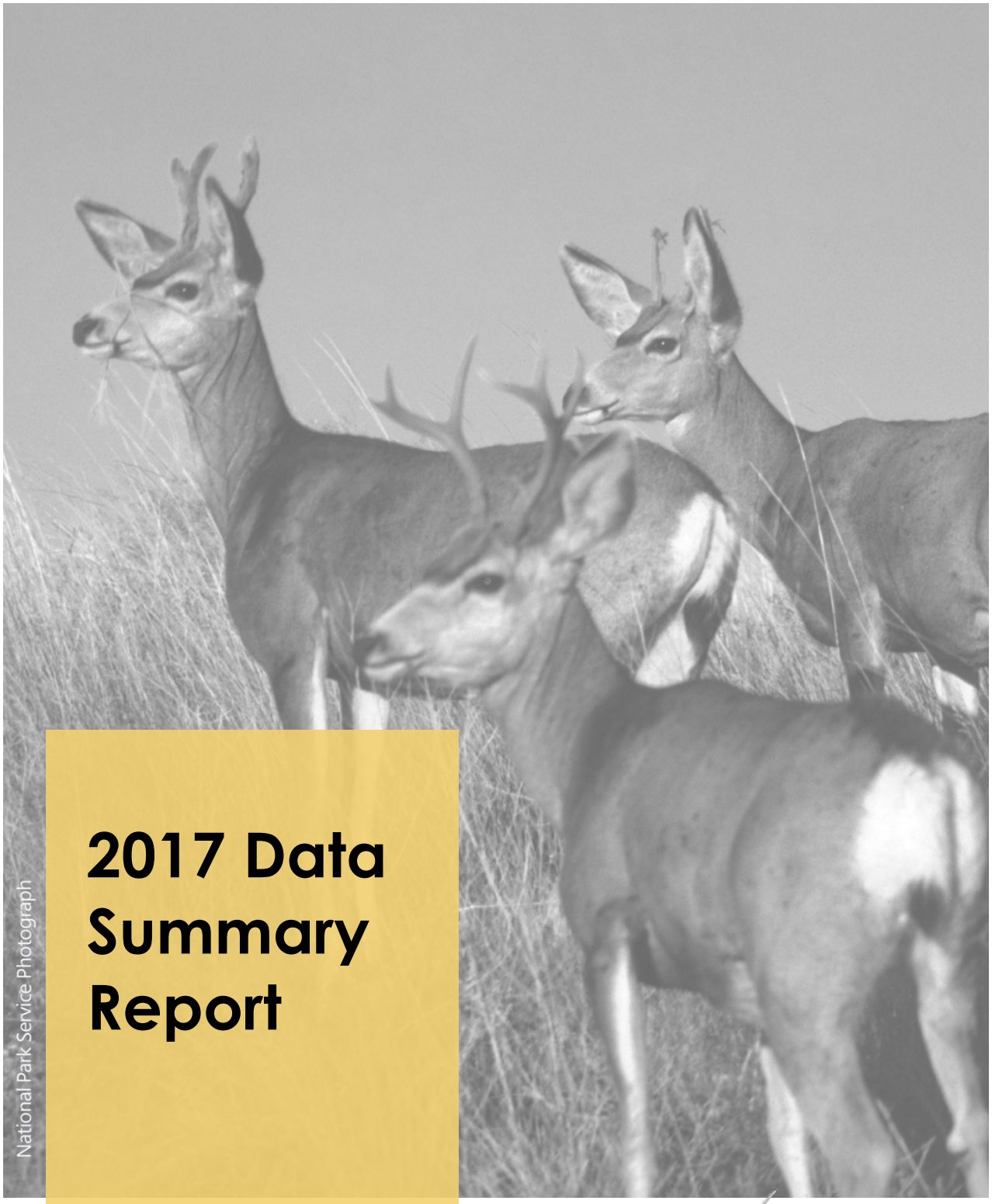
Hanford Environmental Radiation Oversight Program



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2017 Data Summary Report

April 2019

Washington State Department of Health

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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 split into two parts or samples are collocated, with one going to Health, the other to the facility. Each program assesses their 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, soil, sediment, food and farm products, fish and wildlife, vegetation, and radiation levels in the surrounding area.

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.

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 or collocated sampling, and comparing the results. Health investigated any differences in results. The general *good* to *fair* agreement between the limited 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 provides formulas used in sample analysis. Appendix D lists a glossary of radiation terms. Appendix E lists the full element names of the radionuclides discussed in this report.

2. 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 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 D.

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 were 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 follow the same trends over time, but there is a systematic discrepancy between Health and Energy data at some sites.
- Health and Energy semiannual composite air sample results are in fair agreement for Pu-238 and Pu-239/240, in poor agreement for Am-241 and Pu-241, and in good agreement for all other radionuclides.
- Health and Energy H-3 concentrations in atmospheric water vapor are in poor agreement.
- Most Health air concentrations are consistent with historical results. An anomalous event at the Plutonium Finishing Plant resulted in higher than normal concentrations of alpha emitting radionuclides Am-241, Pu-238, Pu-239/240, and Pu-241.

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 gases 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 radionuclides 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 eleven locations, ten 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), the Plutonium Finishing Plant (PFP-N165, PFP N554, PFP N555, PFP N975), and the PUREX facility (N977 and N985), 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 remaining 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 six-month period are dissolved and combined into semiannual composite samples.

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 2017, Health collected only 16 of the 24 scheduled samples, eleven at the 300 Area Water Intake and five at Battelle Complex.

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.

