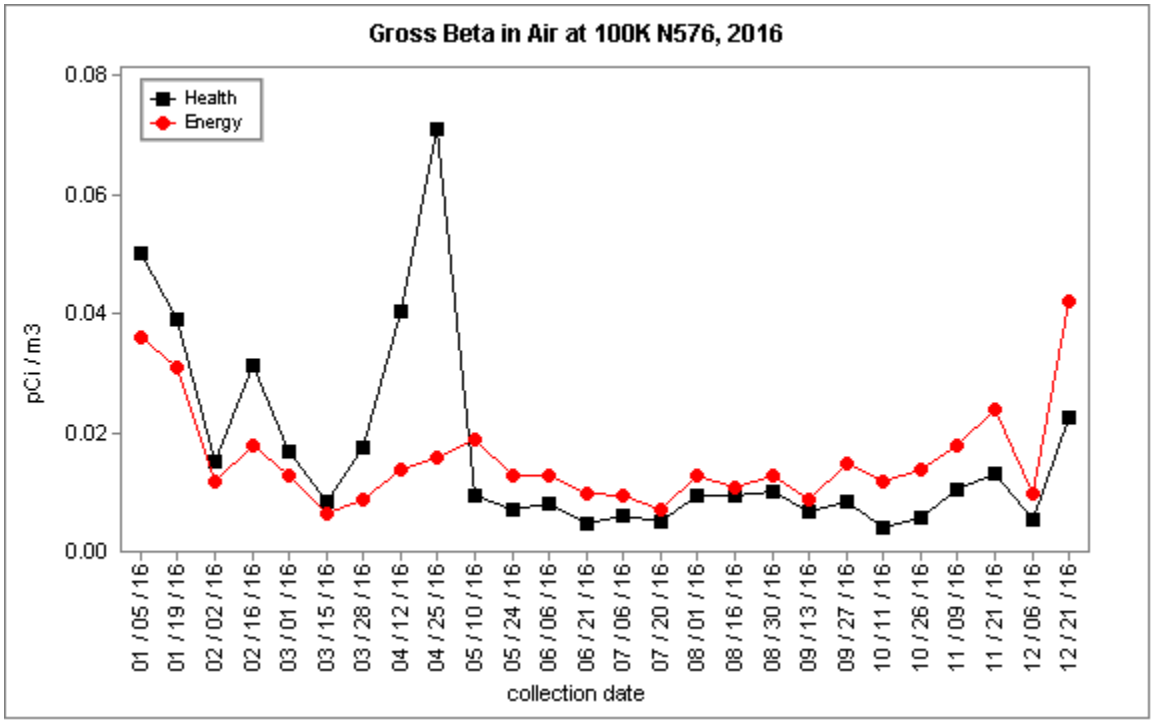

Figure 3.1.9 Health and Energy Gross Beta Concentrations in Air at 100K N576

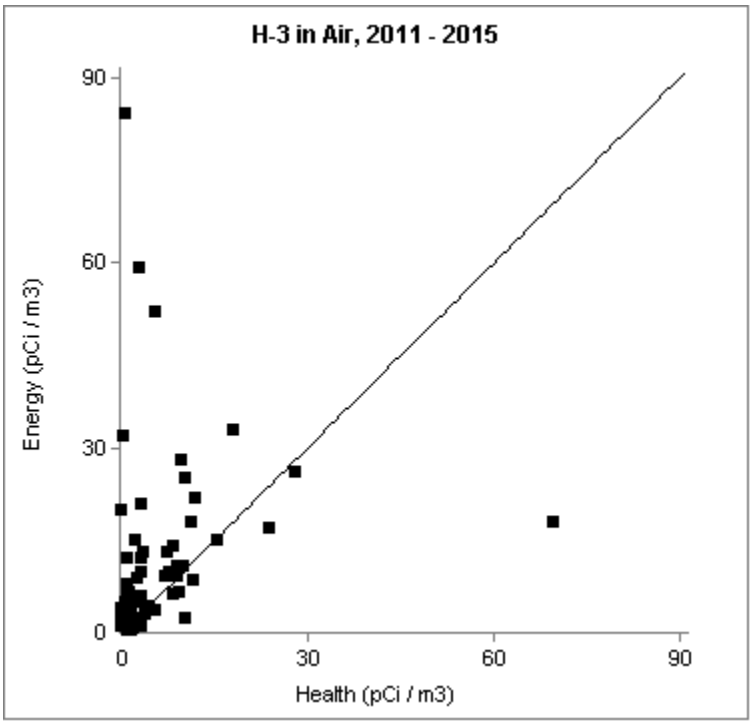

Figure 3.1.10 Health and Energy Scatter Plot for Historical H-3 Concentrations in Air

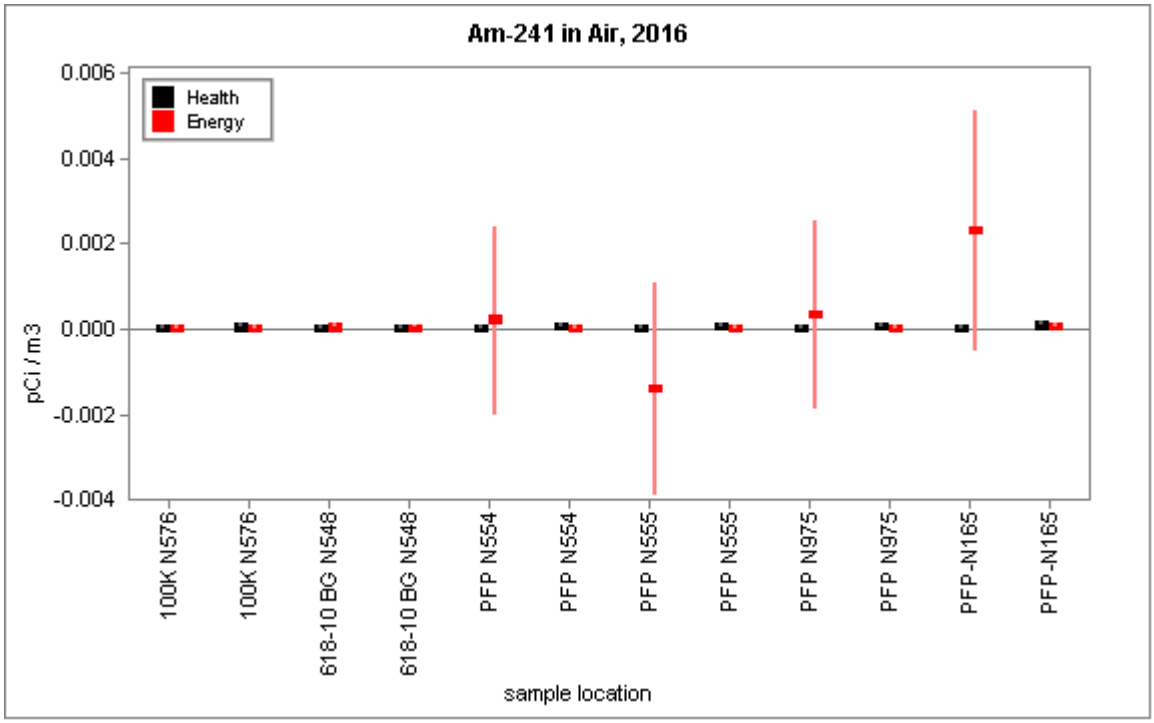

Figure 3.1.11 Health and Energy Am-241 Concentrations in Air

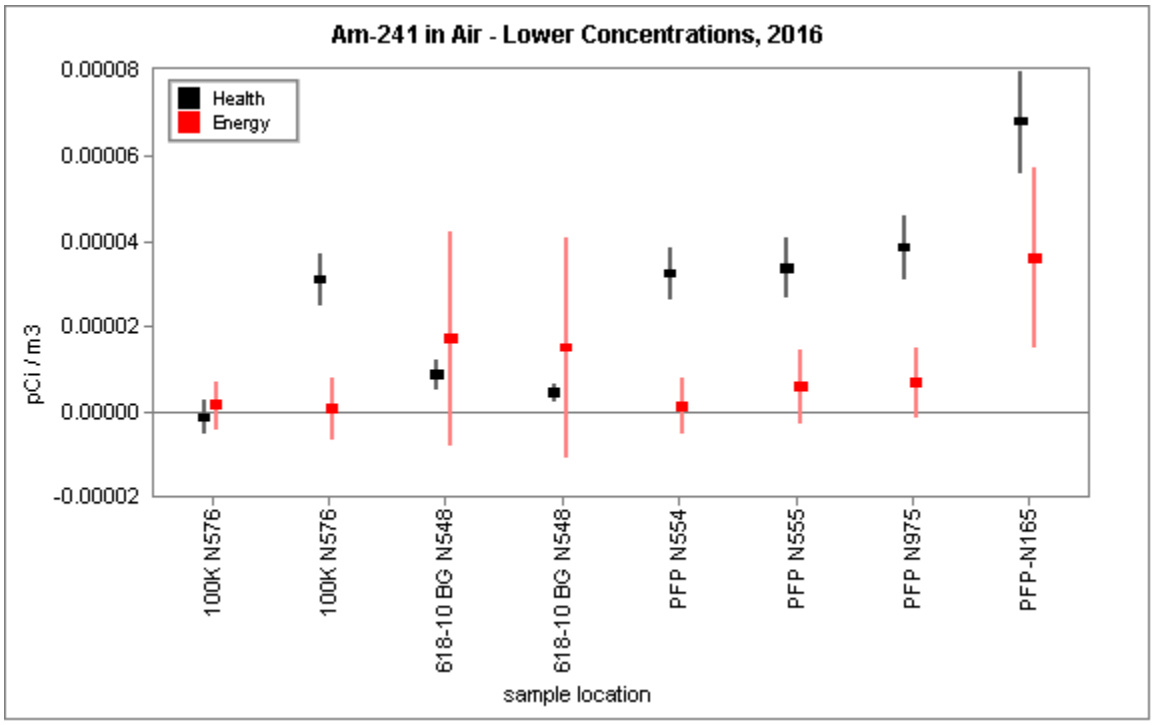

Figure 3.1.12 Health and Energy Am-241 Low Concentration Data in Air

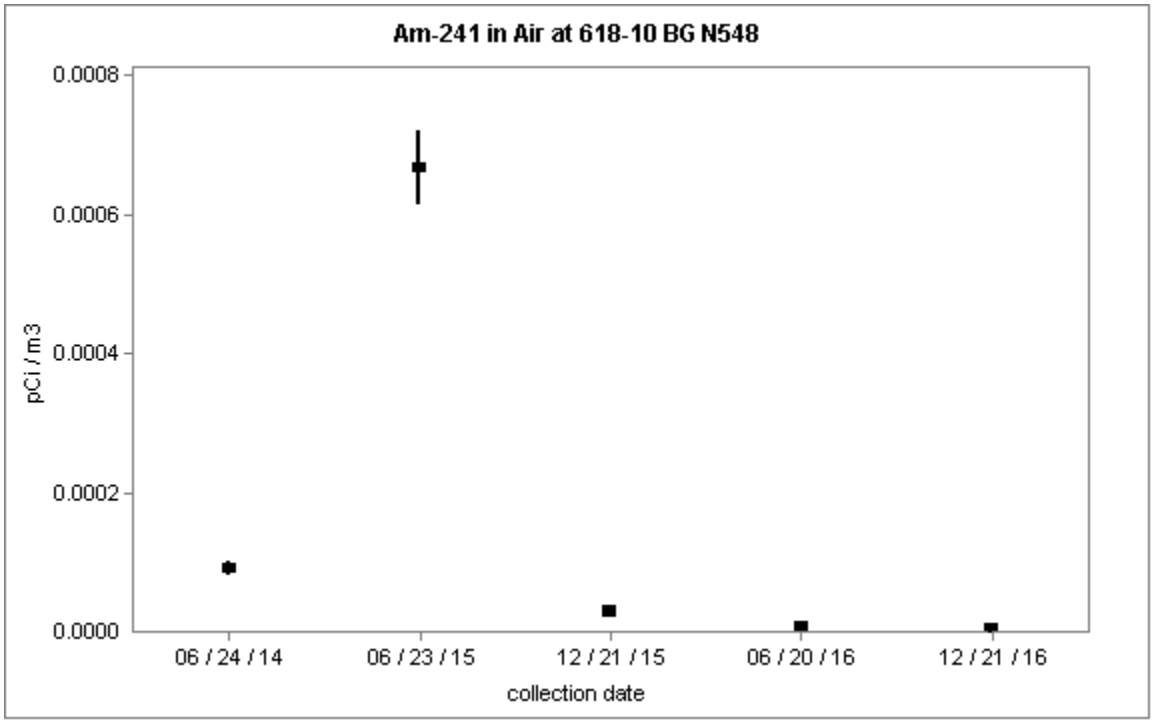

Figure 3.1.13 Health's Historical Am-241 Air Concentrations at 618-10 BG

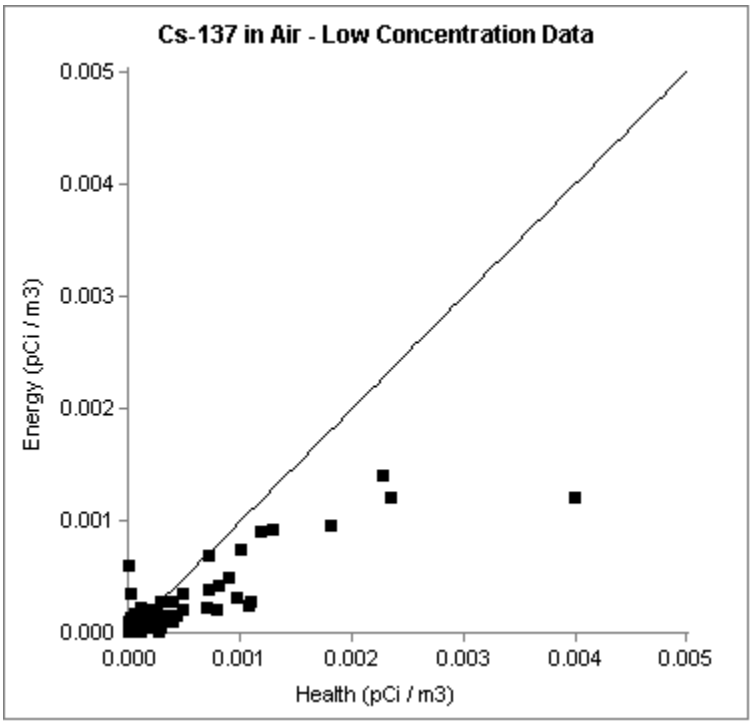

Figure 3.1.14 Health and Energy Scatter Plot for Historical Cs-137 Low Concentration Data in Air

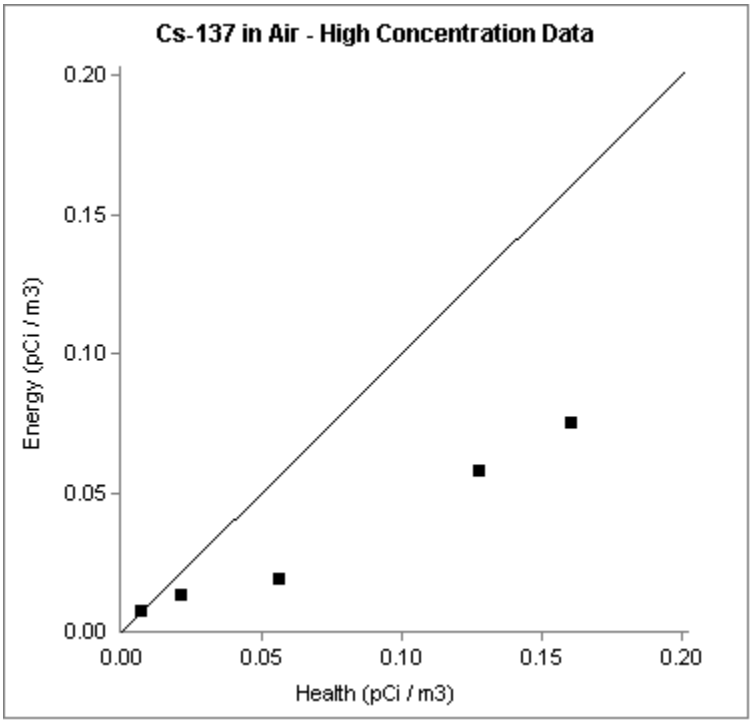

Figure 3.1.15 Health and Energy Scatter Plot for Historical Cs-137 High Concentration Data in Air