Table 3.1.1 - Summary of Air Samples Collocated with Energy

Analyte	Collection Period	Number of Results	Quality of Agreement	Health's Data Range (pCi/m^3)	Anomalous Data?
Gross Alpha	biweekly	372	**fair**	0.0002 to 0.045	**yes**
Gross Beta	biweekly	372	**fair**	0.002 to 0.07	no
H-3	monthly	16	**poor**	< 2 to 15	no
Am-241	semiannual	14	**poor**	< 0.00001 to 0.0008	**yes**
Co-60	semiannual	31	good	< 0.0007	no
Cs-134	semiannual	31	good	< 0.0005	no
Cs-137	semiannual	31	good	< 0.0006	no
Eu-152	semiannual	31	good	< 0.001	no
Eu-154	semiannual	31	good	< 0.001	no
Eu-155	semiannual	31	good	< 0.001	no
Pu-238	semiannual	29	**fair**	< 0.00001 to 0.0002	**yes**
Pu-239/240	semiannual	29	**fair**	< 0.000005 to 0.0035	**yes**
Pu-241	semiannual	10	**poor**	< 0.0003 to 0.012	**yes**
Sr-90	semiannual	26	good	< 0.00006 to 0.0002	no
U-234	semiannual	23	good	< 0.00001 to 0.00002	**yes**
U-235	semiannual	23	good	< 0.000005	no
U-238	semiannual	23	good	< 0.00001 to 0.00014	**yes**

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, Figure 3.1.12 lists each site 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 bi-weekly gross alpha concentrations are in fair agreement. Figure 3.1.2 shows the collocated data at Battelle Complex. 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 ERDF SE, shown in Figure 3.1.3, do not show the same systematic bias and are in good agreement.

Figures 3.1.4 through 3.1.7 show the gross alpha concentrations at the four locations near the Plutonium Finishing Plant. Anomalously high concentrations were detected in the November and December samples, and several of the Health and Energy results do not agree. The anomalous event that caused these high concentrations is discussed in Section 3.1.5.

Figure 3.1.8 shows the scatter plot for gross alpha concentrations at all monitoring locations. The higher concentration data from sites near the Plutonium Finishing Plant are not included in the plot, as they would obscure the majority of the data at lower concentrations. 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. These data are similar to historical results.

Health and Energy biweekly gross beta concentrations are in fair agreement. Figure 3.1.9 shows the collocated data at 100K N576. 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 ERDF SE, shown in Figure 3.1.10, do not show the same systematic bias and are in good agreement.

Figure 3.1.11 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.

Health and Energy H-3 (tritium) concentrations in monthly atmospheric water vapor are in poor agreement. When Health and Energy both report low concentrations, those below 5 pCi/m^3, the agreement is good. However, anytime either Health or Energy report higher concentrations, the agreement is poor. Figure 3.1.12 shows the collocated data. Historically, the agreement is poor, with Energy often reporting higher concentrations than Health.

Heath and Energy Am-241 concentrations in semiannual air samples are in poor agreement. Both Health and Energy detected Am-241 in all samples collected near the Plutonium Finishing Plant, with concentrations ranging up to 0.001 pCi/m^3 (the high PFP concentrations are discussed in Section 3.1.5). Figure 3.1.13 shows the Am-241 data. Most of the results at the PFP locations do not agree.

Most 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 most are below detection limits. The single exception is a Co-60 concentration of 0.008 pCi/m^3 detected by Energy at the 300 Area Water Intake during the first half of 2017. Health did not detect Co-60 in their collocated sample (detection limit 0.0007 pCi/m^3). Figure 3.1.14 shows the Co-60 data.

Historically, Health and Energy occasionally detect Cs-137 in air samples. When it is detected, the concentrations reported by Energy are typically one-half the concentration value reported by Health. Cs-137 was not detected in this reporting period.

Anomalously high isotopic plutonium concentrations were detected from the locations near the Plutonium Finishing Plant. The event that caused these high concentrations is discussed in Section 3.1.5.

Health and Energy Pu-238 concentrations in semiannual air samples are in fair agreement, and most concentrations are below Health's detection limit of 0.00001 pCi/m^3 (see Figure 3.1.15). Pu-238 was detected at the locations near the Plutonium Finishing Plant, and two of the eight samples from these sites do not agree (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.

The Health and Energy Pu-239/240 concentrations in semiannual air samples are in fair agreement, and most concentrations are below the detection limit of 0.000005 pCi/m^3. Figure 3.1.17 shows all the data, while Figure 3.1.18 shows the detected concentrations for locations near the PFP, of which several of the Health and Energy results do not agree. Plutonium-239/240 is occasionally 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, as four of the eight results do not agree. Figure 3.1.19 shows these data.

The Health and Energy Sr-90 concentrations in semiannual air samples are in good agreement. Health's results ranged from below the detection limit of 0.00006 pCi/m^3 to 0.0002 pCi/m^3. 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.

Most of the U-234 and U-238 concentrations are in good agreement. However, Health's results for the first half of 2017 at the 618-10 Burial Ground are anomalous. Health reports a U-238 concentration approximately ten times greater than the U-234 result. Typically, the difference between U-234 and U-238 concentrations is within a factor of two. Energy's results do not support the anomalous ratio detected by Health. Historically, there is a systematic discrepancy between Health and Energy's isotopic uranium results, with Health typically reporting concentrations significantly greater than Energy.

See Section 4, Summary of Evaluation of Health and Energy Contractor Results, for further discussion on data comparison.

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. Figure 3.1.20 shows the historical gross beta activity at Wye Barricade, demonstrating the annual cycle of increased gross beta activity in the winter months.

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 at this site are consistent with historical data. All other radionuclides were not detected.

During 2017, the period covered by this report, Energy continued work on demolishing and removing the last two buildings of the Plutonium Finishing Plant complex (PFP), which included the main PFP processing building and the Plutonium Reclamation Facility. These buildings, located in the central part of the Hanford Site, were highly contaminated.

In June 2017, Energy reported contamination at onsite monitors. Around the same time, Health detected Am-241 in an air sample along highway 240, adjacent to the Hanford Site, 3.1 miles from PFP. Demolition work stopped at PFP until there was agreement further work would not result in additional release of radioactive contamination. However, after work restarted, it was clear there was widespread contamination of americium and plutonium from the demolition activities. Work was suspended again in December and did not resume by the end of 2017.

The release of contamination from PFP demolition activity resulted in anomalously high concentrations of gross alpha, Am-241, and isotopes of plutonium in air samples, as discussed in Section 3.1.4. The urgency of understanding this event resulted in Health modifying their standard air sampling procedures (discussed in Section 3.1.3).

Typically, Health combines the bi-weekly air particulate filter samples for a six-month period and then analyzes the composite sample for specific radioactive contaminants including

plutonium and americium. These semiannual air particulate samples results are not usually available to Health for several months.

For locations near PFP, it was important to assess the presence and extent of contamination from demolition more quickly. Health decided to deviate from normal protocol and analyze the November and December individual PFP bi-weekly filters for plutonium, americium, and strontium. The remaining bi-weekly filters for July through October were composited and analyzed per normal protocol. The results of the July through October composite analysis were mathematically combined with the November and December individual filter results to determine the semiannual particulate air concentrations for Sr-90, Am-241, and isotopes of plutonium. The semiannual concentrations for all other radionuclides only include the July through October composite analysis, as the November through December individual filters were un-usable for further analysis after their concentrations of Sr-90, Am-241, and isotopic plutonium were determined.

Figure 3.1.1 –

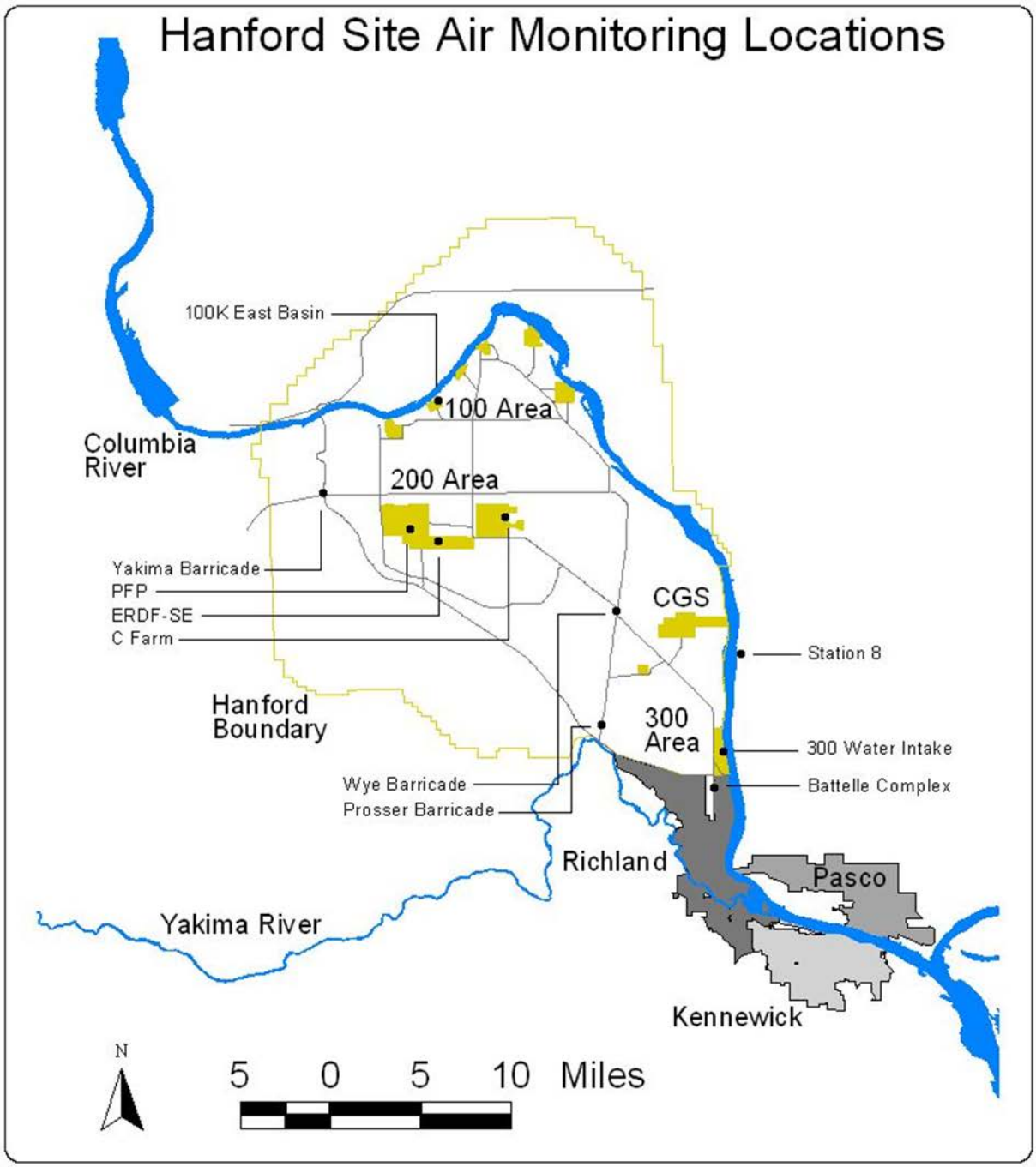

Hanford Site Air Monitoring Locations
100K East Basin
100 Area
Columbia River
200 Area
Yakima Barricade
PFP
ERDF-SE
C Farm
CGS
Station 8
Hanford Boundary
300 Area
300 Water Intake
Wye Barricade
Prosser Barricade
Battelle Complex
Richland
Pasco
Yakima River
Kennewick
N
5 0 5 10 Miles