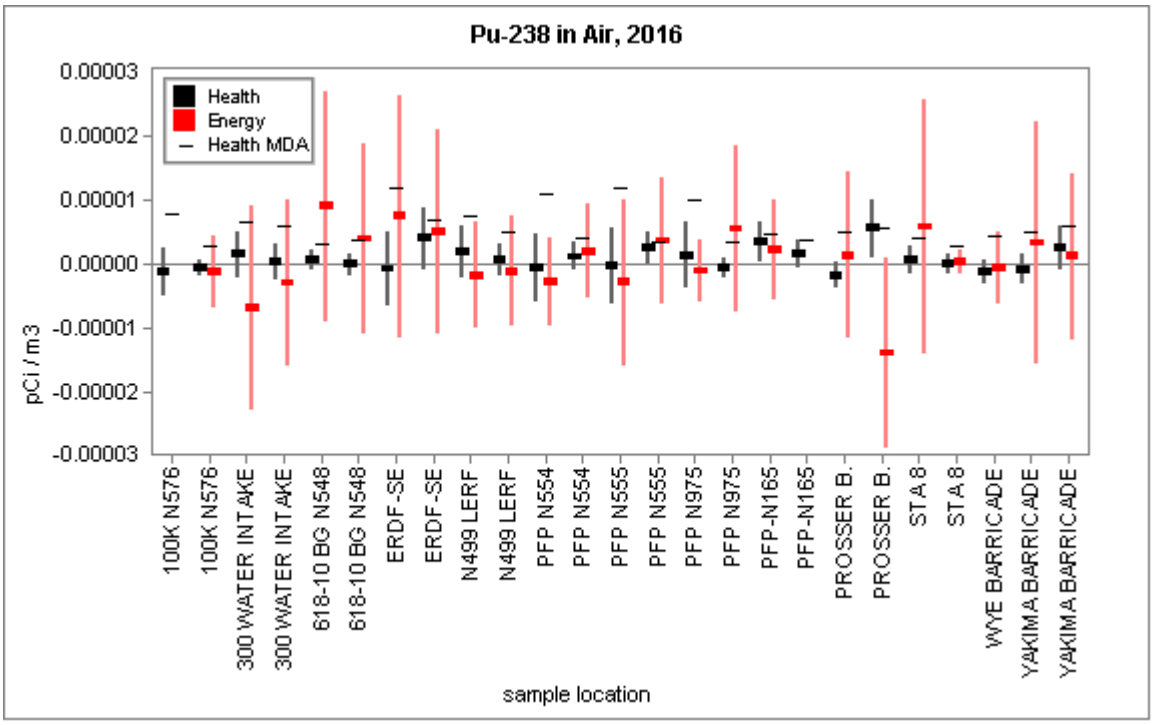

Figure 3.1.16 Health and Energy Pu-238 Concentrations in Air

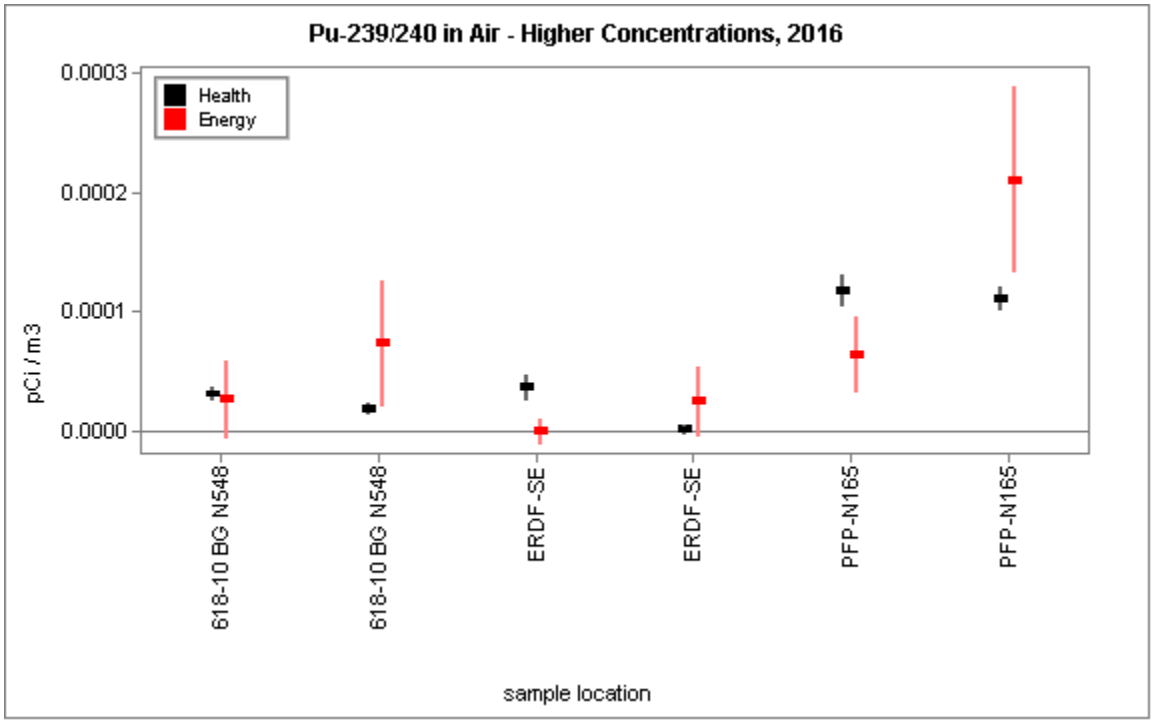

Figure 3.1.17 Health and Energy Pu-239/240 Higher Concentration Data in Air

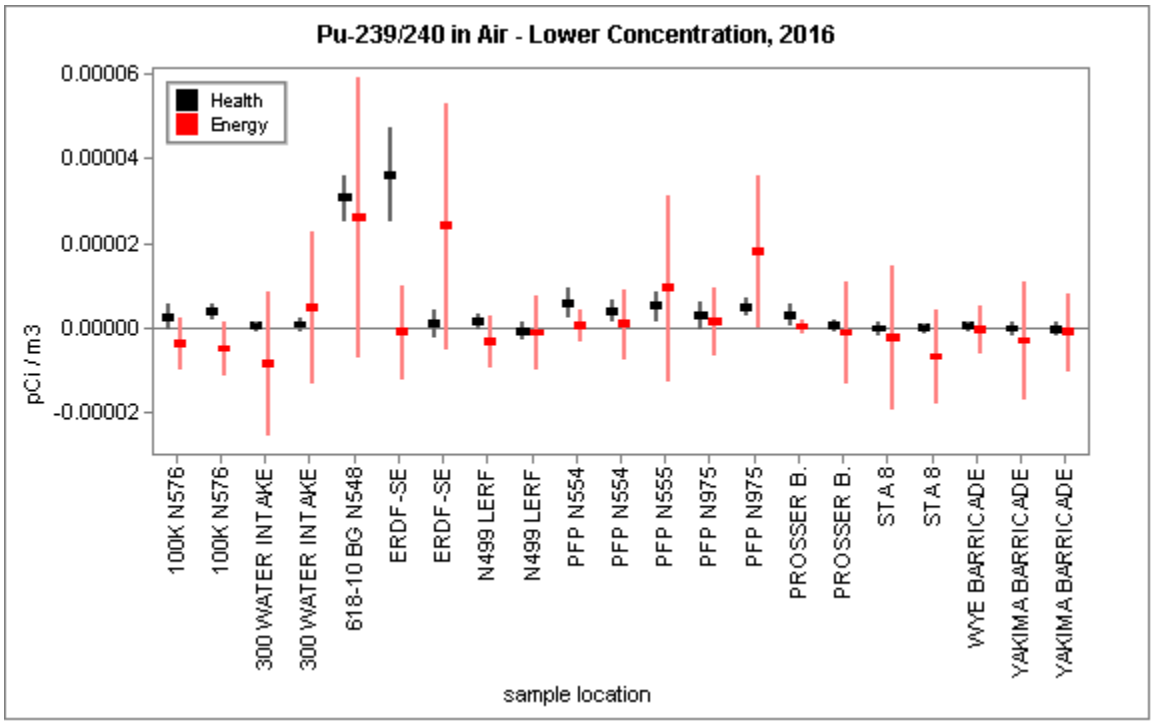

Figure 3.1.18 Health and Energy Pu-239/240 Lower Concentration Data in Air

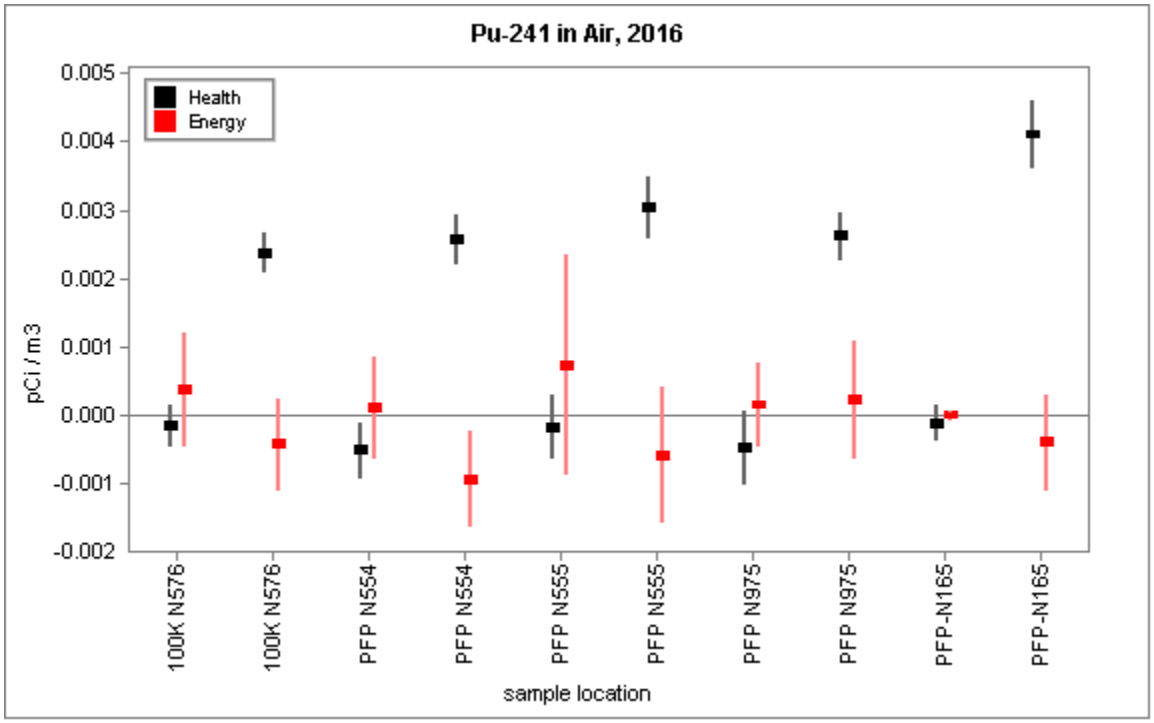

Figure 3.1.19 Health and Energy Pu-241 Concentrations in Air

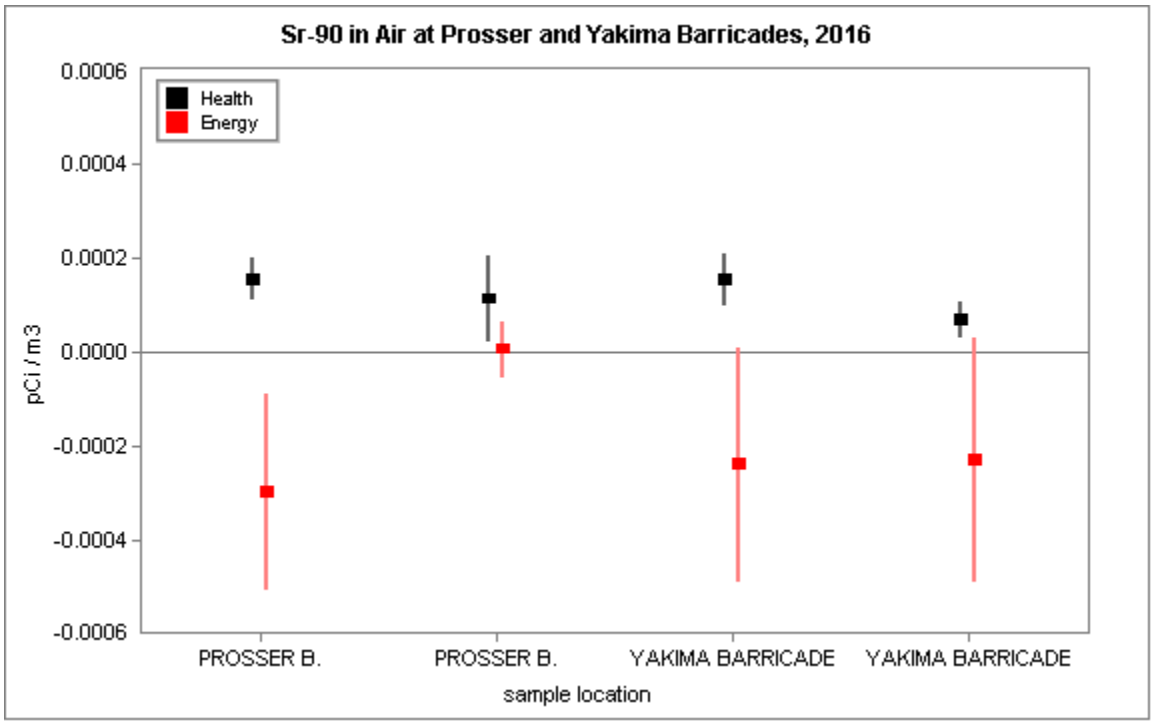

Figure 3.1.20 Health and Energy Sr-90 Concentrations at Prosser and Yakima Barricades

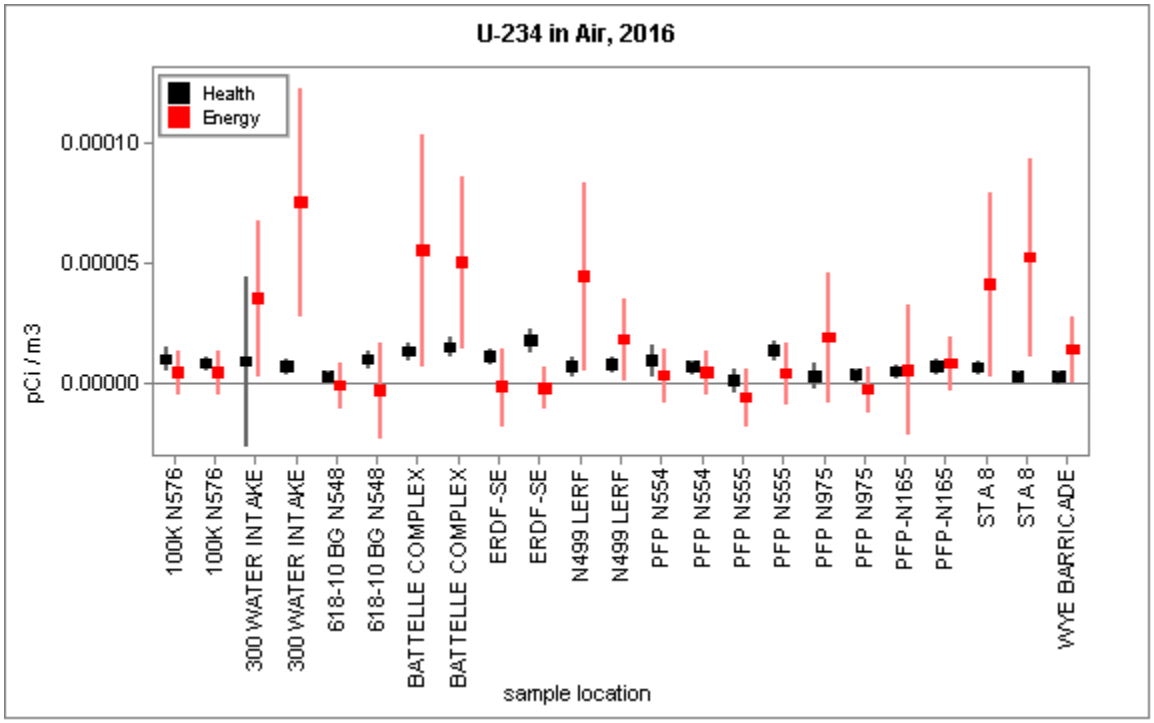

Figure 3.1.21 Health and Energy U-234 Concentrations in Air

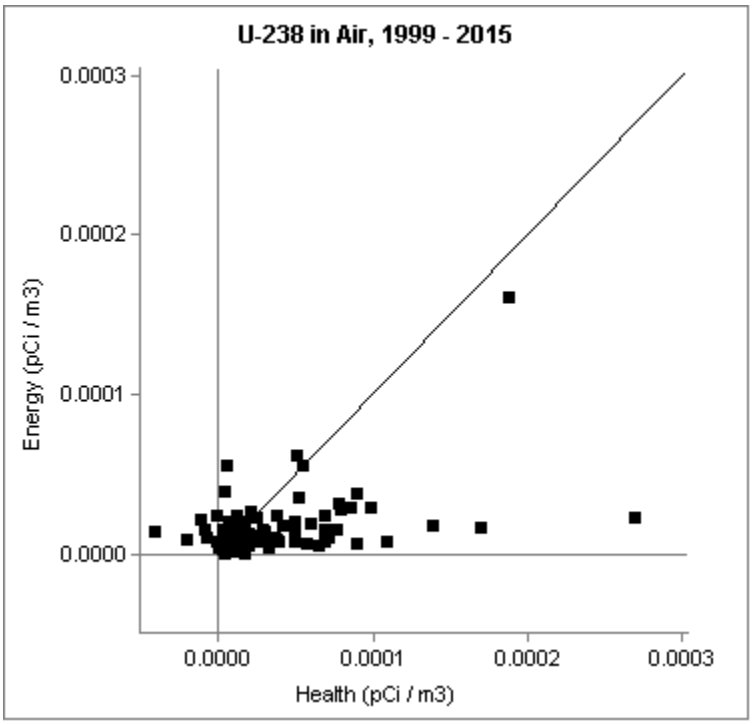

Figure 3.1.22 Health and Energy Scatter Plot for Historical U-238 Concentrations in Air

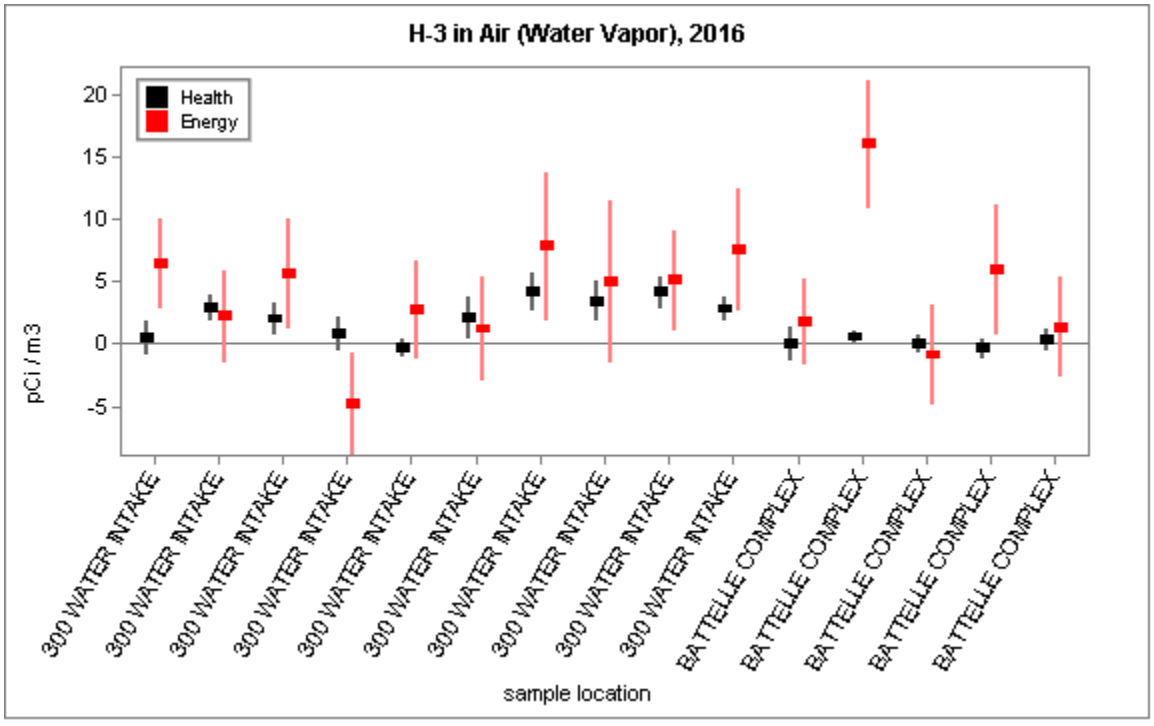

Figure 3.1.23 Health and Energy H-3 Concentrations in Air

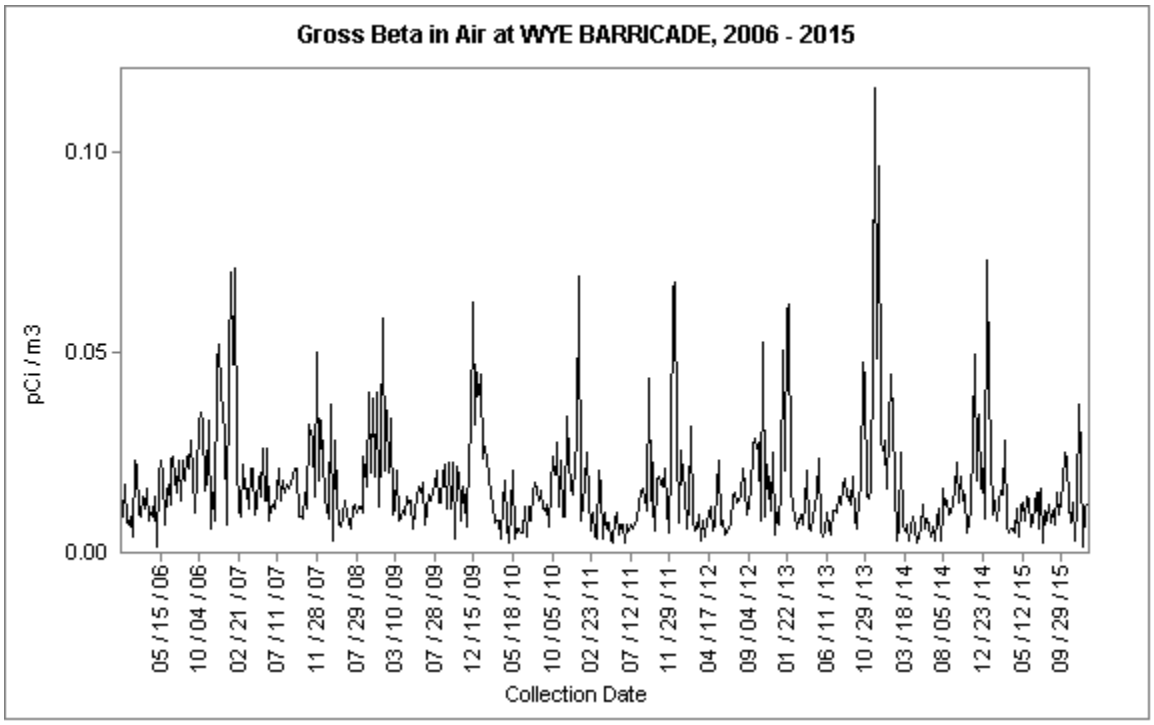

Figure 3.1.24 Health's Historical Gross Beta Concentrations in Air at Wye Barricade

3.2 Groundwater, Riverbank Seep, Drinking Water and Surface Water Monitoring

Major Findings:

- Health and Energy split water concentrations are in fair agreement for gross alpha, gross beta, C-14, and I-129; and good agreement for all other reported radionuclides.
- Radionuclides were detected in groundwater near known groundwater plumes, and in riverbank seep water and Columbia River surface water near plumes known to be entering the Columbia River.
- Health detected C-14, Co-60, Cs-137, H-3, I-129, Pu-239/240, Sr-90, Tc-99, and isotopes of uranium in some Hanford groundwater, seep water, or surface water samples. Most concentrations are consistent with historical trends. C-14 concentrations in 100K Area groundwater appear to be increasing.
- Drinking water samples met federal standards.

3.2.1 Purpose and General Discussion

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

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

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

3.2.2 Sample Types and Monitoring Locations

Figure 3.2.1 shows some of Health's historical water sampling sites, indicating the general areas on the Hanford site targeted for sampling. Note that the map does not show all of the current sampling locations. Locations may vary from year to year.