Figure 3.1.2 –

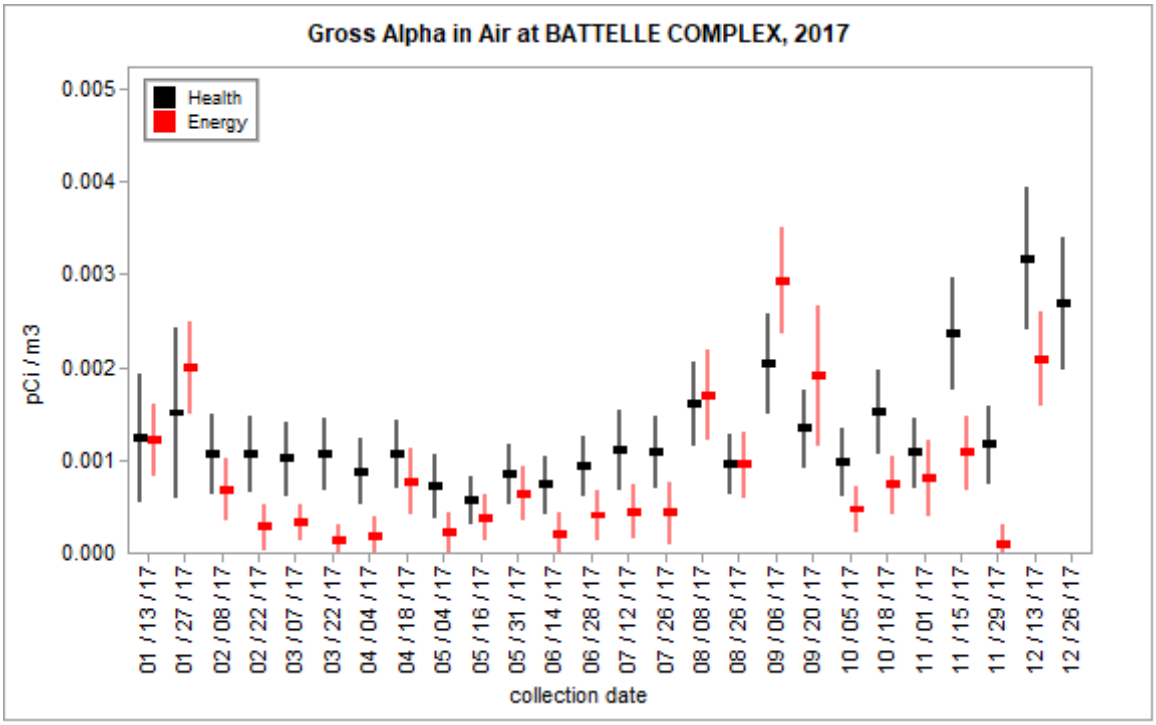


Figure 3.1.3 –

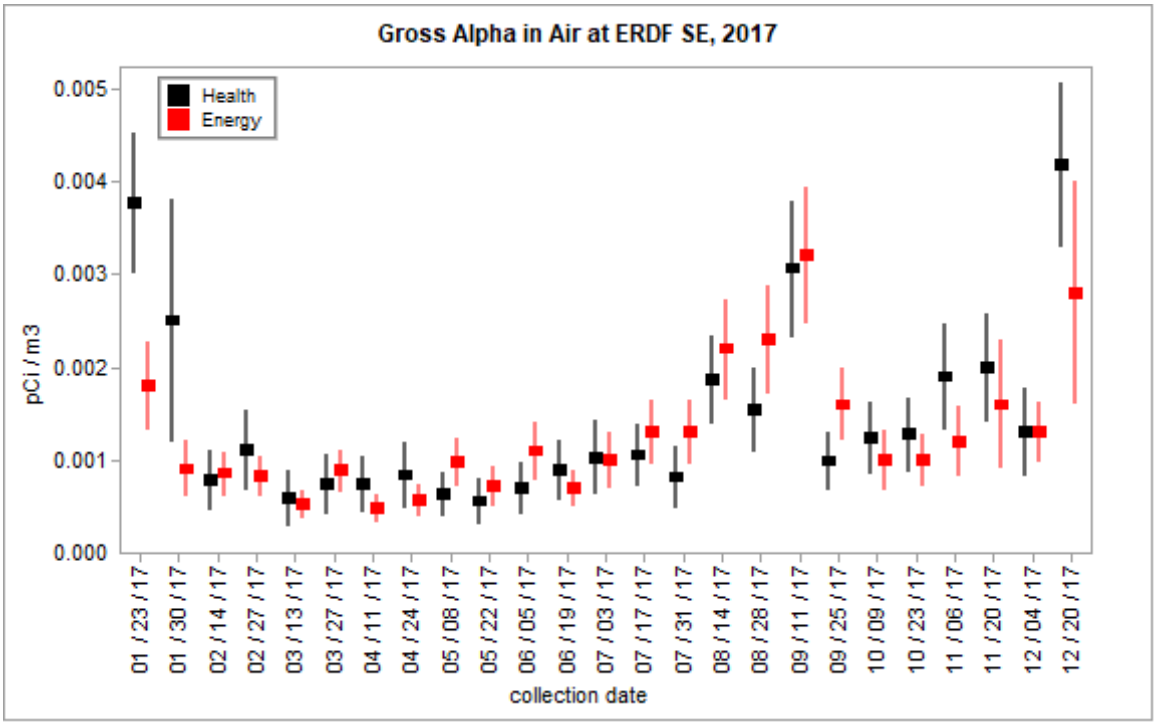


Figure 3.1.4 –

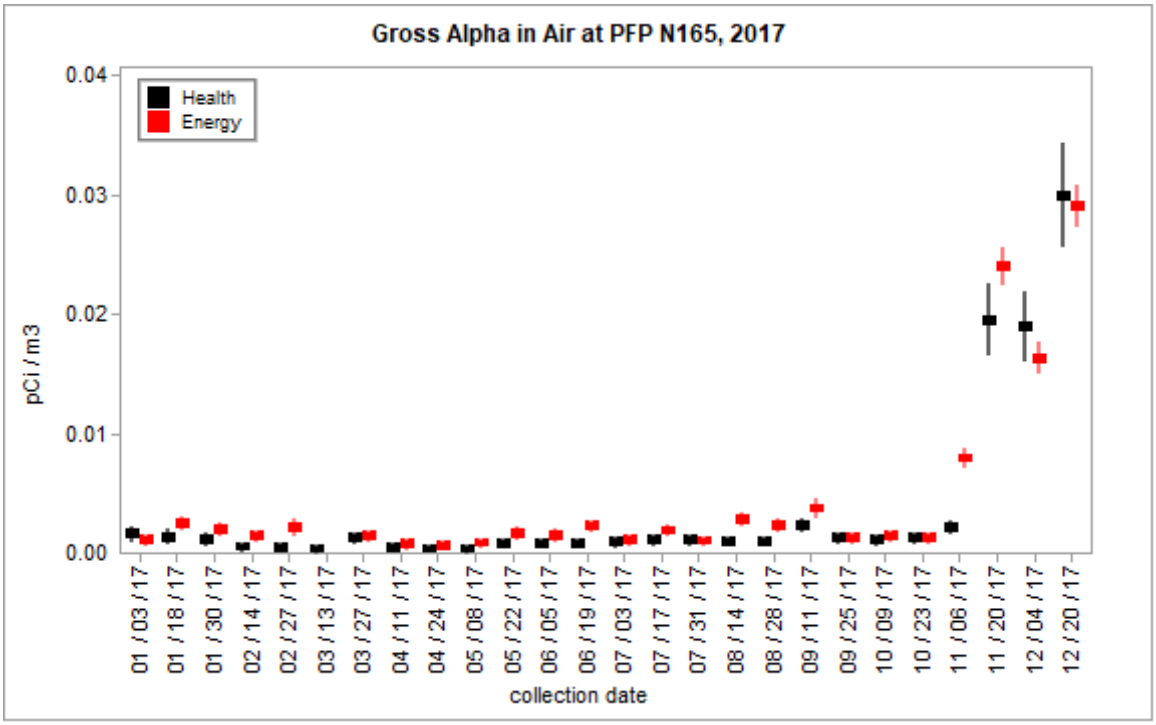


Figure 3.1.5 –

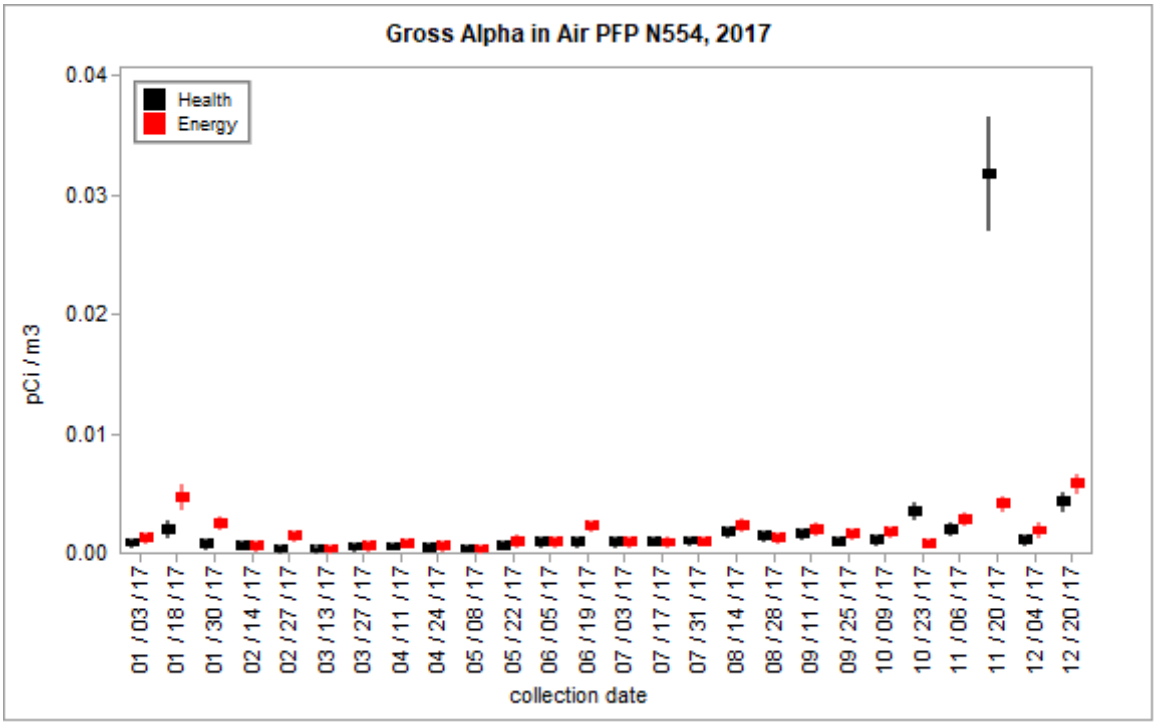


Figure 3.1.6 –