Groundwater

Health split 15 groundwater samples (one sample from each of 15 groundwater wells) with the Energy contractor (CH2MHILL). Well locations are on the Hanford Site, either within contaminated plumes, near waste sites, or along the Columbia River shoreline.

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), C-14, and Sr-90 are contaminants commonly found in groundwater beneath the reactor facilities. A primary objective of the groundwater collection in the 100 Area is to monitor contaminants that may enter the Columbia River. At the 100K Area, groundwater is sampled to evaluate potential changes in radioactivity as spent nuclear fuel, shield water, and sludge are removed from the 100K East Fuel Storage Basin.

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

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

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

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

Riverbank Seeps

Health and the Energy contractor (MSA) split six Columbia River riverbank seep samples. Groundwater enters the Columbia River through riverbank seeps. Split samples are collected from the historically predominant areas for discharge of riverbank seep water to the Columbia River, which include the 100 Area (five split samples), the Old Hanford Town Site (no split samples for this reporting period), and the 300 Area (one split sample).

Surface Water

Health and the Energy contractor (MSA) split nine surface water samples from five different locations. Three samples were collected from the Columbia River upstream of Hanford (two from Priest Rapids Dam and one from Vernita Bridge). Two samples were collected from irrigation canals, one located across the Columbia River at Riverview and the other at the southern boundary of the Hanford Site at the Horn Rapids Yakima River irrigation pumping station. Four samples were collected from the Columbia River (two from the 100 Area, and two from the 300 Area).

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

Drinking Water

Drinking water is supplied to Energy facilities on the Hanford Site by numerous water systems, most of which use water from the Columbia River. One of these systems, in the 400 Area at the Fast Flux Test Facility (FFTF), uses groundwater from the unconfined aquifer beneath the site. One composite drinking water sample from a drinking water storage tank in the 400 Area was split with the Energy contractor (PNNL).

Historically, in addition to the split 400 Area drinking water sample, Health independently collects three drinking water samples, one from the LIGO Facility on the Hanford Site and two from the Edwin Markham elementary school in Pasco; however, Health did not collect these independent samples in 2016.

Note that Figure 3.2.1 does not show the drinking water sample locations.

3.2.3 Monitoring Procedures

Groundwater

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

Riverbank Seeps

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

Surface Water

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

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

Drinking Water

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

3.2.4 Comparison of Health and Energy Contractor Data

Table 3.2.1 summarizes the comparison of Health and Energy data (see Section 2.2). The first columns in the table list the analytes assessed in the laboratory sample analyses and the sample collection period. Then, for each analyte, the table lists the number of split results, the quality of agreement between the Health and Energy results (see Section 2.2.4.1), and the range of concentrations measured by Health. A concentration value prefaced by the “less than” symbol (<) indicates that the value is the detection limit and that some or all Health results are less than this value. Finally, the “Anomalous Data ?” column denotes whether any of the measured Health concentrations for the current year are anomalous compared to historical results (see Section 2.2.5).

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

Analyte	Collection Period	Number of Split Results	Quality of Agreement	Health's Data Range (pCi/l)	Anomalous Data ?
C-14	annual	6	**fair**	< 50 to 25,000	**yes**
Co-60	annual	11	good	< 2 to 11	no
Cs-134	annual	11	good	< 2	no
Cs-137	annual	11	good	< 2 to 840	no
Eu-152	annual	11	good	< 5	no
Eu-154	annual	11	good	< 5	no
Eu-155	annual	11	good	< 8	no
Gross Alpha	annual	21	**fair**	<5 to 51	no
Gross Beta	annual	21	**fair**	< 2 to 24,000	no
H-3	annual	27	good	< 75 to 320,000	no
I-129	annual	4	**fair**	< 1 to 12	no
Pu-238	annual	3	good	< 0.1	no
Pu-239/240	annual	3	good	0.8 to 10	no
Sr-90	annual	19	good	< 1 to 10,000	no
Tc-99	annual	13	good	< 4 to 13,000	no
U-234	annual	11	good	0.16 to 26	no
U-235	annual	11	good	< 0.1 to 1.3	no
U-236[(a)]	annual	0		0.5 to 0.7	no
U-238	annual	11	good	0.17 to 26	no

(a) Energy did not report U-236 results for any samples.

Table 3.2.1 Summary of Water Samples Split with Energy Contractors.

Health and Energy C-14 concentrations in water samples are in fair agreement. Figure 3.2.2 shows all six of the C-14 split data. Because the large range of concentrations in Figure 3.2.2 obscures the results at lower concentrations, the lower concentration data are shown in Figure 3.2.3. Four of the results are in good agreement, in that the Health and Energy error bars overlap; however, two of the results are in significant disagreement. Historically, C-14 results for water samples have been in poor agreement.

The C-14 result reported by both Health and Energy at 199-K-106A is anomalously high compared to historical data at that well. Health's historical data are shown in Figure 3.2.4.

Health and Energy Co-60 concentrations in water samples are in good agreement, and all but one result are below the detection limit. Cobalt-60 is not typically detected in water samples. However, since 2013, both Health and Energy have detected Co-60 at groundwater well 299-E28-24 within Hanford's 200 Area. Health and Energy have split a sample at this well since 2011 (Health's historical results are shown in Figure 3.2.5), and in the first two years, Co-60 was not detected.

Health and Energy concentrations for the gamma emitting radionuclides Cs-134, Cs-137, Eu-152, Eu-154, and Eu-155 are all in good agreement, and most concentrations are below detection limits. Both Health and Energy commonly detect Cs-137 from groundwater wells within Hanford's 200 Area, with concentrations ranging up to 1,000 pCi/L. Figure 3.2.6

shows the split Cs-137 results. The three wells from the 200 Area (those whose names start with 299) have detectable concentrations of Cs-137 ranging up to 840 pCi/L.

Health and Energy gross alpha concentrations in water samples are in fair agreement. Figure 3.2.7 shows the split gross alpha concentrations. The graph shows that Health often reports slightly higher concentrations than Energy, and this trend in the 2016 data is consistent with historical split gross alpha results.

Health and Energy gross beta concentrations in water samples are in fair agreement. Because of the large range in concentration values, the higher and lower concentration data are shown separately in Figures 3.2.8 and 3.2.9, respectively. In many cases, the Health and Energy data are in good agreement, but in other cases Health reports higher concentrations than Energy, and this trend is consistent with historical split gross beta results.

Health and Energy H-3 (tritium) concentrations in water samples are in good agreement. All sample results are in good agreement for concentrations ranging from below the detection limit of 75 pCi/L up to 320,000 pCi/L. Figure 3.2.10 shows the H-3 split results for concentrations less than 50,000 pCi/L (if all the data were shown, the large range of concentrations would obscure most of the data). The split H-3 data are historically in good agreement.

Health and Energy I-129 concentrations in water samples are in fair agreement. The data are shown in Figure 3.2.11, where it can be seen that the split results are similar but there are significant discrepancies, consistent with historical split results.

Health and Energy Pu-238, Pu-239/240, Sr-90, Tc-99, U-234, U-235, and U-238 concentrations in water samples are all in good agreement. The Pu-238 concentrations are all below the detection limit. The Pu-239/240, Sr-90, Tc-99, and U-238 results are shown in Figures 3.2.12 – 3.2.17.

Health reported U-236 in one riverbank seep sample and two groundwater samples. Energy did not report U-236 for any split water samples. Protocol calls for reporting U-236 anytime it is detected. Health's U-236 results are discussed in Section 3.2.5.

3.2.5 Other Discussion

Isotopic uranium results are typically reported for U-234, U-235, and U-238. These isotopes occur in nature as well as in Hanford byproducts. Uranium-236 is an isotope that does not occur in nature, but rather is a byproduct of reactor operations. Detection of U-236 indicates a Hanford contaminant, rather than naturally occurring radioactivity. Uranium-236 is occasionally detected in Columbia River sediments and in groundwater or river water samples.

Health reported U-236 from one riverbank seep sample adjacent to the 300 Area and from two groundwater wells in the 200 Area, with concentrations ranging from 0.3 to 0.5 pCi/L.

Both Health and Energy analyzed a drinking water sample from the 400 Area Drinking Water Tank. Both agencies detected tritium (H-3) at approximately 1,000 pCi/L and did not detect Sr-90. The U.S. Environmental Protection Agency's drinking water standards are 15 pCi/L for gross alpha; 50 pCi/L for gross beta; 20,000 pCi/L for H-3; 8 pCi/L for Sr-90; and 21 pCi/L for total uranium.