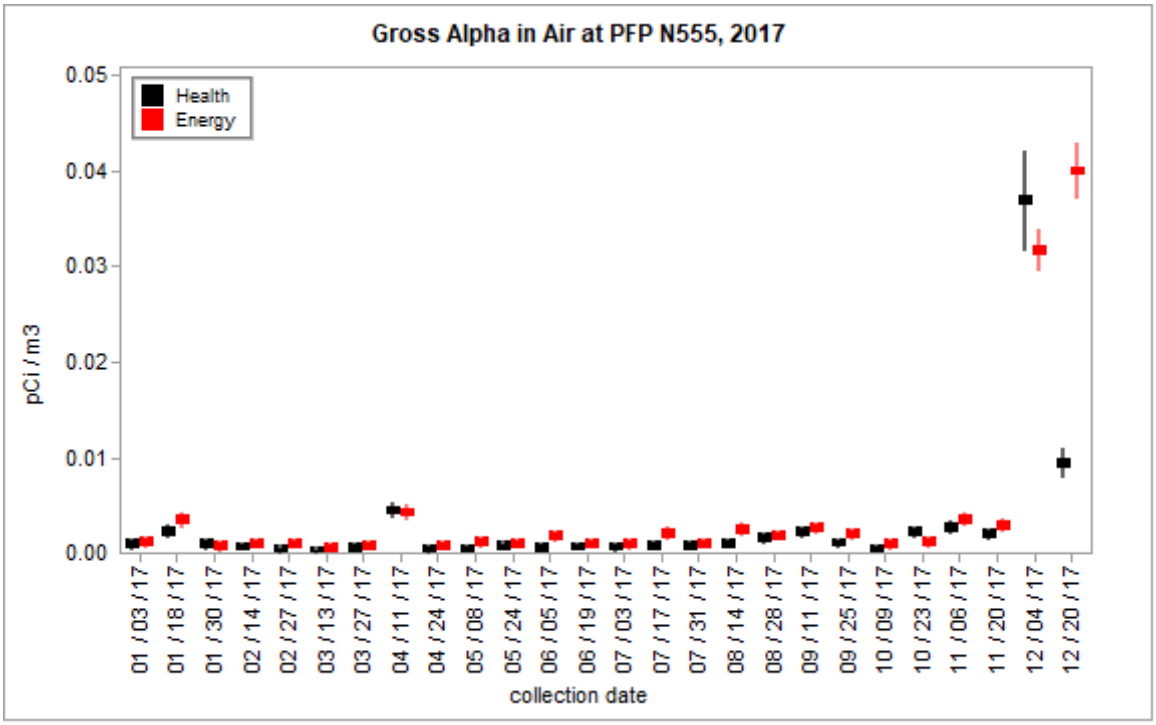


Figure 3.1.7 –

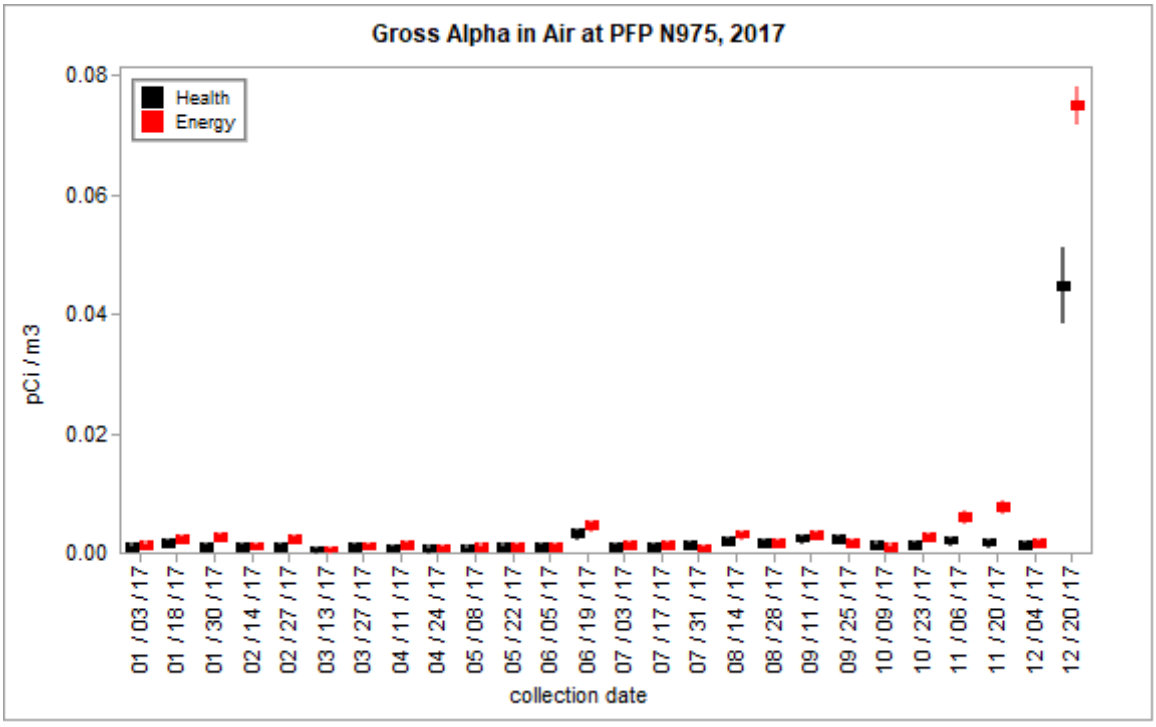


Figure 3.1.8 –

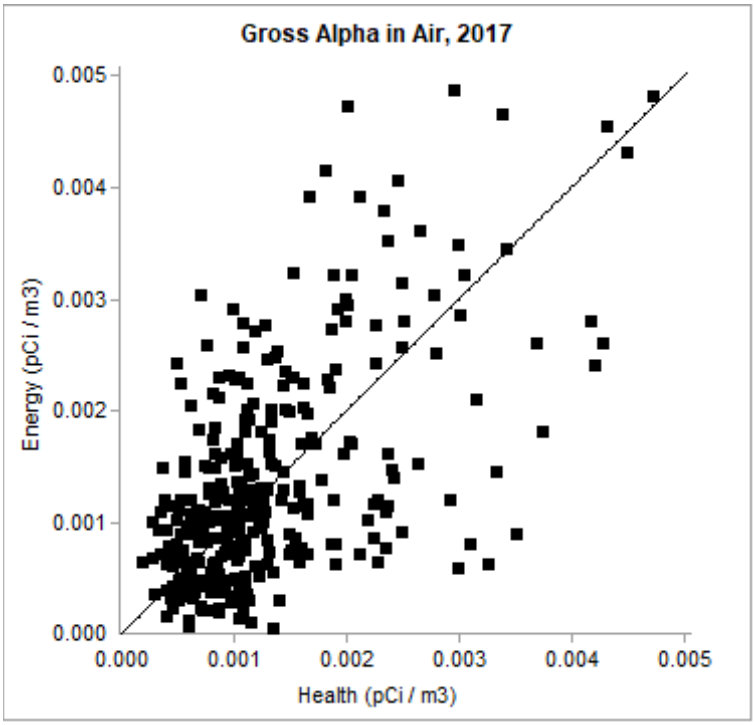