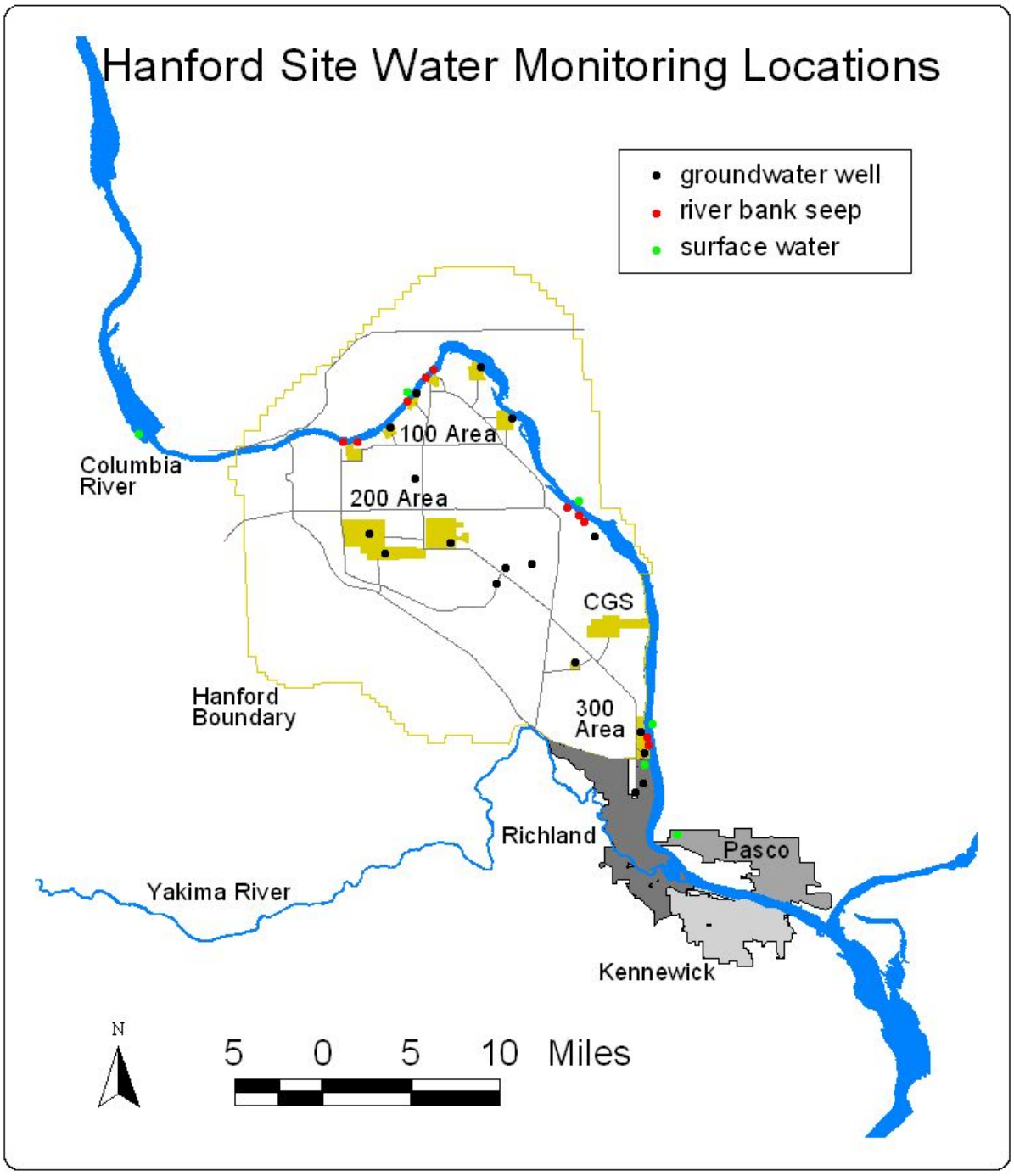

Figure 3.2.1 Historical Locations for Split Water Samples

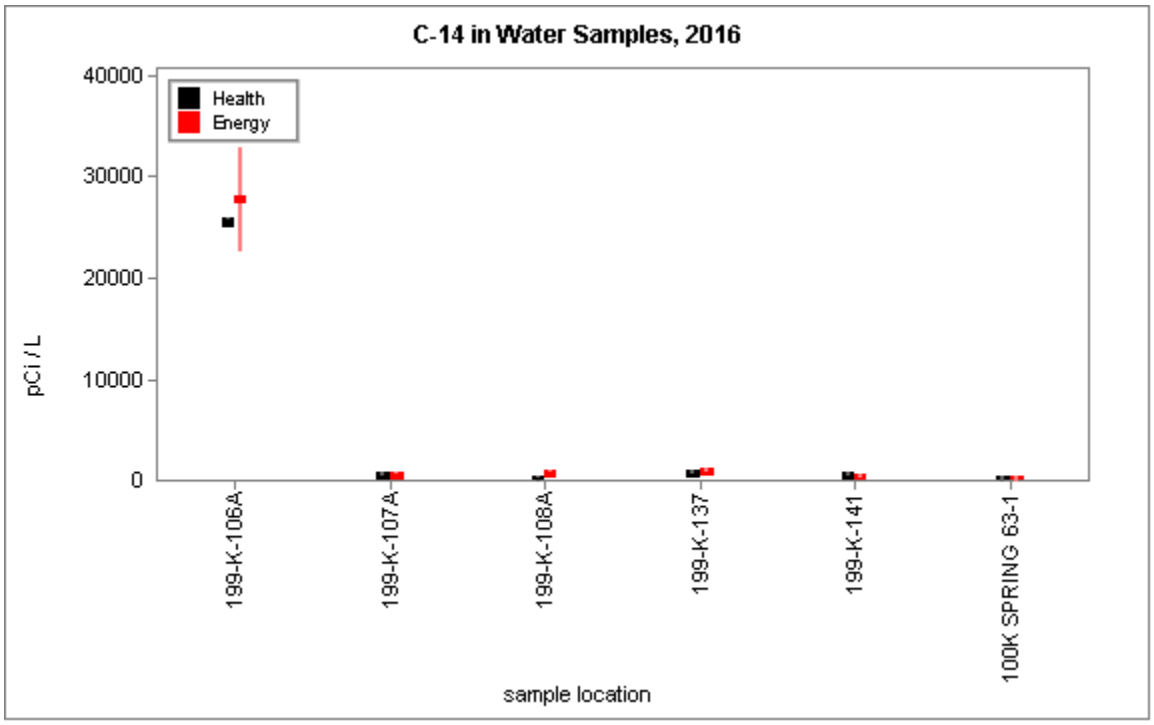

Figure 3.2.2 Health and Energy C-14 Concentrations in Water Samples

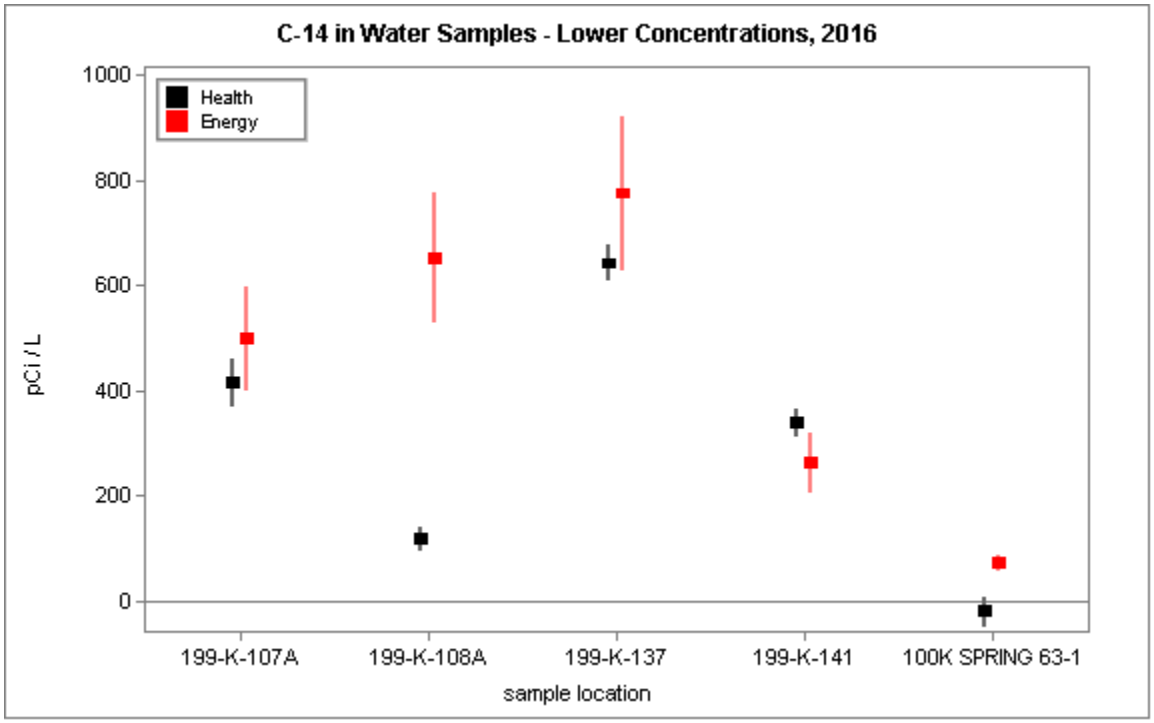

Figure 3.2.3 Health and Energy Low Concentration C-14 Results in Water Samples

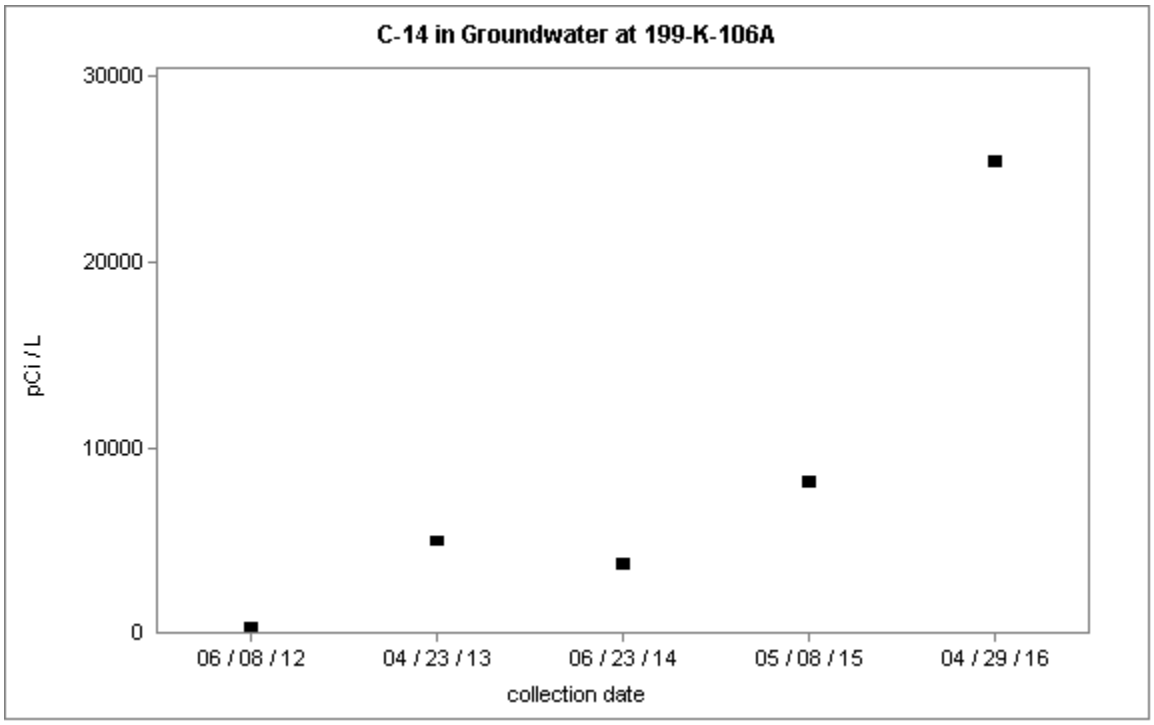

Figure 3.2.4 Historical C-14 Concentrations at Groundwater Well 199-K-106A

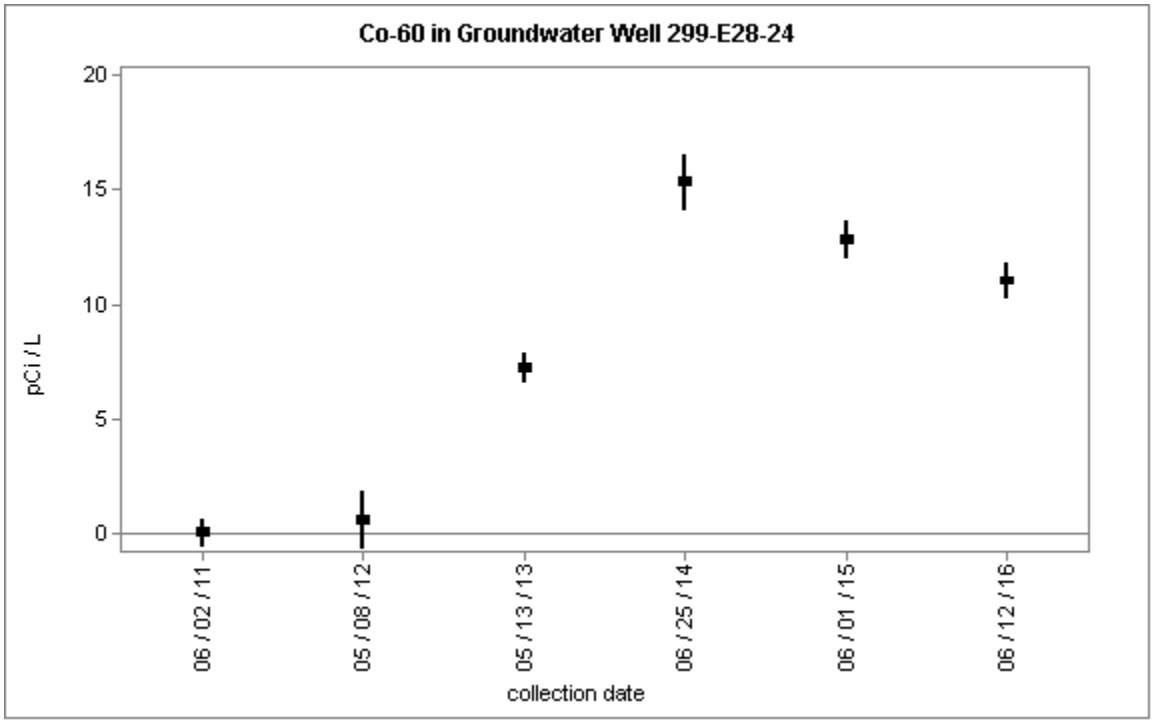

Figure 3.2.5 Historical Co-60 Concentrations at Groundwater Well 299-E28-24

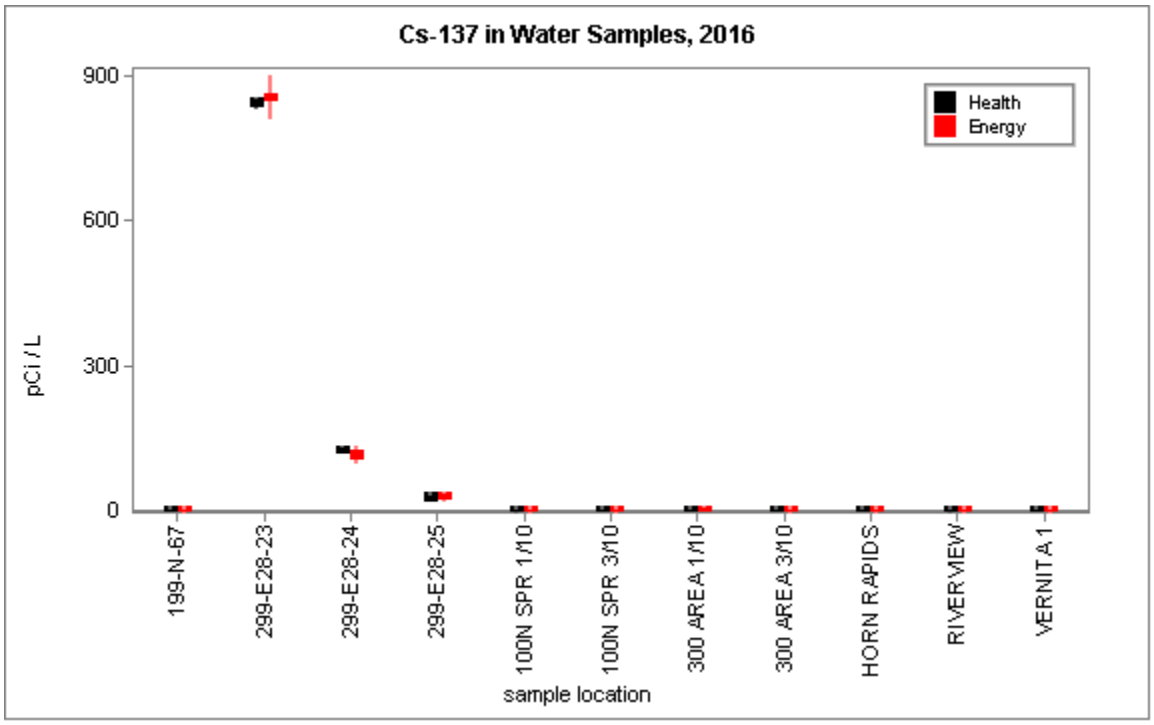

Figure 3.2.6 Health and Energy Cs-137 Concentrations in Water Samples

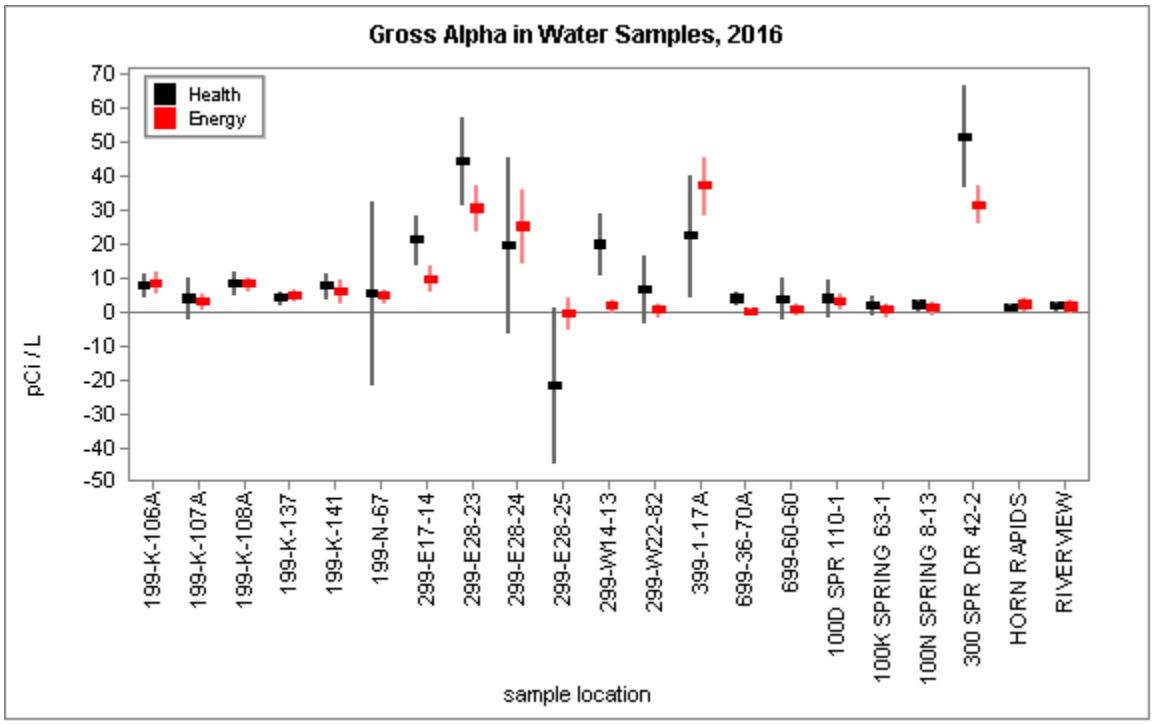

Figure 3.2.7 Health and Energy Gross Alpha Concentrations in Water Samples

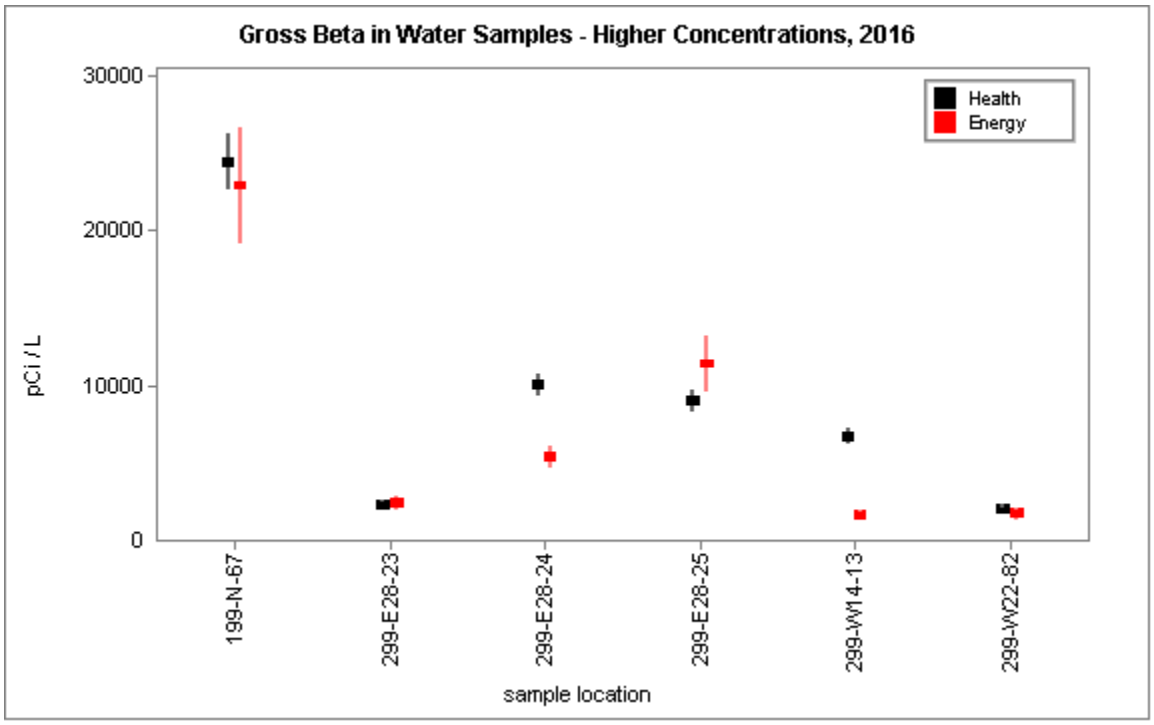

Figure 3.2.8 Health and Energy High Concentration Gross Beta Results in Water

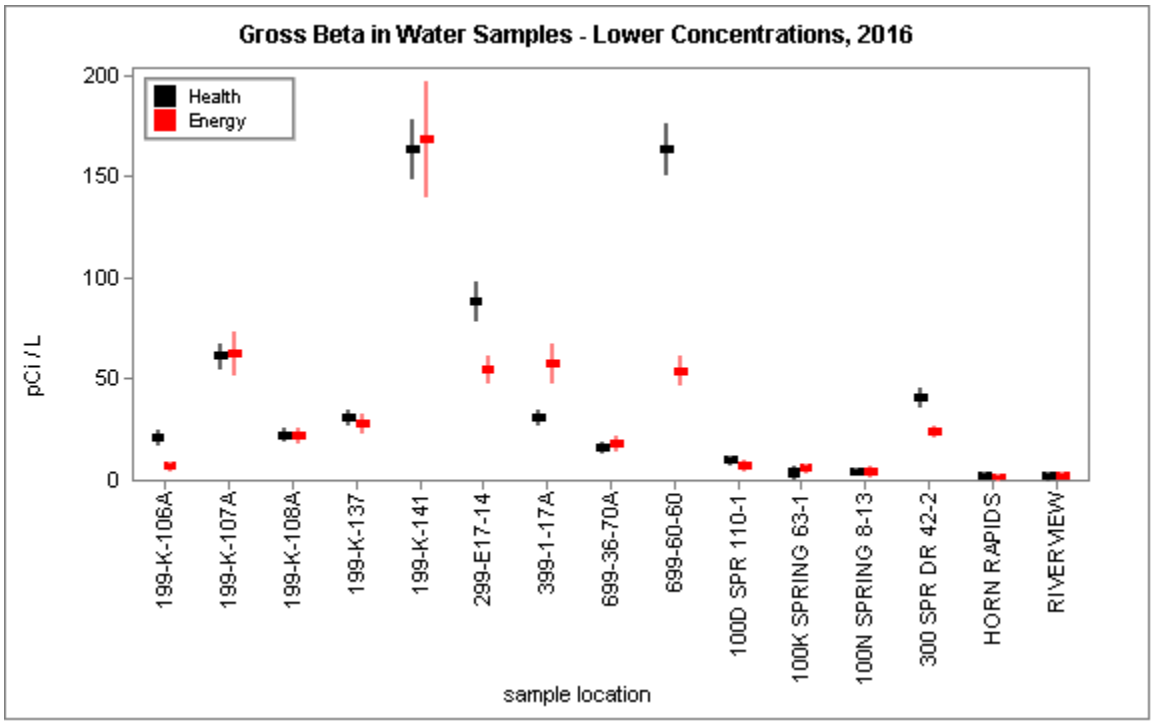

Figure 3.2.9 Health and Energy Low Concentration Gross Beta Results in Water

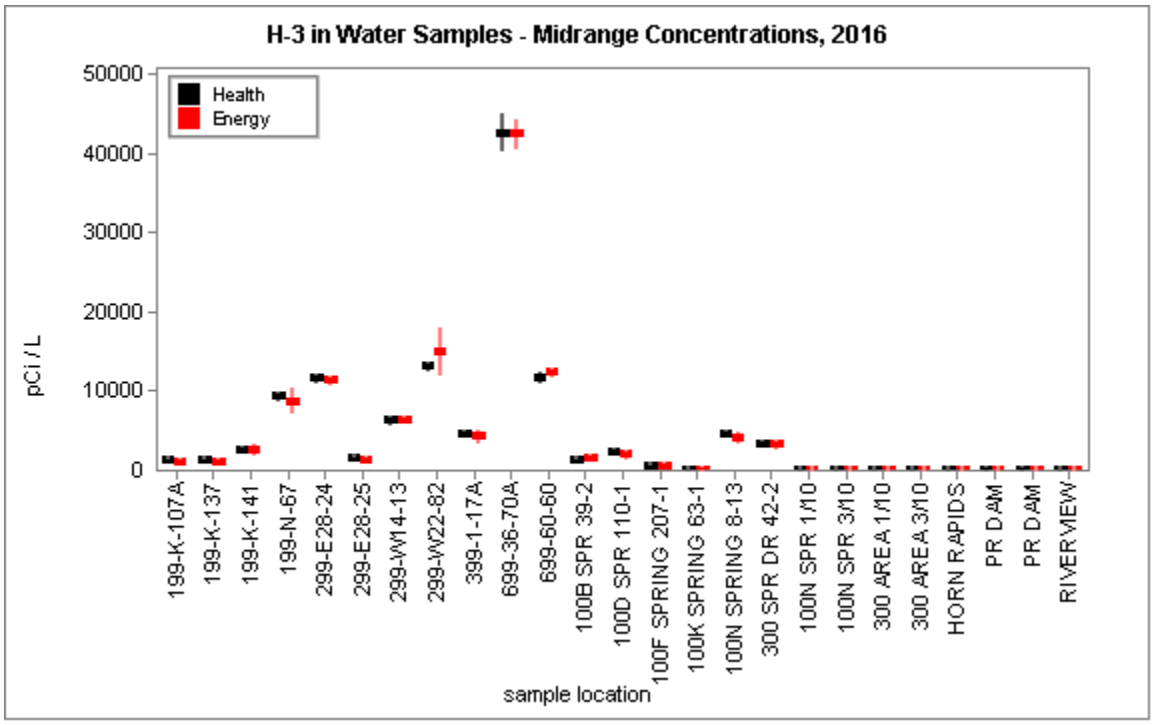

Figure 3.2.10 Health and Energy Mid Concentration H-3 Results in Water

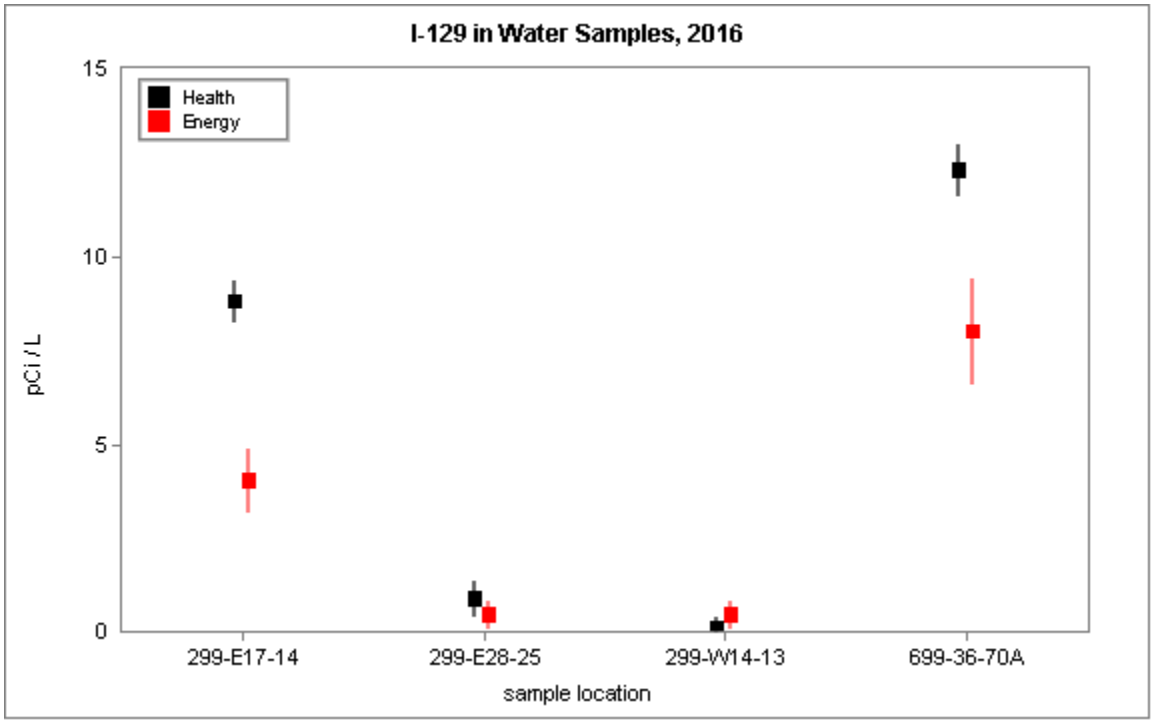

Figure 3.2.11 Health and Energy I-129 Concentrations in Water Samples

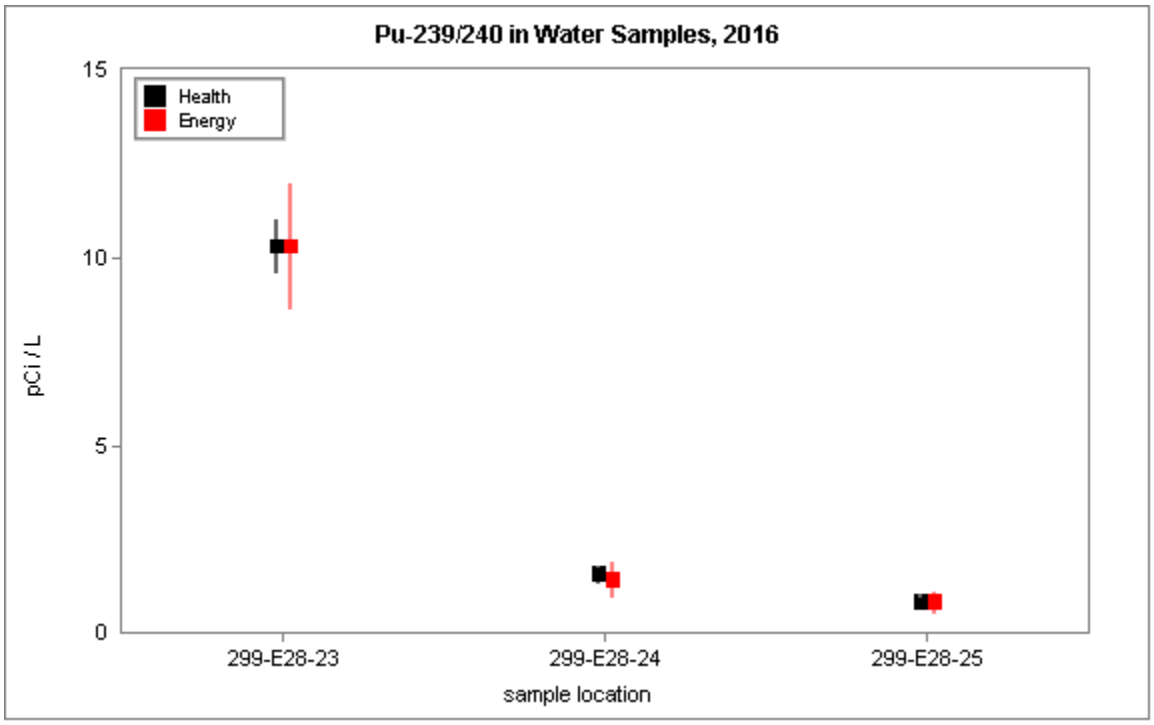

Figure 3.2.12 Health and Energy Pu-239/240 Concentrations in Water Samples

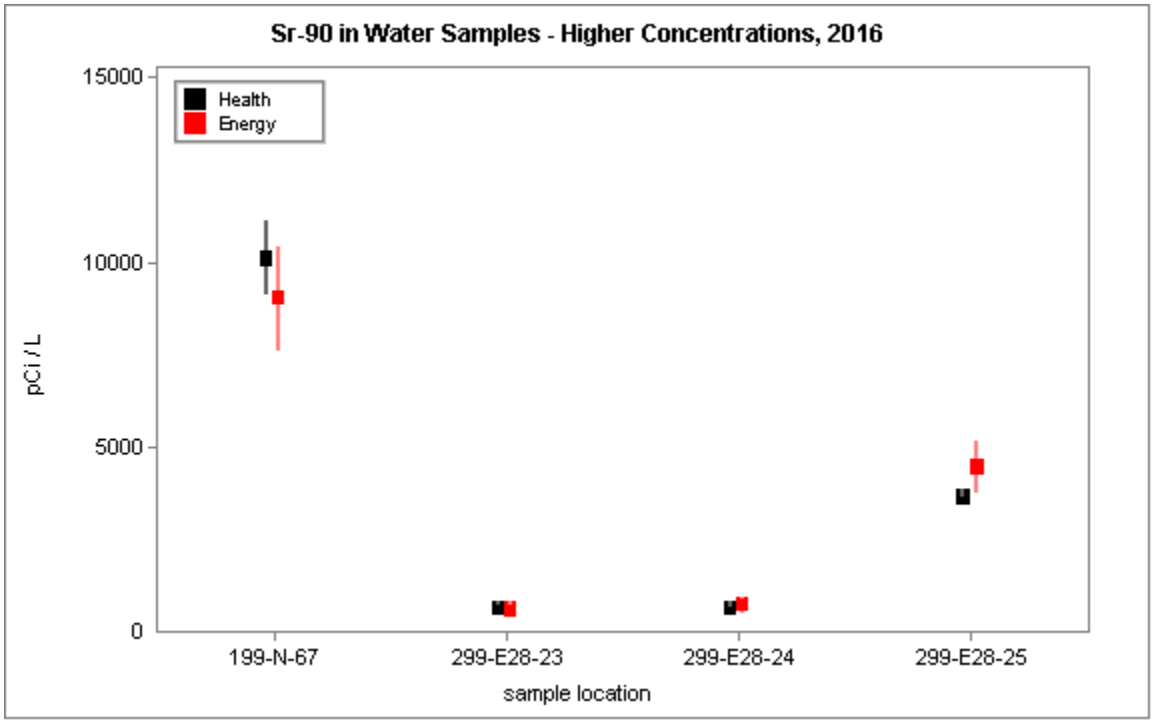

Figure 3.2.13 Health and Energy High Concentration Sr-90 Results in Water Samples

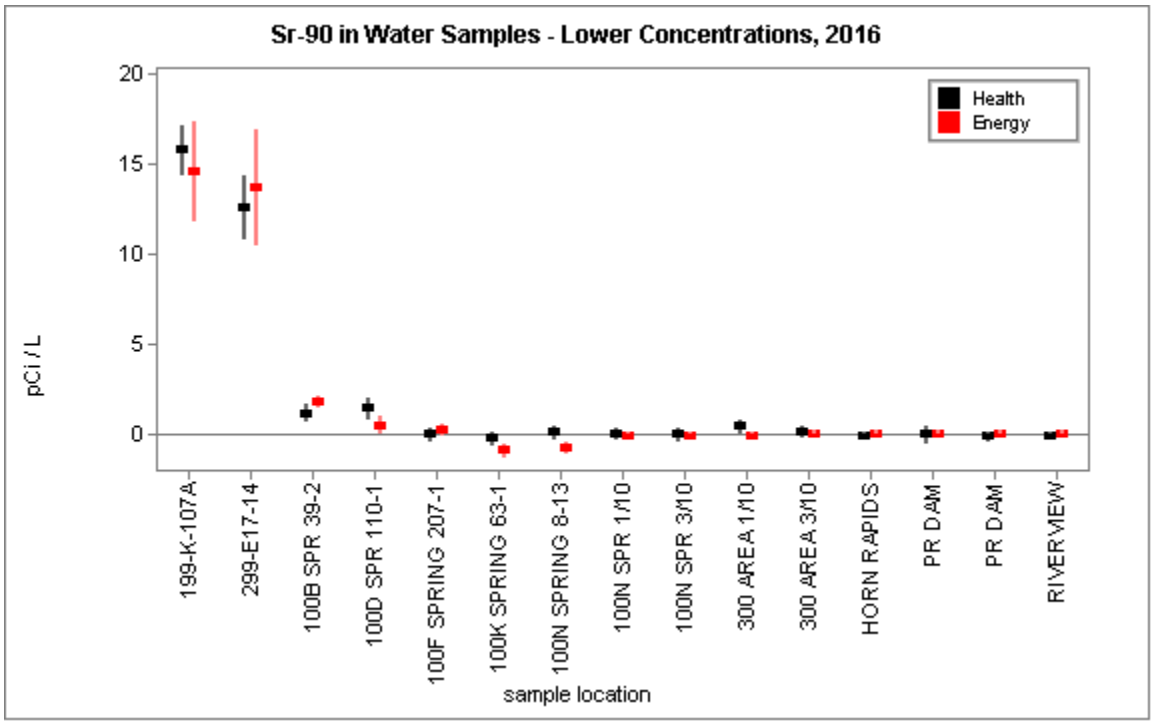

Figure 3.2.14 Health and Energy Low Concentration Sr-90 Results in Water Samples

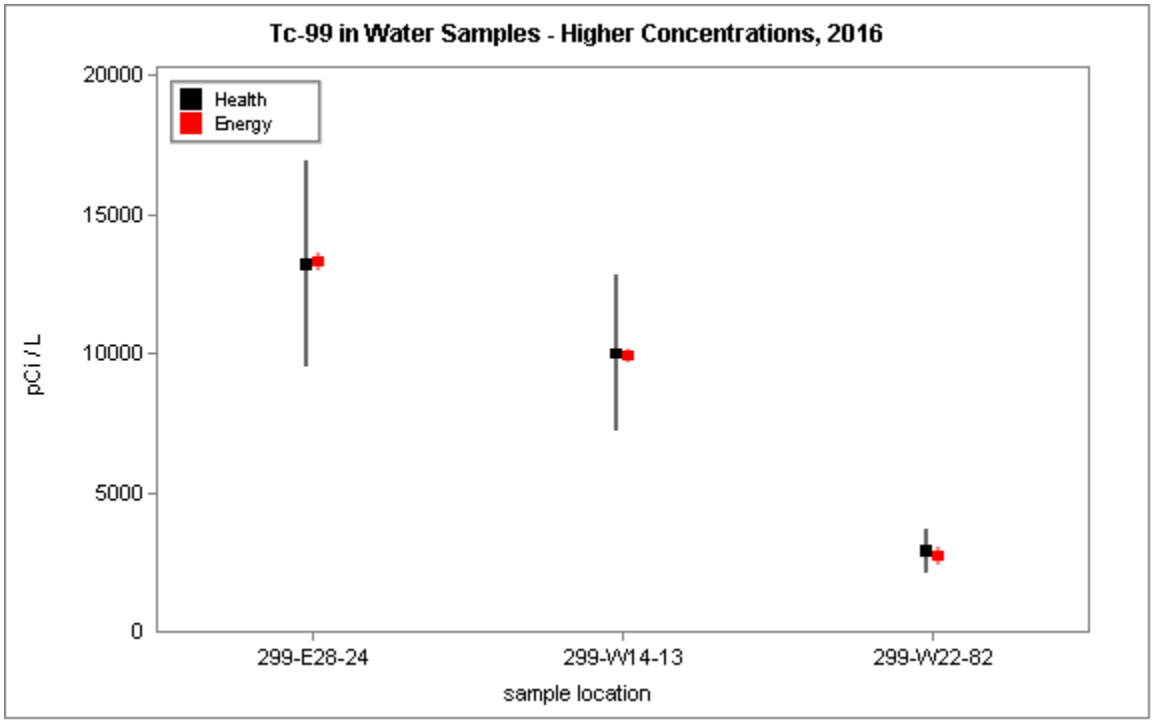

Figure 3.2.15 Health and Energy High Concentration Tc-99 Results in Water Samples

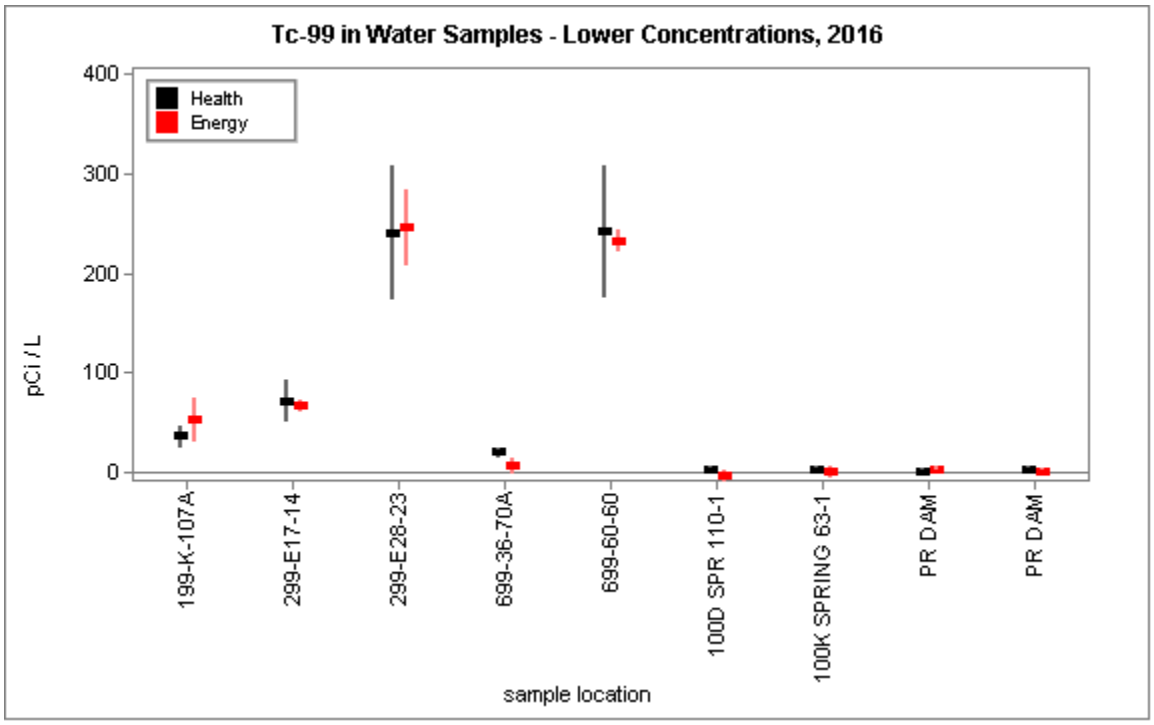

Figure 3.2.16 Health and Energy Low Concentration Tc-99 Results in Water Samples

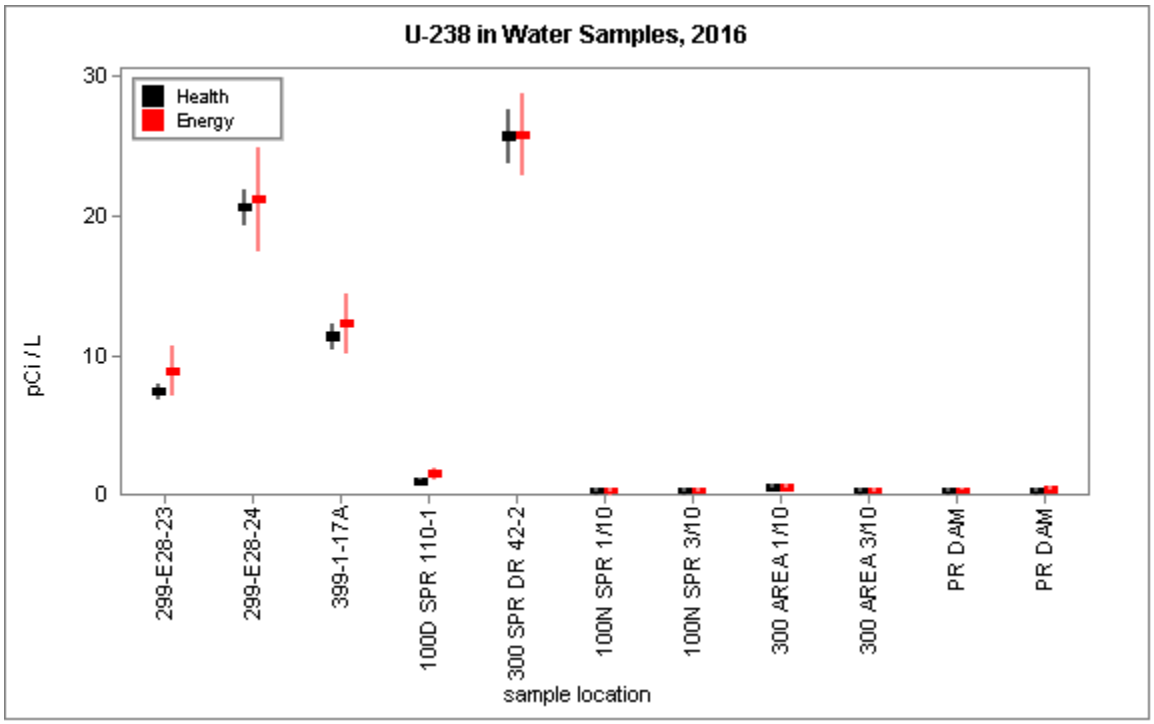

Figure 3.2.17 Health and Energy U-238 Concentrations in Water Samples

3.3 External Radiation Monitoring

Major Findings:

- Health and Energy external radiation exposure rates are in good agreement.
- Exposure rates on the Hanford Site are consistent with historical results, and are similar to rates at locations along the Hanford perimeter and offsite locations.
- Exposure rates along the Columbia River are consistent with background.

3.3.1 Purpose and General Discussion

It is possible to receive radiation exposure from a radioactive source outside the body at a distance. External radiation is the name of radiation emitted from a source external to the human body or other living organisms. This radiation travels through space and may interact with a living organism, resulting in radiation exposure.

Sources of background external radiation include natural cosmic and terrestrial radiation, as well as fallout from historical atmospheric testing of nuclear weapons. Contamination from the Hanford Site may contribute to man-made sources of external radiation. In addition to oversight of Energy's monitoring program, Health compares on-site and off-site radiation rates to determine if Hanford impacts workers or the public.

External radiation levels can vary by up to 25 percent over the course of a year at any one location. This variation is primarily due to changes in soil moisture and snow cover, both of which affect shielding of natural radiation from the earth's crust.

Health has historically maintained external radiation monitoring sites collocated with Energy. In 2006, Energy terminated its Site-Wide and Offsite external radiation monitoring program. In response, Health added 26 new monitoring sites along the Columbia River to independently monitor locations that were previously monitored by Energy. In addition, Health will continue to maintain its original monitoring sites that were collocated with Energy. Therefore, from 2006 forward, this report will cover the sites collocated with Energy's Near-Facilities and Operations program, as well as the sites operated independently by Health.

3.3.2 Sample Types and Monitoring Locations

Historically, Health has used thermoluminescent dosimeters (TLDs) to measure external radiation. Starting in 2012, Health switched to using optically stimulated luminescence dosimeters (OSLs), while Energy continues to use TLDs. Both OSLs and TLDs, referred to as dosimeters, measure the time-integrated exposure to external radiation at their location.

Health operates 60 external radiation monitoring locations that are relevant to the Hanford Site. Health's Hanford Environmental Radiation Oversight Program operates 51 of these sites, in which dosimeters from five sites are collocated with Energy's Near-Facilities and Operations program currently run by Mission Support Alliance (MSA), and 46 sites are independently monitored by Health. The remaining nine sites are part of Health's Columbia Generating Station Oversight Program, and they are included in this report because the sites are located along the Hanford perimeter.

Figure 3.3.1 shows most of Health's external radiation monitoring locations. Twenty of the sites are near Hanford facilities with known, suspected, or potential radiation sources. Three sites (Yakima and Wye Barricades, and LIGO Facility) are located on the Hanford Site, but away from radiation sources. Twenty-five sites are along the Columbia River shoreline from the Vernita Bridge to downstream of Bateman Island at the mouth of the Yakima River. Nine sites are located around the Hanford Site perimeter. The remaining three sites (Othello, Yakima Airport, and Benton County Shops) are significantly distant from the Hanford Site. Many of these dosimeter sites are collocated with the air monitoring sites discussed in Section 3.1.

3.3.3 Monitoring Procedures

Most collocated dosimeters are deployed on a quarterly basis at each monitoring location, with the dosimeters retrieved at the end of each calendar quarter. Columbia River dosimeters are deployed semi-annually. Starting in 2012, Health sends its dosimeters to a contracted laboratory (Landauer); while prior to 2012, Health sent its dosimeters to Health's Public Health Laboratory. In both cases, the time-integrated external radiation exposure is determined for the deployment period. The results are converted to an average daily radiation rate reported in units of milliroentgen per day (mR/day). At the same time the dosimeters are retrieved, new dosimeters are placed at each site.

3.3.4 Comparison of Health and Energy Contractor Data

Table 3.3.1 summarizes the comparison of Health and Energy data (see Section 2.2). The first columns in the table list the analyte assessed in the laboratory sample analysis and the sample collection period. Then the table lists the number of collocated results, the quality of agreement between the Health and Energy results (see Section 2.2.4.1), and the range of concentrations measured by Health. Finally, the "Anomalous Data ?" column denotes whether any of the measured Health concentrations for the current year are anomalous compared to historical results (see Section 2.2.5).

Analyte	Collection Period	Number of Results	Quality of Agreement	Health's Data Range (mR/day)	Anomalous Data ?
External Rad	quarterly	20	good	0.17 to 0.27	no

Table 3.3.1 Summary of External Radiation Collocated Dosimeters

Historically, the agreement between Health and Energy external radiation rates has been fair. The Energy contractors have systematically reported slightly higher exposure rates (approximately 10 percent averaged over all data) than Health.

For 2016, however, the Health and Energy quarterly collocated external radiation rate data are in good agreement. Figure 3.3.2 shows the collocated data for dosimeters collected in 2016. At each location, the graph first shows the fourth quarter data from 2015, followed by the first, second, and third quarter data for 2016. The prior year's fourth quarter results are included because the collection date for these dosimeters was in early January of 2016.

Figure 3.3.3 shows the scatter plot for the Health/Energy collocated external radiation rate data. All of the data are closely scattered about the line where Health and Energy results are theoretically equal, indicating good agreement.

3.3.5 Other Discussion

In addition to the five sites collocated with the Energy contractor discussed above, Health independently monitors 46 sites, and monitors nine sites collocated with the Columbia Generating Station that are associated with the Hanford Site. Table 3.3.2 summarizes the data from these additional 55 sites.