Figure 3.1.9 –

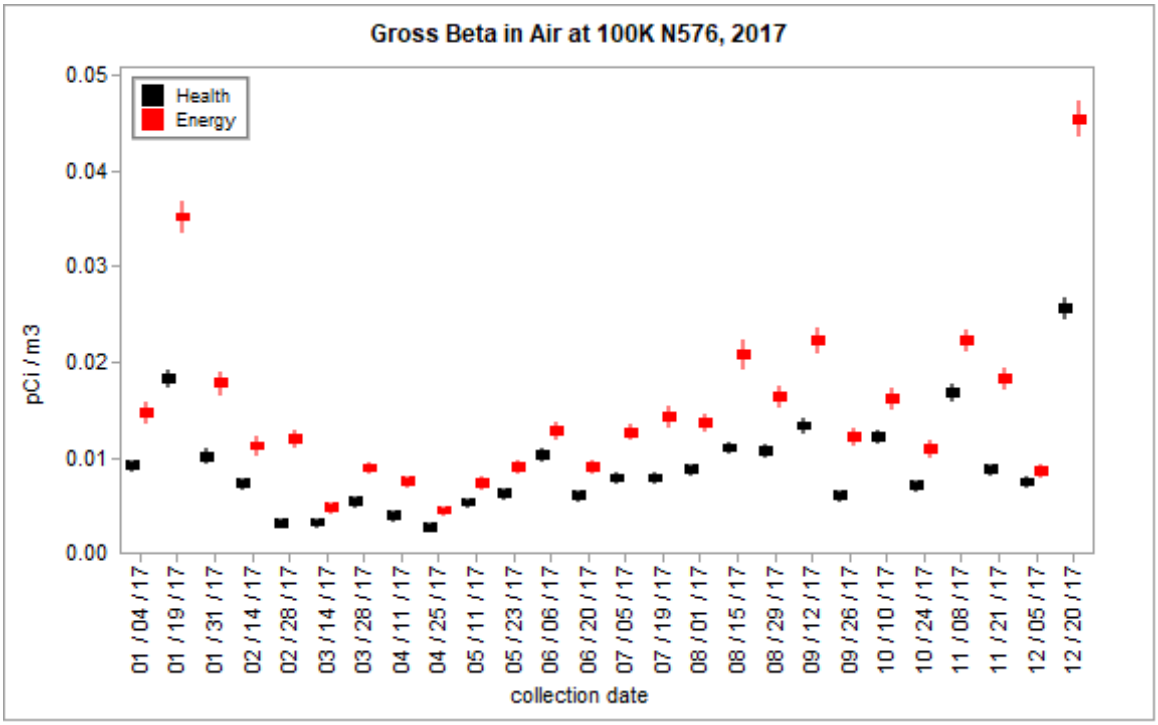


Figure 3.1.10 –

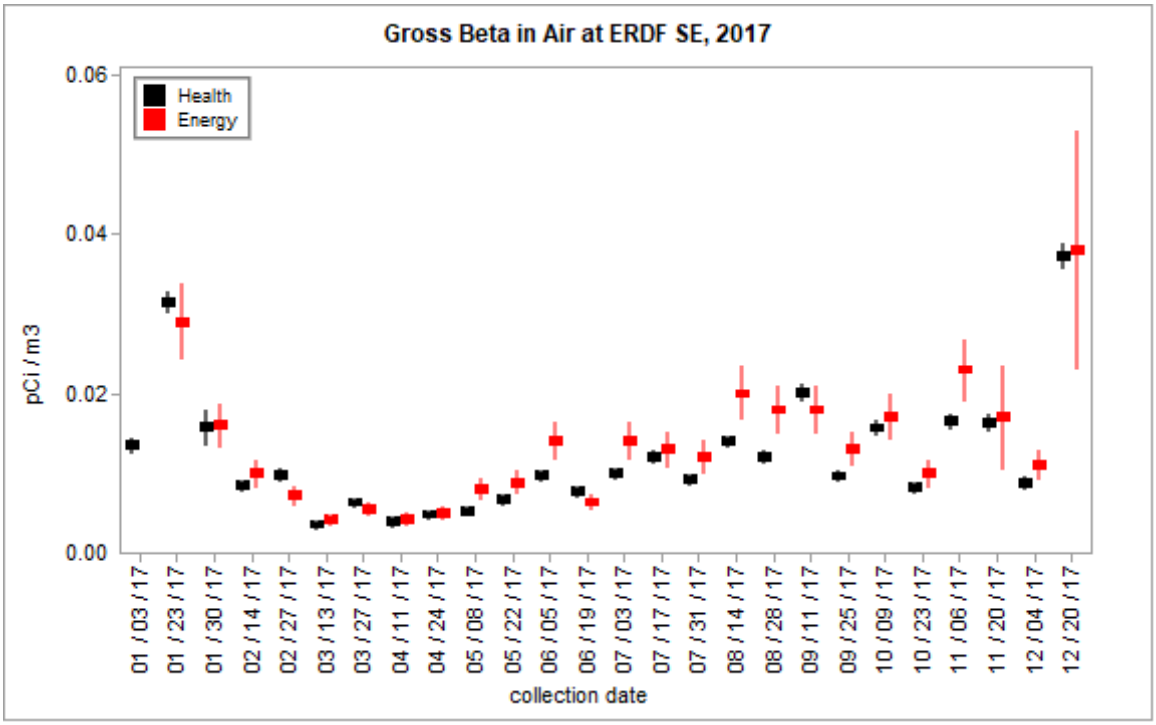