The table lists the analyte, the collection period, and the number of samples. The table also lists the range of external radiation rates measured by Health. Finally, the "Anomalous Data ?" column denotes whether any of the Health exposure rates for the current year are anomalous compared to historical results (see Section 2.2.5). The exposure rates reported by Health are consistent with historical results, and Health did not encounter anomalous data.

Analyte	Collection Period	Number of Results	Health's Data Range (mR/day)	Anomalous Data ?
External Rad	Quarterly / Semiannual	147	0.16 to 0.39	no

Table 3.3.2 Summary of Independent Department of Health External Radiation Dosimeters

Health categorizes its external radiation monitoring sites by their location type, as described in Section 3.3.2. Figure 3.3.4 shows the average, minimum, and maximum radiation rates for all of the sites in each location category. This graph includes data from the 55 sites discussed in this section and the five sites collocated with Energy discussed in Section 3.3.4 (all 60 Health sites). As can be seen, the average radiation rates are similar for all location categories, except for the distant sites where the average is lower. The maximum radiation rates are slightly higher for the sites that are onsite and near to contaminated or operational facilities, or along the Hanford perimeter.

The average radiation rates are slightly lower at sites distant from Hanford, most likely because these sites are located in areas covered by concrete, which has a greater shielding factor than the soil cover for most other sites.

Historically, external radiation rates were elevated compared to background at site 100N Spring, which is within Hanford's 100N Area. The exposure rate at this site has steadily been decreasing with time, due to the natural decay of Co-60 surface contamination. With the recent cleanup of contaminated surface soil, exposure rates over the past several years now are constant, and are consistent with exposure rates from locations away from contaminated areas. Historical radiation rates at 100N Spring are shown in Figure 3.3.5.

External radiation rates were elevated compared to background at the 100K East Basin from 2005 through 2011. This site is near a fuel storage basin within Hanford's 100K East Area. Radioactive material had been temporarily stored outside of the facility, resulting in increased radiation rates. In addition, cleanup activities during that time resulted in temporary increased radiation rates. The storage area was properly posted and access restricted. Since 2011, radiation rates have returned to pre-2005 values. Measurements along the Columbia River at the 100K Area (site location 100K Boat Ramp), the closest public access point, did not indicate elevated exposure rates. Historical radiation rates at 100K East Basin are shown in Figure 3.3.6.

Figures 3.3.5 and 3.3.6 show a slight increase in radiation rates going from the year 2011 to 2012, and then a slight decrease going from 2012 to 2013. As discussed in Sections 3.3.2 and 3.3.3, in the year 2012 Health switched dosimeter types from TLD to OSL and switched the dosimeter analysis laboratory from Health's Public Health Laboratory to the outside contract laboratory Landauer. Health observed a slight increase in radiation rates at all of their monitoring locations in 2012.

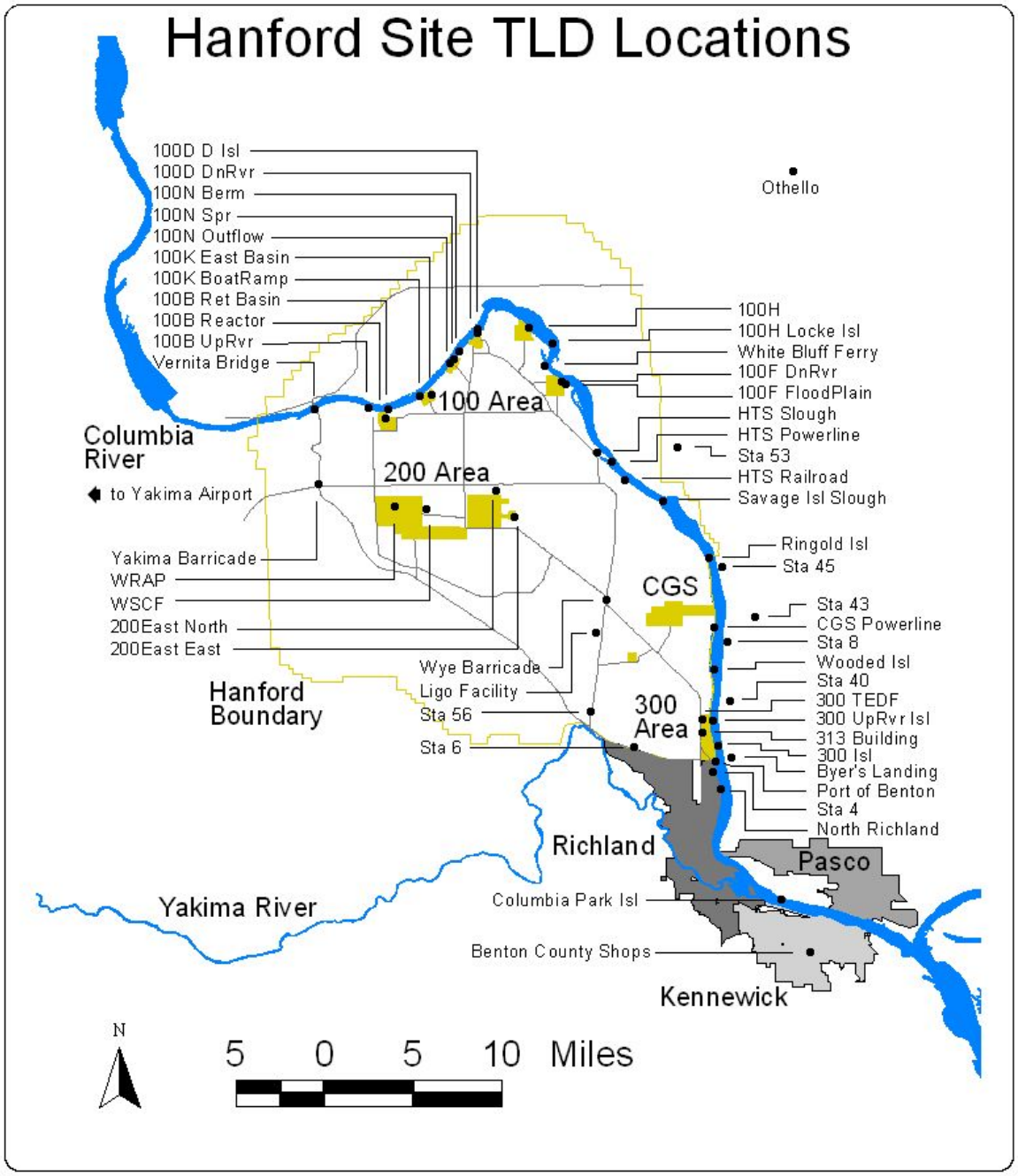

Figure 3.3.1 DOH External Radiation Monitoring (TLD) Locations

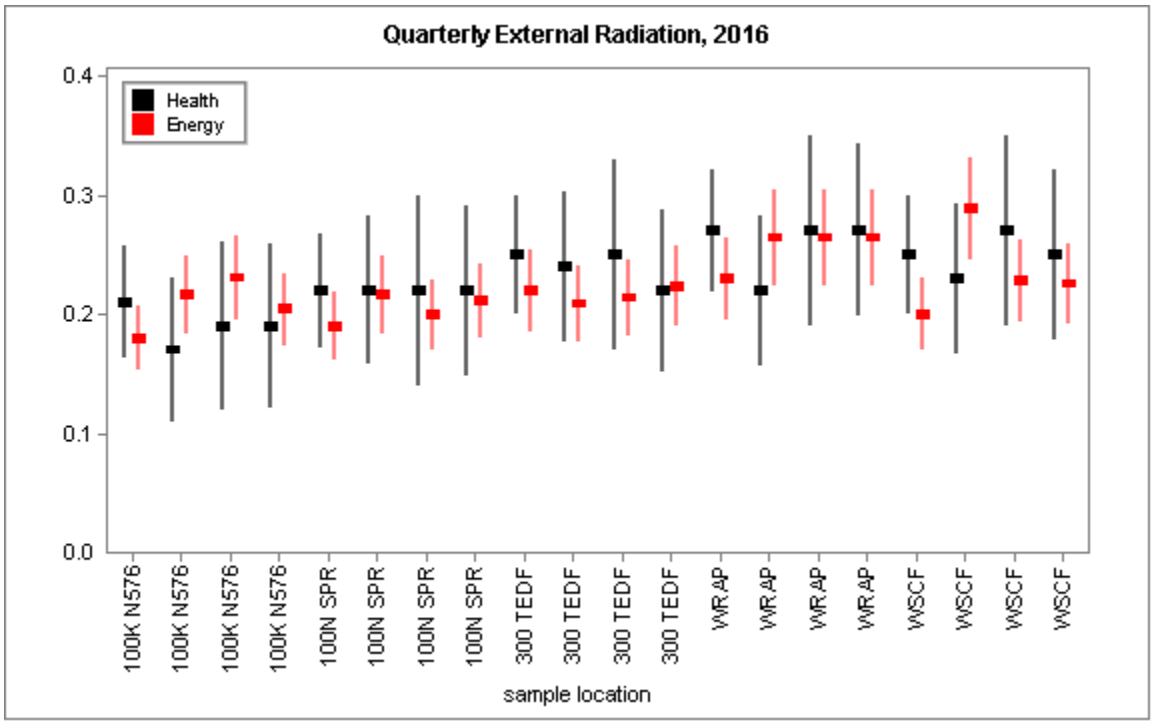

Figure 3.3.2 Health and Energy Quarterly External Radiation

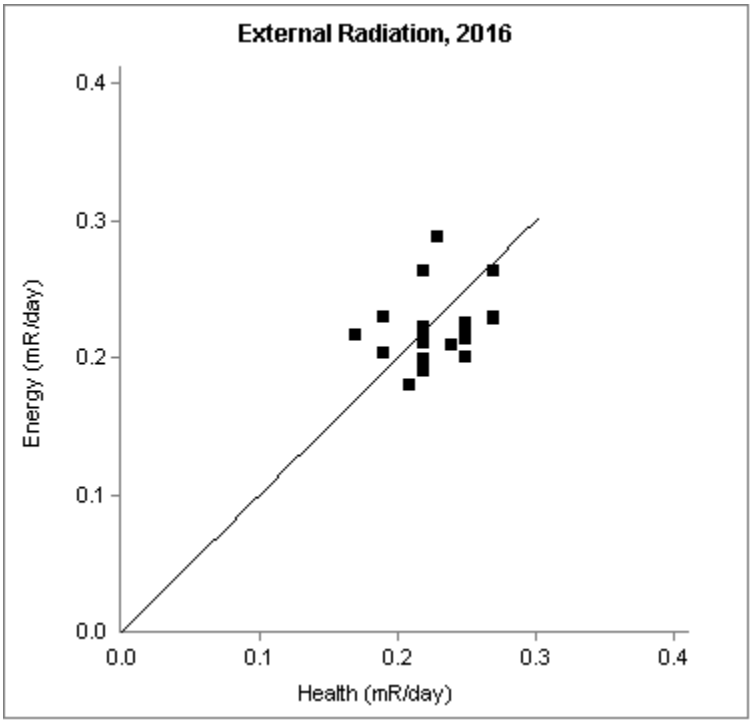

Figure 3.3.3 Health and Energy Scatter Plot for Quarterly External Radiation

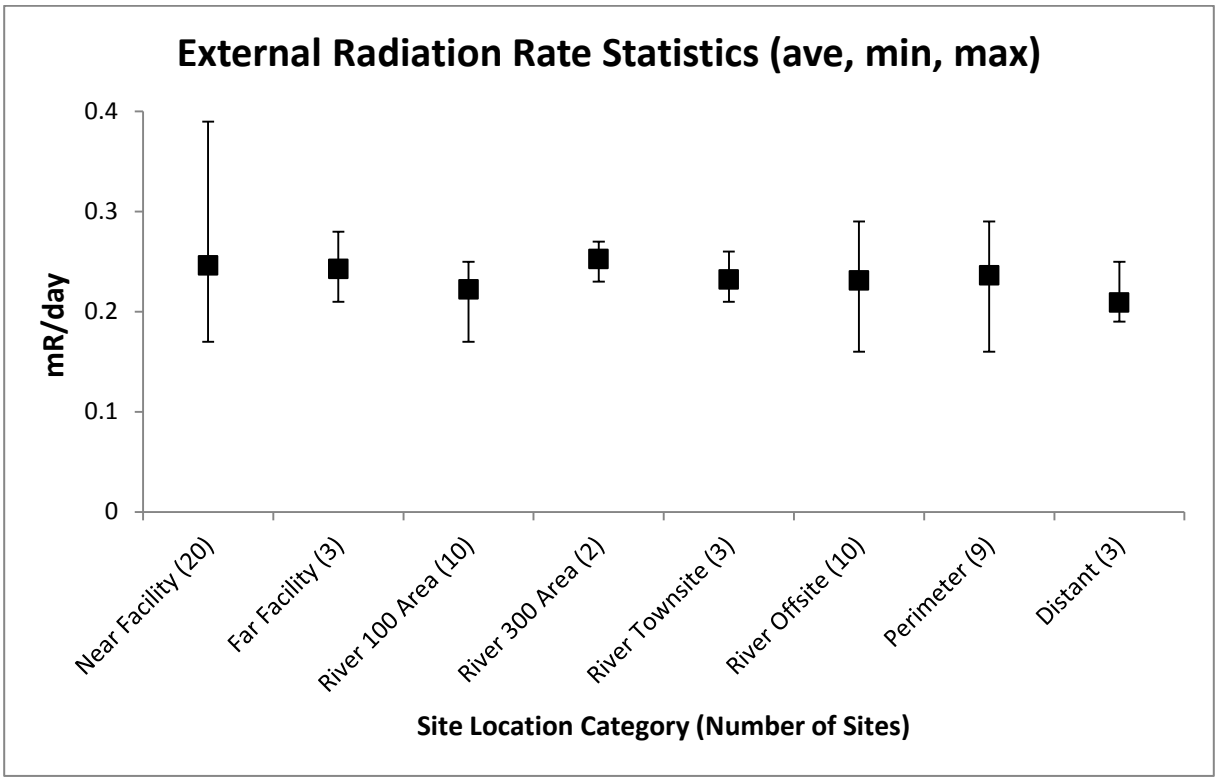

Figure 3.3.4 External Radiation Rate Statistics by Location Type

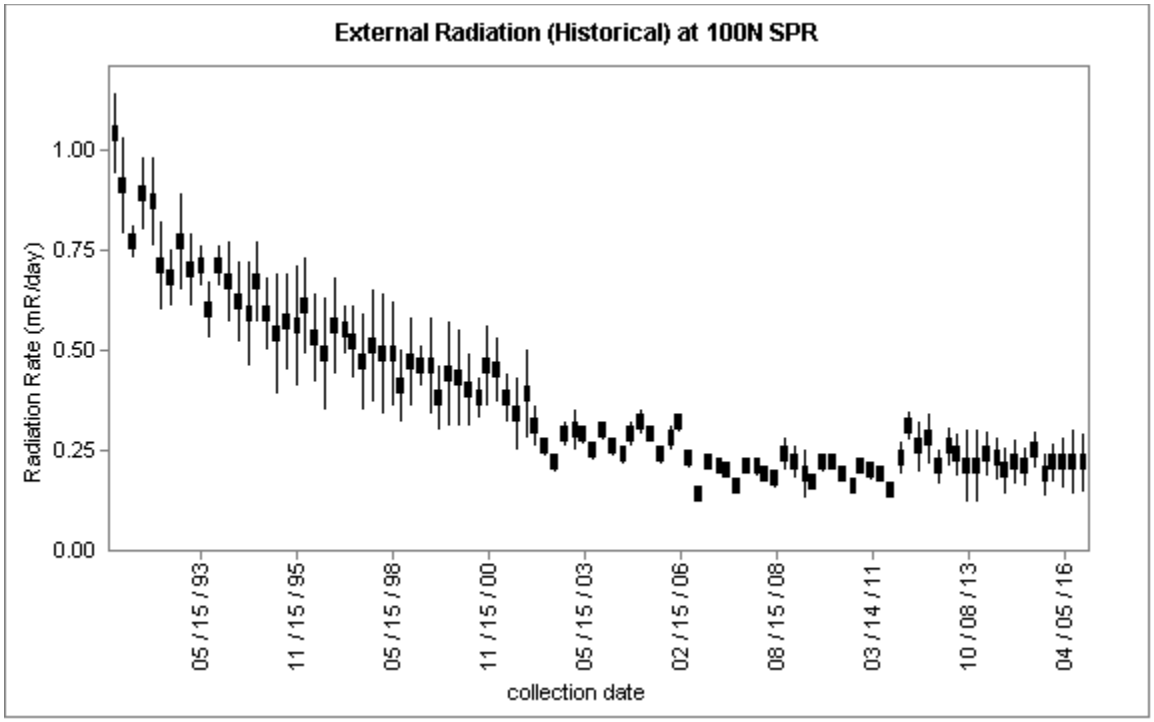

Figure 3.3.5 Historical External Radiation Rates at 100N Spring

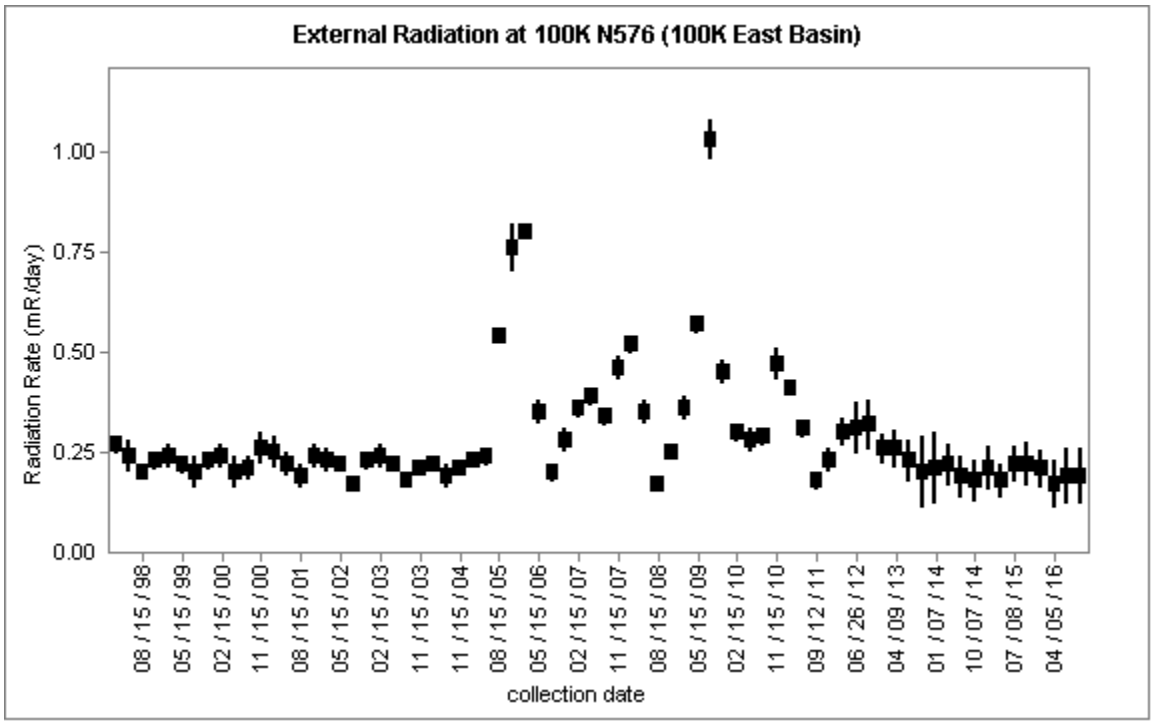

Figure 3.3.6 Historical External Radiation Rates at 100K East Basin

3.4 Soil and Sediment Monitoring

Major Findings:

- Health and Energy soil and sediment data are in fair agreement for Cs-137, Sr-90, U-234, and U238; and are in good agreement for all other radionuclides.
- Most radionuclide concentrations either are below detection limits or are consistent with historical values.

3.4.1 Purpose and General Discussion

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

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

3.4.2 Sample Types and Monitoring Locations

Health and Energy (contractor MSA) split eight sediment samples from the Columbia River. Two sediment samples were collected upriver from Hanford at Priest Rapids Dam, two from the 100 Area, one from the 300 Area, one from the Hanford Site perimeter at the White Bluff Slough, and two downriver from Hanford at McNary Dam. Figure 3.4.1 shows historical sediment sample locations.

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

Health and Energy split six soil samples from locations on the Hanford Site, one sample each from the 100N, 200 East, 200 West, 300, and 600 Areas, and one from the Environmental Restoration Disposal Facility.

3.4.3 Monitoring Procedures

Soil samples are collected by compositing four one-square foot areas, each excavated to a depth of one inch. The composited samples are split, and then dried prior to radiochemical analysis. Samples are analyzed for radionuclides that are most likely present in the area sampled, which at Hanford typically include gamma emitting radionuclides, Sr-90, isotopic uranium, and isotopic plutonium.

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

Radiochemical analysis methods for soil and sediment are identical. Soil and sediment concentrations are reported in units of pCi/g dry weight.

3.4.4 Comparison of Health and Energy Contractor Data

Table 3.4.1 summarizes the comparison of Health and Energy data (see Section 2.2). The first columns in the table list the analytes assessed in the laboratory sample analyses and the sample collection period. Then, for each analyte, the table lists the number of split results, the quality of agreement between the Health and Energy results (see Section 2.2.4.1), and the range of concentrations measured by Health. A concentration value prefaced by the “less than” symbol (<) indicates that the value is the detection limit and that some or all Health results are less than this value. Finally, the “Anomalous Data ?” column denotes whether any of the measured Health concentrations for the current year are anomalous compared to historical results (see Section 2.2.5).

Analyte	Collection Period	Number of Split Results	Quality of Agreement	Health's Data Range (pCi/g)	Anomalous Data ?
C-14	annual	1	good	0.9	no
Co-60	annual	11	good	< 0.02	no
Cs-134	annual	11	good	< 0.08	no
Cs-137	annual	11	**fair**	< 0.1 to 5.6	no
Eu-152	annual	11	good	< 0.05	no
Eu-154	annual	11	good	< 0.05	no
Eu-155	annual	11	good	< 0.08	no
Pu-238	annual	14	good	< 0.04	no
Pu-239/240	annual	14	good	< 0.02 to 0.024	no
Sr-90	annual	14	**fair**	< 0.005 to 0.22	no
U-234	annual	14	**fair**	0.6 to 1.7	no
U-235	annual	14	good	< 0.03 to 0.09	no
U-238	annual	14	**fair**	0.7 to 1.4	no

Table 3.4.1 Summary of Sediment Samples

Most of the Health and Energy soil and sediment data are in good agreement, with concentrations either below detection limits or consistent with historical values.

Figures 3.4.2 and 3.4.3 show the Health and Energy split results for Cs-137. The one sample where both Health and Energy report a result greater than 1 pCi/g (soil sample from 200 East Area) is not in good agreement, while all data below 1 pCi/g are in good agreement.

The one sample where both Health and Energy report a Sr-90 result greater than 0.1 pCi/g is not in good agreement (Health reports 0.22 pCi/g while Energy reports 0.034 pCi/g, from a soil sample in the 200 East Area), while all data below 0.1 pCi/g are in good agreement.

The Health and Energy U-235 results are in good agreement with most concentrations below the detection limit. However, the U-234 and U-238 results are only in fair agreement. Figure 3.4.4 shows the U-234 data; while Figure 3.4.5 shows the scatter plot of the same data (the U-238 data are similar). Regression analysis in the scatter plot indicates that on average, Energy's results are approximately 0.2 pCi/g less than Health's. This difference is small, but it does indicate a systematic difference in which Energy reports concentrations slightly less than Health.

3.4.5 Other Discussion

Radionuclides consistently identified by Health in soil and sediment samples include Cs-137, Pu-239/240, U-234, U-235, and U-238. Other radionuclides identified in some soil or sediment samples include C-14, Eu-152 and Sr-90. The range of detected results reported in Table 3.4.1 is consistent with expected results.

Cesium-137, Sr-90, Eu-152, and plutonium isotopes exist in worldwide fallout because of nuclear weapons testing and these radionuclides were also produced from past Hanford

operations. Uranium isotopes occur naturally in the environment and may be present in Hanford Site effluent. All of these isotopes may transport through the environment into sediment.

Typically, radionuclide concentrations in sediment at locations downriver from Hanford are not significantly different from those at the upstream background location at Priest Rapids Dam. For example, as can be seen in Figures 3.4.2 and 3.4.3, the Cs-137 and U-234 concentrations at McNary Dam (downriver location) are similar to the concentrations at Priest Rapids Dam (upriver location).

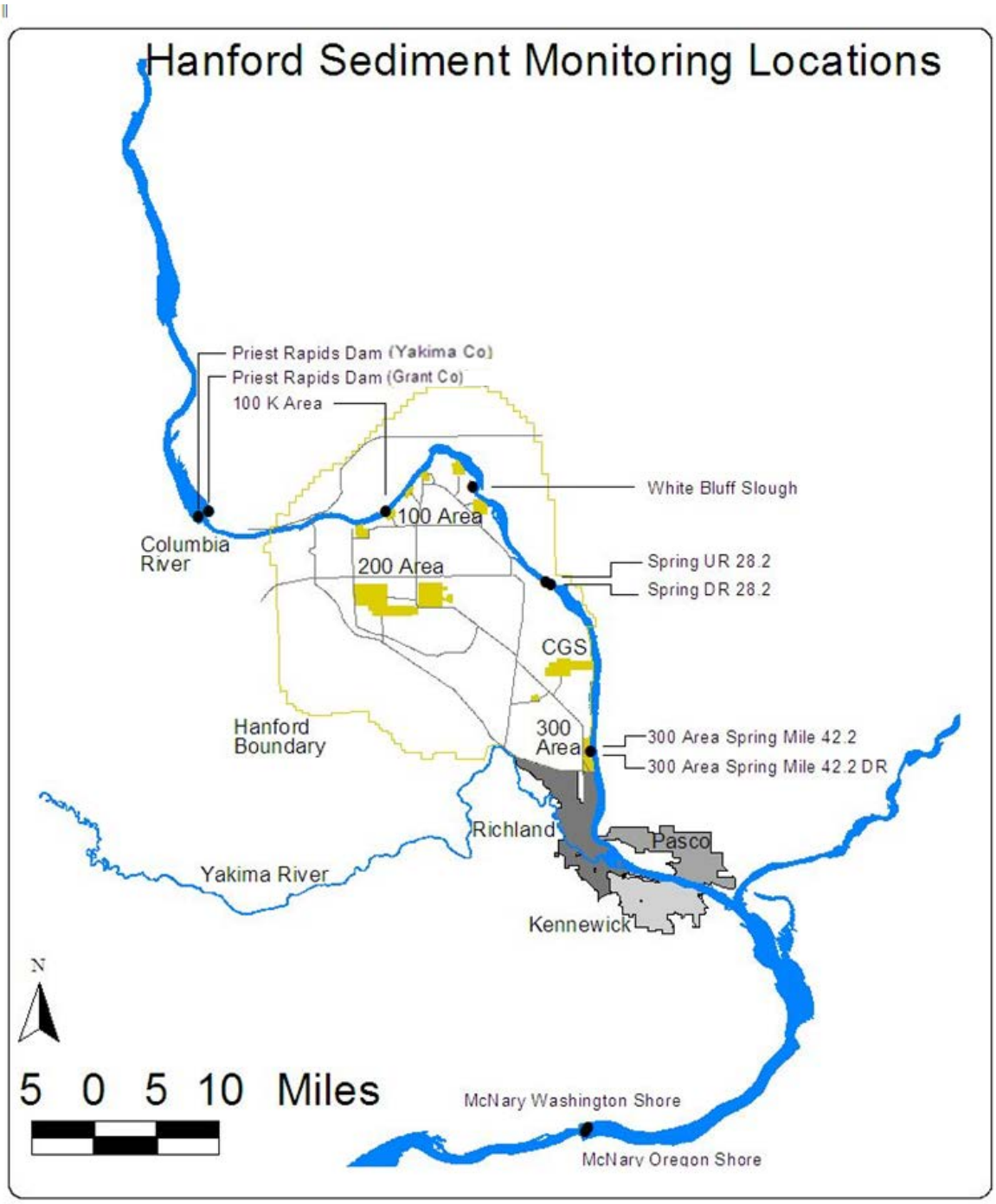

Figure 3.4.1 Typical Sediment Monitoring Locations

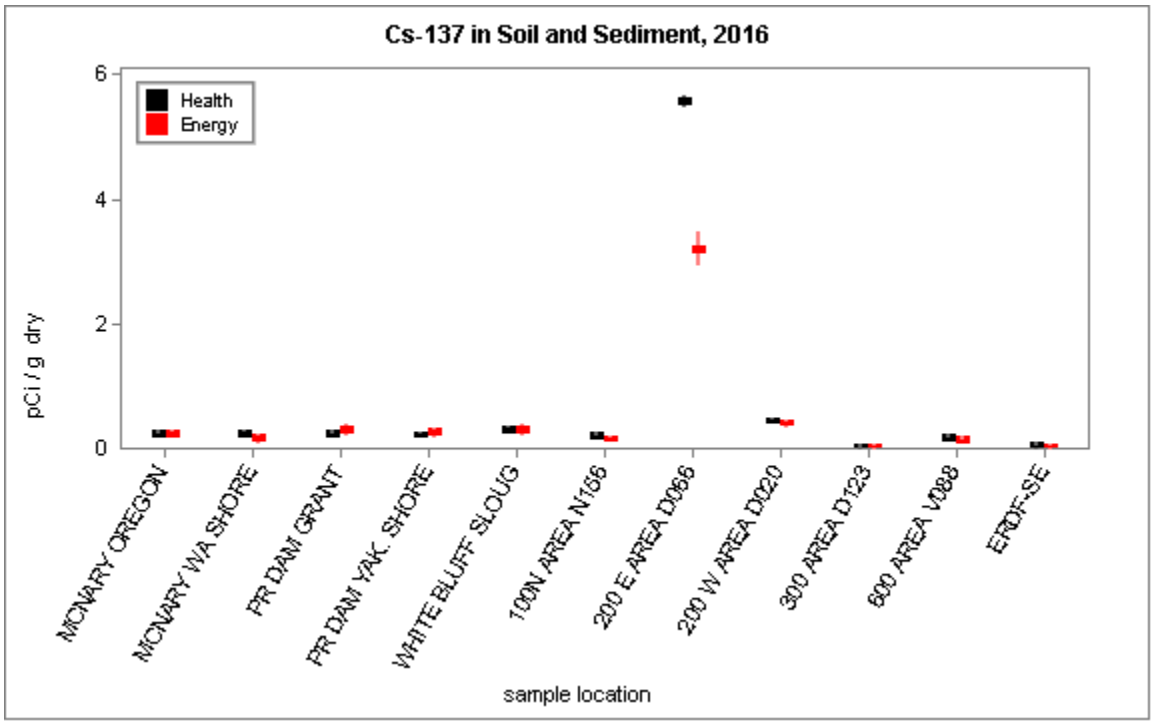

Figure 3.4.2 Health and Energy Cs-137 Concentrations in Soil and Sediment

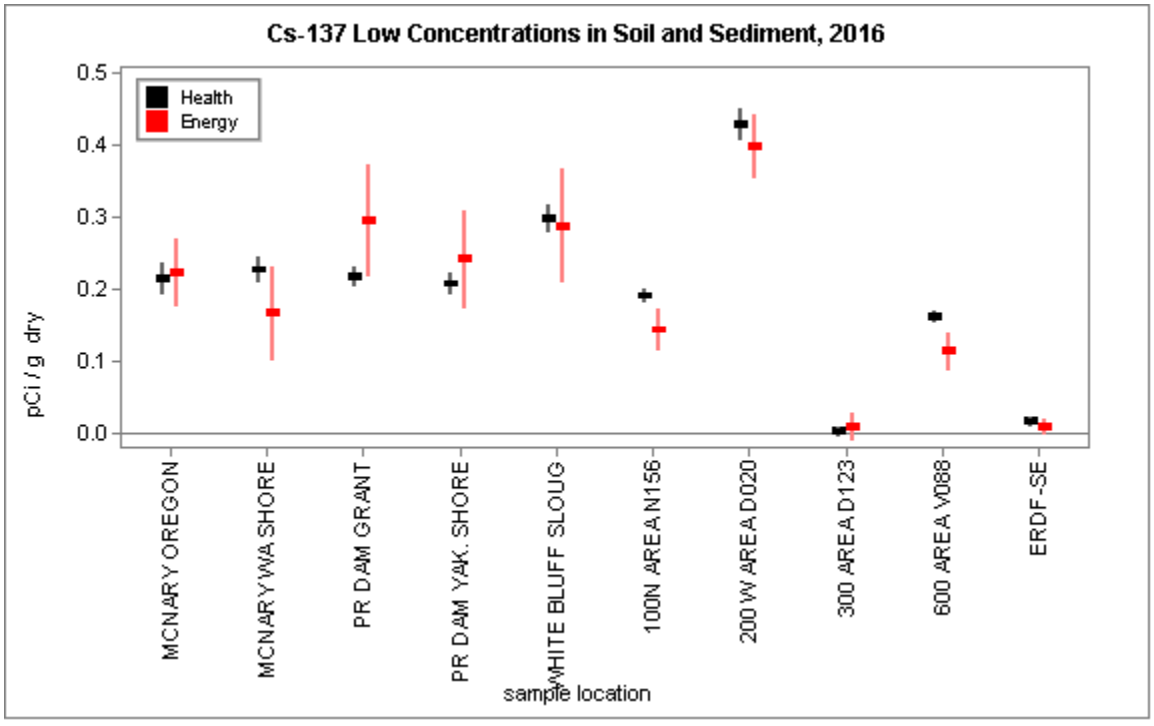

Figure 3.4.3 Health and Energy Low Concentration Cs-137 in Soil and Sediment

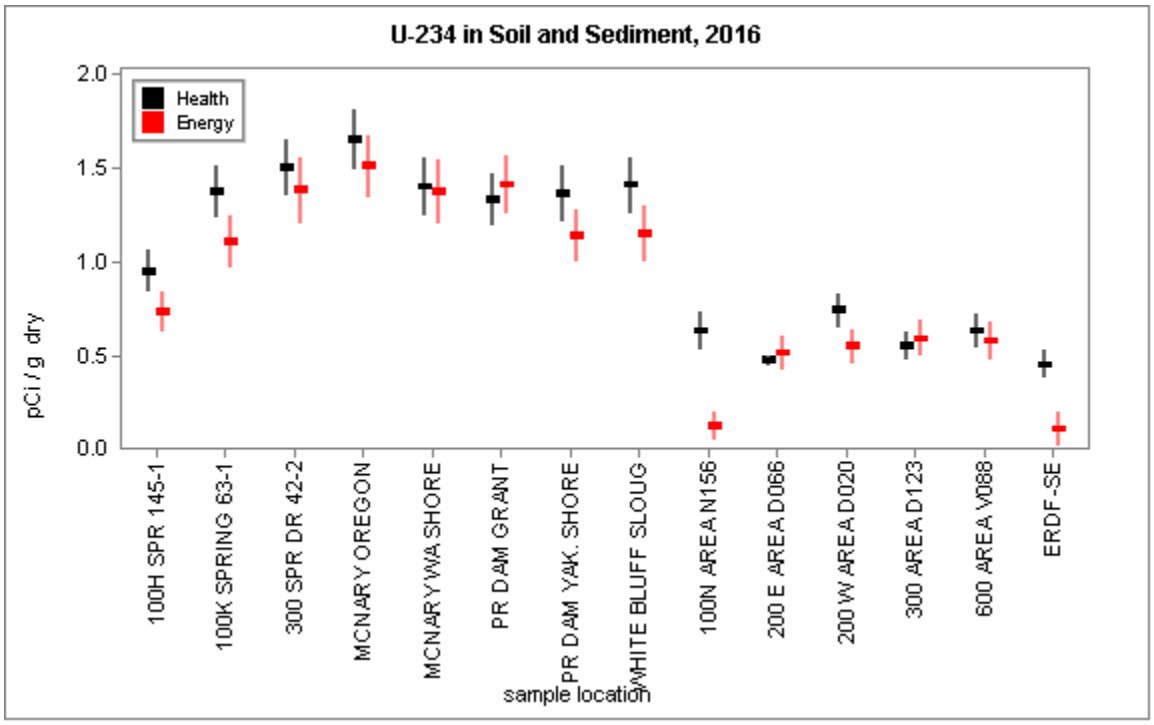

Figure 3.4.4 Health and Energy U-234 Concentrations in Soil and Sediment

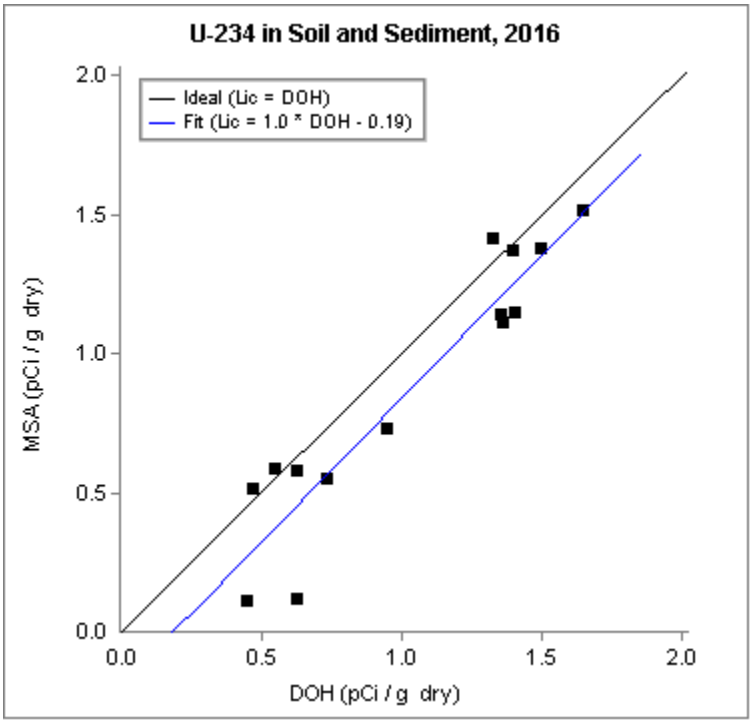

Figure 3.4.5 Scatter plot for Health and Energy U-234 Concentrations in Soil and Sediment

3.5 Biota Monitoring

Major Findings:

- All Health and Energy radionuclide concentrations are in good agreement.
- Most Health radionuclide concentrations are below detection limits. Strontium-90 and isotopes of uranium were detected in a few biota samples, with concentrations consistent with the range of concentrations typically detected in these media.

3.5.1 Purpose and General Discussion

Health and Energy contractors monitor farm products, fish and wildlife, and vegetation to determine if contamination has migrated into the food chain, potentially exposing people or other biota.

Farm product sampling includes food, milk, and wine. Sample locations include farms near to, but offsite of the Hanford Reservation. Contaminants in farm products may result from deposition of contaminated air or irrigation with contaminated water.

Fish and wildlife sampling includes fish, shellfish, small and large mammals, and game birds. Sample locations include the Hanford Site, adjacent to the Hanford boundary, and nearby to the Hanford Site. Contaminants in fish may arise from exposure to contaminated water, sediment, and aquatic biota. Contaminants in wildlife may arise from ingestion of contaminated soil, vegetation, and water.

Vegetation sampling includes various grass, brush, and leaves and twigs from tress. Sample locations include the Hanford Site, adjacent to Hanford along the Columbia River, and nearby to the Hanford Site. Contaminants in vegetation may arise from airborne deposition, soil to plant transfer, and water to plant transfer.

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

3.5.2 Sample Types and Monitoring Locations

For this year's oversight program, farm products include three apricot samples, four corn samples, three leafy vegetable samples, three melon samples, two potato samples, and three samples each of red wine and white wine.

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

Fish and wildlife samples include three carp samples from the Columbia River; one from the 100 Area, one from the 300 Area, and one from a background location near Vantage. One quail sample was collected near the 300 Area, and one elk sample was collected from a background location.

Five vegetation samples (rabbit brush and reed canary grass) were collected from the Hanford Site; one sample each from the 100N, 200 East, 200 West, 300, and 600 Areas. Health did not obtain Energy's vegetation results in time to be included in this report.

3.5.3 Monitoring Procedures

Farm Products

The Energy contractor (currently MSA) collects farm product samples and then splits the samples with Health. Energy collects the samples once a year, typically in the fall at harvest.

Fruit and vegetable samples are analyzed for Sr-90 and gamma emitting radionuclides, which include Co-60, Cs-134, Cs-137, Eu-152, Eu-154, Eu-155, Ru-106, and Sb-125. Concentration units are pCi/g (wet weight). Some samples are also analyzed for C-14.

Wine is analyzed for gamma emitting radionuclides and tritium (H-3). Concentration units are pCi/L.

Fish and Wildlife

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

The Energy contractor collects most wildlife samples. Some of the samples are split with Health. In other cases, multiple collocated samples are collected, with Health taking one of the samples and the Energy contractor taking one or more of the remaining samples. Health occasionally collects deer or elk from western Washington for background samples, although none were collected for this reporting period.

Carcass and bone samples are analyzed for Sr-90, as strontium accumulates in the bone, not the meat. Liver samples, when collected, are analyzed for isotopes of plutonium, as plutonium accumulates in the liver. Meat samples are analyzed for gamma emitting radionuclides, which include Co-60, Cs-134, Cs-137, Eu-152, Eu-154, Eu-155, Ru-106, and Sb-125. Concentration units are pCi/g (dry weight).

Vegetation

The Energy contractor (currently MSA) collects vegetation samples and then splits the samples with Health. Energy typically collects the samples in the spring, when the plants are starting to grow and have a high probability to absorb contaminants.

Vegetation samples are analyzed for Sr-90 and gamma emitting radionuclides, which include Co-60, Cs-134, Cs-137, Eu-152, Eu-154, Eu-155, Ru-106, and Sb-125. Some samples are also analyzed for isotopes of uranium and C-14. Concentration units are pCi/g (dry weight).

3.5.4 Comparison of Health and Energy Contractor Data

Tables 3.5.1 and 3.5.2 summarize the comparison of Health and Energy data (see Section 2.2). The first columns list the analytes assessed in the laboratory sample analyses and the sample collection period. Then, for each analyte, the tables list the number of split results, the quality of agreement between the Health and Energy results (see Section 2.2.4.1), and the range of concentrations measured by Health. A concentration value prefaced by the "less than" symbol (<) indicates that the value is the detection limit and that some or all Health results are less than this value. Finally, the "Anomalous Data ?" column denotes whether any of the measured Health concentrations for the current year are anomalous compared to historical results (see Section 2.2.5).

Analyte	Collection Period	Number of Results	Quality of Agreement	Health's Data Range (pCi/g)	Anomalous Data ?
C-14	annual	8	good	< 1	no
Co-60	annual	21	good	< 0.02	no
Cs-134	annual	21	good	< 0.02	no
Cs-137	annual	21	good	< 0.02	no
Eu-152	annual	21	good	< 0.05	no
Eu-154	annual	21	good	< 0.05	no
Eu-155	annual	21	good	< 0.05	no
H-3	annual	3	good	< 0.8	no
Pu-238	annual	3	good	< 0.0007	no
Pu-239/240	annual	3	good	< 0.002	no
Sr-90	annual	21	good	< 0.02 to 0.25	no
U-234	annual	3	good	< 0.0004 to 0.001	no
U-235	annual	3	good	< 0.003	no
U-238	annual	3	good	0.0003 to 0.0007	no

Table 3.5.1 Summary of Split Biota Samples

Analyte	Collection Period	Number of Results	Quality of Agreement	Health's Data Range (pCi/g)	Anomalous Data ?
Co-60	annual	6	good	< 8	no
Cs-134	annual	6	good	< 8	no
Cs-137	annual	6	good	< 8	no
Eu-152	annual	6	good	< 20	no
Eu-154	annual	6	good	< 20	no
Eu-155	annual	6	good	< 20	no
H-3	annual	6	good	< 80	no

Table 3.5.2 Summary of Split Wine Samples

All of the reported Health and Energy concentrations in split biota samples are in good agreement, and most concentrations are below detection limits. All of the Health and Energy concentrations in split wine samples are in good agreement, and all concentrations are below detection limits or are similar to historical results.

3.5.5 Other Discussion

Health occasionally detects small concentrations of Sr-90 in biota, with historical concentrations typically ranging from below the detection limit to 0.3 pCi/g. Health occasionally detects small concentrations of isotopes of uranium, with historical U-234 and U-238 concentrations typically ranging from 0.002 to 0.1 pCi/g. Health does not typically detect gamma emitting radionuclides in biota or wine samples.

Based on analysis of samples from background locations, detected concentrations of Sr-90 and isotopic uranium are most likely due to fallout from historical atmospheric testing of nuclear weapons.

4. Summary of Evaluation of Health and Energy Contractor Results

This report describes the agreement between Health and Energy contractor results qualitatively, with the categories of *good*, *fair*, and *poor*. This section summarizes all data described as fair or poor.

Health and Energy gross alpha concentrations in biweekly air samples are in fair agreement. The data are similar and follow the same temporal trend, but the concentrations reported by Energy are systematically less than those reported by Health. This discrepancy is seen throughout historical data.

Health and Energy gross beta concentrations in biweekly air samples are in fair agreement. The data are similar and follow the same temporal trend, but the concentrations reported by Energy are systematically greater than those reported by Health. This discrepancy is seen throughout historical data.

Historically, Health and Energy tritium (H-3) concentrations in monthly air samples are in poor agreement. Significant differences between the Health and Energy concentrations occur, and Energy often reports concentrations higher than those reported by Health. This discrepancy is seen throughout historical data.

As a result of the historical poor agreement for H-3 in air samples, Health conducted a review of their analysis method for tritium in air samples. Based on the findings, in 2004, Health's laboratory added a second distillation step to assure all of the tritium captured in the collection process is measured. Between 2014 and 2016, Health undertook a project to validate the H-3 measurement method. This included contracting with a vendor to provide samples with certified concentration of tritium for a qualitative validation of the analysis protocol. The project showed Health's analysis method yields results that are accurate within the range of its measurement uncertainty. The 2016 split H-3 data in air are in much better agreement than historical data and is categorized for this reporting period as fair.

Health and Energy Am-241 and Pu-239/240 concentrations in semiannual composite air samples are in fair agreement. Historically, when concentrations are below or only slightly above the detection limit, the Health and Energy data are in good agreement. However, in cases where the concentration is above the detection limit, Health often reports higher concentrations, up to four times greater than those reported by Energy.

Health bases analysis of Pu-239 and Am-241 analysis on National Institute of Science and Technology, NIST, traceable standards. These standards follow the sample through all chemistry and measurement steps to assure the accuracy of the measured value. This process is tested with each set of samples by running a quality control sample that mimics the sample matrix. Historical performance on proficiency test samples for these analytes in air filters has been very good, although the tendency has been for a slightly high-bias. Taken together, these facts tend to give high confidence in the accuracy of the results reported by Health on these analytes in air filters and air filter composites.

Health and Energy Pu-241 concentrations in semiannual composite air samples are in poor agreement. For five of the ten samples analyzed for Pu-241, Health detected this radionuclide at small concentrations while Energy did not.

Plutonium 241 is a relatively new analyte for Health to quantify. At this time there is no independent proficiency evaluation test available for Pu-241 in air filters. As such, Health's confidence in Pu-241 results relies on internal quality assurance steps. Plutonium 241 is a beta emitter and, along with other isotopes of plutonium (Pu-238, 239/240) is chemically separated from other elements through a series of steps. A NIST traceable standard is used to assess the success of the chemical separations. Quality control samples are run with each batch to validate the accuracy of the analysis. Samples spiked with a known concentration of Pu-241 test the accuracy of the batch of measurements and samples with no Pu-241 assess the potential for measurement bias in excess of instrument background.

Health and Energy Sr-90 concentrations in semiannual composite air samples are in fair agreement. Health detected small concentrations of Sr-90 in four of the samples, while Energy did not detect this radionuclide in their collocated samples.

Health and Energy U-234 and U-238 concentrations in semiannual composite air samples are in fair agreement, as the data display a non-systematic random discrepancy.

Historically, Health and Energy Cs-137 concentrations in semiannual composite air samples are in fair agreement when concentrations are significantly above the detection limit. However, all Cs-137 concentrations for 2016 samples are below detection limits. Health's laboratory has found cause to believe their counting efficiency for gamma radiation analysis of air samples (which includes Cs-137) needs to be updated. A future report will discuss this effort.

Health and Energy C-14 concentrations in water samples are in fair agreement. Concentrations in five of the six samples are in good agreement, but for one of the samples there is a significant discrepancy. Historically, the agreement has been poor, as much greater differences have been observed.

Health's laboratory is reviewing published methods to quantify C-14 in water samples. Three viable methods have been identified, each with their own challenges. The laboratory intends to a) identify a procedure to better concentrate the carbon contained in the sample, and b) develop a procedure to address the case where the presence of other radionuclides interferes with the ability to quantify concentrations of C-14. A future report will discuss this effort.

Health and Energy gross alpha and gross beta concentrations in water samples are in fair agreement, as Health often reports higher concentrations than Energy.

Health and Energy I-129 results in water samples are in fair agreement. The data follow the same general trend; however, there is a non-systematic discrepancy for some of the samples.

Health and energy Cs-137, Sr-90, U-234, and U-238 results in soil and sediment samples are in fair agreement, as Health often reports higher concentrations than Energy.

All discrepancies are under investigation, and findings will be discussed in future annual reports as issues are resolved.

Appendix A - Radiation Tutorial

A.1 Radiation and Radioactivity

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

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

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

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

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

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

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

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

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

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

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

A.2 Radiological Units and Measurement

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

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

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

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

Source		Dose (mrem/yr)	Dose (mSv/yr)	Percent of Total
Ubiquitous background		**311**	**3.11**	**49.8**
	Internal, inhalation (radon and thoron)	228	2.28	36.5
	External, space	33	0.33	5.3
	External, terrestrial	21	0.21	3.4
	Internal, ingestion	29	0.29	4.6
Medical		**300**	**3.00**	**48.0**
	CT	147	1.47	23.5
	Nuclear Medicine	77	0.77	12.3
	Interventional Fluoroscopy	43	0.43	6.9
	Conventional radiography and fluoroscopy	33	0.33	5.3
Consumer		**13**	**0.13**	**2.1**
	Industrial, security, medical, educational, and research		0.003	<0.05
	Occupational		0.005	0.1
Grand Total		**620**	**6.2**	**100%**

Table A.1 Annual Effective Dose Equivalent (National Council on Radiation Protection and Measurements Report No. 160, *Ionizing Radiation Exposure of the Population of the United States, 2006*)

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

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

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

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

Appendix B - Laboratory a priori Lower Limits of Detection

Air Cartridge (pCi/m^3)

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

Air Filter (pCi/m^3)

	Nuclide	Volume (m^3)	Method	Standard LLD (100 min.)
Alpha	Gross	450	$\alpha\beta$ Cntr	5.00E-03
Beta	Gross	450	$\alpha\beta$ Cntr	1.00E-03

Quarterly Composite Air Filter (pCi/m^3)

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

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

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

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

	Nuclide	Volume (m3)	Method	Standard LLD (1000 min.)
Alpha	Nat U	10400	Alpha Spec	1.25E-05
	U-234	10400	Alpha Spec	1.25E-05
	U-235	10400	Alpha Spec	5.00E-06
	U-238	10400	Alpha Spec	1.25E-05
	Pu-238	10400	Alpha Spec	5.00E-06
	Pu-239/240	10400	Alpha Spec	5.00E-06
	Pu-241	10400	LSC	5.00E-04

Food (pCi/g)

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

Milk (pCi/l)

	Nuclide	Volume (L)	Method	Standard LLD (400 min.)
Gamma	K-40	3	INGe	3.00E+01
	I-131	3	INGe	2.00E+00
	Cs-134	3	INGe	2.00E+00
	Cs-137	3	INGe	2.00E+00
	Ba-140	3	INGe	9.00E+00

				Standard LLD (1000 min.)
	I-131	4	IXR/INGe	7.00E-01

				Standard LLD (100 min.)
Beta	Sr-90	1	Nitric Acid/ $\alpha\beta$ Cntr	7.00E-01

Meat (pCi/g)

	Nuclide	Mass (g)	Method	Standard LLD (1000 min.)
Gamma	K-40	400	INGe	1.40E-01
	Mn-54	400	INGe	7.00E-03
	Co-58	400	INGe	7.00E-03
	Co-60	400	INGe	8.00E-03
	Cs-137	400	INGe	6.00E-03
	I-131	400	INGe	2.00E-02
	Ra-226(DA)	400	INGe	2.50E-01
	Am-241(GA)	400	INGe	2.00E-02
Alpha	Nat U	10	Alpha Spec	4.00E-03
	U-234	10	Alpha Spec	3.00E-03
	U-235	10	Alpha Spec	2.00E-03
	U-238	10	Alpha Spec	3.00E-03
	Pu-238	10	Alpha Spec	5.00E-03
	Pu-239	10	Alpha Spec	4.00E-03
	Am-241	10	Alpha Spec	4.00E-03
Beta	Sr-90 (bone)	5	Nitric Acid/ $\alpha\beta$ 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
				Standard LLD (1000 min.)
Gamma	K-40	600	INGe	1.50E-01
	Mn-54	600	INGe	1.00E-02
	Co-60	600	INGe	1.00E-02
	Zn-65	600	INGe	2.00E-02
	Zr-95	600	INGe	1.00E-02
	Ru-103	600	INGe	1.50E-02
	Ru-106	600	INGe	1.00E-02
	Sb-125	600	INGe	2.00E-02
	Cs-134	600	INGe	1.20E-02
	Cs-137	600	INGe	1.50E-02
	Ce-144	600	INGe	5.00E-02
	Eu-152	600	INGe	1.50E-02
	Eu-154	600	INGe	1.50E-02
	Eu-155	600	INGe	2.00E-02
	Ra-226(DA)	600	INGe	1.00E-01
	Am-241(GA)	600	INGe	2.00E-02
	Tot U(GA)	600	INGe	2.00E-01
				Standard (100 min.)
Beta	Sr-90	150	Nitric Acid/	1.80E-03
	Tc-99	10	3M/LS	2.00E-01

	Gross beta	0.4	αβ Cntr	1.50E+00

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

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

Water (pCi/l)	Nuclide	Volume (L)	Method	Standard LLD (1000 min.)	Standard LLD (100 min.)
Alpha	Nat U	0.5	Alpha Spec	1.30E-01	
	U-234	0.5	Alpha Spec	8.00E-02	
	U-235	0.5	Alpha Spec	6.00E-02	
	U-238	0.5	Alpha Spec	8.00E-02	
	Ra-226	0.5	$\alpha\beta$ 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

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

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. Minimum Detectable Activity (MDA)

MDA = (2.71/T1 + 4.66(BKGCPM/T1)1/2)/(2.22)(E)(V)(Y)(D)

E. Definitions

2.22	=	conversion factor from dpm to picocuries
BKGCPM	=	background counts per minute
B	=	background counts
D	=	decay factor = $e^{-(\ln 2/T1/2)(t)}$
E	=	counting efficiency: counts per disintegration
LLD	=	the a priori determination of the smallest concentration of radioactive material sampled that has a 95 percent probability of being detected, with only five percent probability that a blank sample will yield a response interpreted to mean that radioactivity is present above the system background
MDA	=	The a posteriori determination of the activity level in a sample where there a 5% probability of making Type I and 5% probability of making a Type II error.
n	=	number of samples analyzed (number of data points)
RU	=	random uncertainty at the 95 percent confidence level (sometimes referred to as counting error)
s	=	sample standard deviation
S	=	one standard deviation of the background count rate (which equals $(BKG/T_2)^{1/2}$)
sample cpm	=	counts per minute of sample
t	=	elapsed time between sample collection and counting
T_1	=	sample count time
T_2	=	background count time
$T_{1/2}$	=	half-life of radionuclide counted
U	=	uncertainty (standard error) of the sample mean

V	=	volume in liters (or mass in grams) of sample
Y	=	fractional radiochemical yield (when applicable)

Appendix C - Glossary of Terms

Alpha Particle	A heavy particle emitted from the nucleus of an atom. It consists of two protons and two neutrons, which is identical to the nucleus of a helium atom without orbital electrons. These heavy charged particles lose their energy very rapidly in matter. Thus, they are easily shielded by paper or the surface layer of skin. Alpha particles are only hazardous when they are internally deposited.
Analyte	The specific radioisotope measured in a radiochemical analysis. For example, tritium, Sr-90, and U-238 are analytes.
Background (Background Radiation)	Radiation that occurs naturally in the environment. Background radiation consists of cosmic radiation from outer space, radiation from the radioactive elements in rocks and soil, and radiation from radon and its decay products in the air we breathe.
Baseline Samples	Environmental samples taken in areas unlikely to be affected by any facilities handling radioactive materials.
Becquerel	A unit, in the International System of Units (SI), of measurement of radioactivity equal to one transformation per second.
Beta Particle	A high-speed particle emitted from the nucleus, which is identical to an electron. They can have a -1 or +1 charge and are effectively shielded by thin layers of metal or plastic. Beta particles are generally only hazardous when they are internally deposited.
Curie	The basic unit of activity. A quantity of any radionuclide that undergoes an average transformation rate of 37 billion transformations per second. One curie is the approximate activity of 1 gram of radium. Named for Marie and Pierre Curie, who discovered radium in 1898.
Decay, Radioactive	The decrease in the amount of any radioactive material with the passage of time, due to the spontaneous emission from the atomic nuclei of either alpha or beta particles, often accompanied by gamma radiation.

Detection Level	The minimum amount of a substance that can be measured with a 95-percent confidence that the analytical result is greater than zero.
Dose	A generic term that means absorbed dose, equivalent dose, effective dose, committed equivalent dose, committed effective dose, or total effective dose.
Fallout	Radioactive materials that are released into the earth's atmosphere following a nuclear explosion or atmospheric release and eventually fall to earth.
Gamma Ray	Electromagnetic waves or photons emitted from the nucleus of an atom. They have no charge and are best shielded by thick layers of lead or steel. Gamma energy may cause an external or internal radiation hazard. (X-rays are similar to gamma radiation but originate from the outer shell of the atom instead of the nucleus.)
Gross Alpha / Gross Beta	A screening test that reports alpha particle activity in a sample. The test is not intended to identify specific radioisotopes. The tests are primarily used to evaluate trends. In addition, screening tests are used to determine if further radioisotope specific analysis is necessary; and if radioisotope analysis has been carried out, to determine if the activities from specific radioisotopes account for all of the activity found in the screening test.
Half-life	The time in which half the atoms of a particular radioactive substance disintegrate to another nuclear form. Measured half-lives vary from millionths of a second to billions of years. Also called physical half-life.
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.

Minimum Detectable Activity (MDA)	The smallest amount of radioactivity in a sample that will be detected with a 5% probability a false positive (Type I error) and a 5% probability of a false negative (Type II error).
mR (one milliroentgen)	One-thousandth of a Roentgen
Optically Stimulated Luminescence (OSL)	A radiation monitoring device used to measure accumulated ambient radiation dose OSLs are similar to the thermoluminescence dosimeters, TLDs, but use light rather than heat to release the stored energy and measure the dose of ionizing radiation received.
pCi (picocurie)	10^{-12} curies (one trillionth of a curie)
Quality Assurance	All those planned and systematic actions necessary to provide adequate confidence that a facility, structure, system, or component will perform satisfactorily and safely in service.
Quality Control	A component of Quality Assurance; comprises all those actions necessary to control and verify that a material, process, or product meets specified requirements.
Quality Factor (Q)	A numerical factor assigned to describe the average effectiveness of a particular kind (and sometimes energy) of radiation in producing biological effects on humans.
Rad	The special unit of absorbed dose. It is a measure of the energy absorbed per mass of material. One rad is equal to an absorbed dose of 0.01 J kg^{-1} (1 rad = 0.01 gray).
Radioactivity	The process of undergoing spontaneous transformation of the nucleus, generally with the emission of alpha or beta particles, often accompanied by gamma rays. The term is also used to designate radioactive materials.
Radioisotope	A radioactive isotope; i.e., an unstable isotope that undergoes spontaneous transformation, emitting radiation. Approximately 2500 natural and artificial radioisotopes have been identified.
Radionuclide	A radioactive nuclide.

Rem	The special unit of dose equivalent. The dose equivalent in rem is equal to the absorbed dose in rad multiplied by a quality factor that accounts for the biological effect of the radiation (1 rem = 0.01 sievert).
Replicate Sample	Two or more samples from one location that are analyzed by the same laboratory.
Roentgen	A unit of exposure to ionizing radiation. It is that amount of gamma or x-rays required to produce ions carrying 1 electrostatic unit of electrical charge in 1 cubic centimeter of dry air under standard conditions. Named after Wilhelm Roentgen, German scientist who discovered x-rays in 1895.
Split Sample	A sample from one location that is divided into two samples and analyzed by different laboratories.
TLD	Thermoluminescent Dosimeters
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
Pu-241	Plutonium-241
Ru-106	Ruthenium-106
Sb-125	Antimony-125
Sr-90	Strontium-90
Tc-99	Technetium-99
Total U	Total Uranium
U-234	Uranium-234
U-235	Uranium-235
U-236	Uranium-236
U-238	Uranium-238