Figure 3.1.11 –

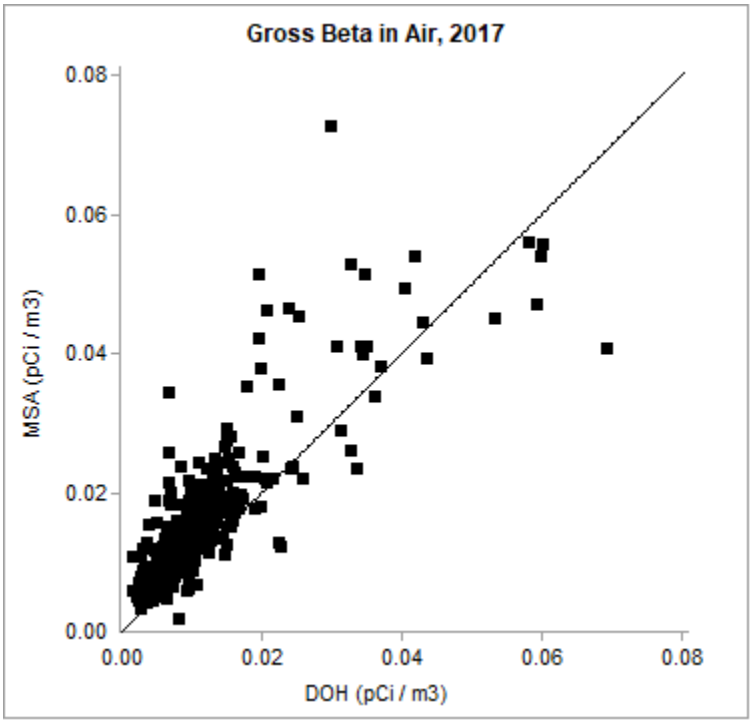


Figure 3.1.12 –

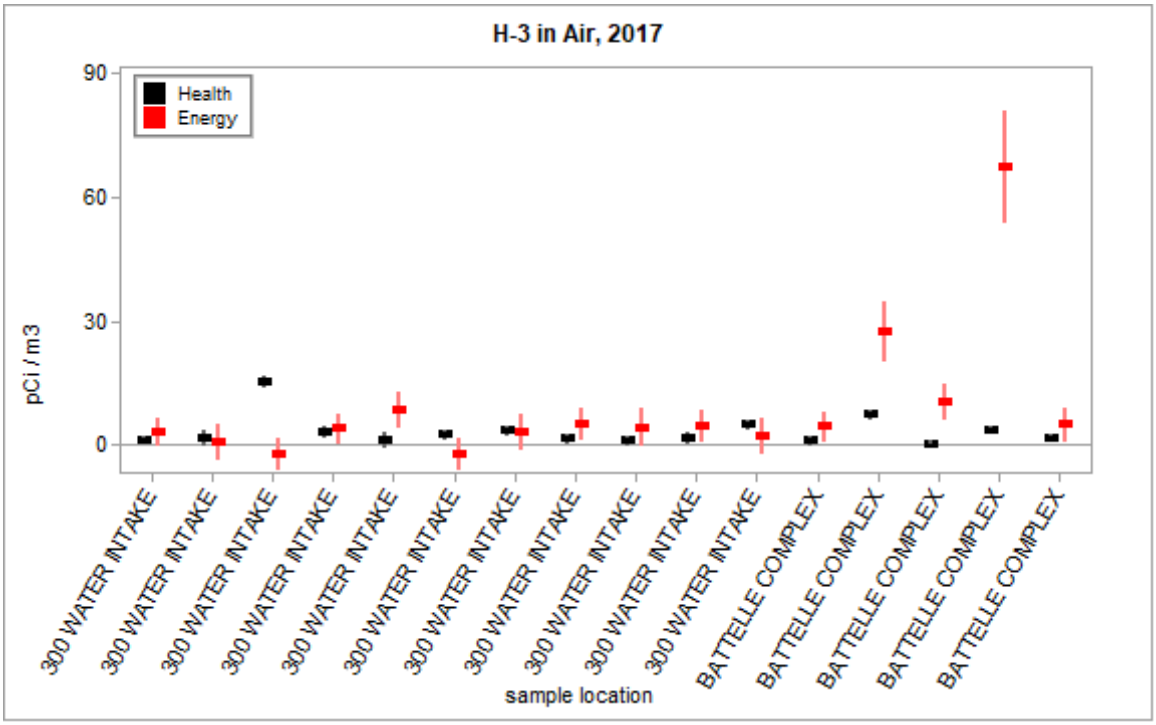


Figure 3.1.13 –

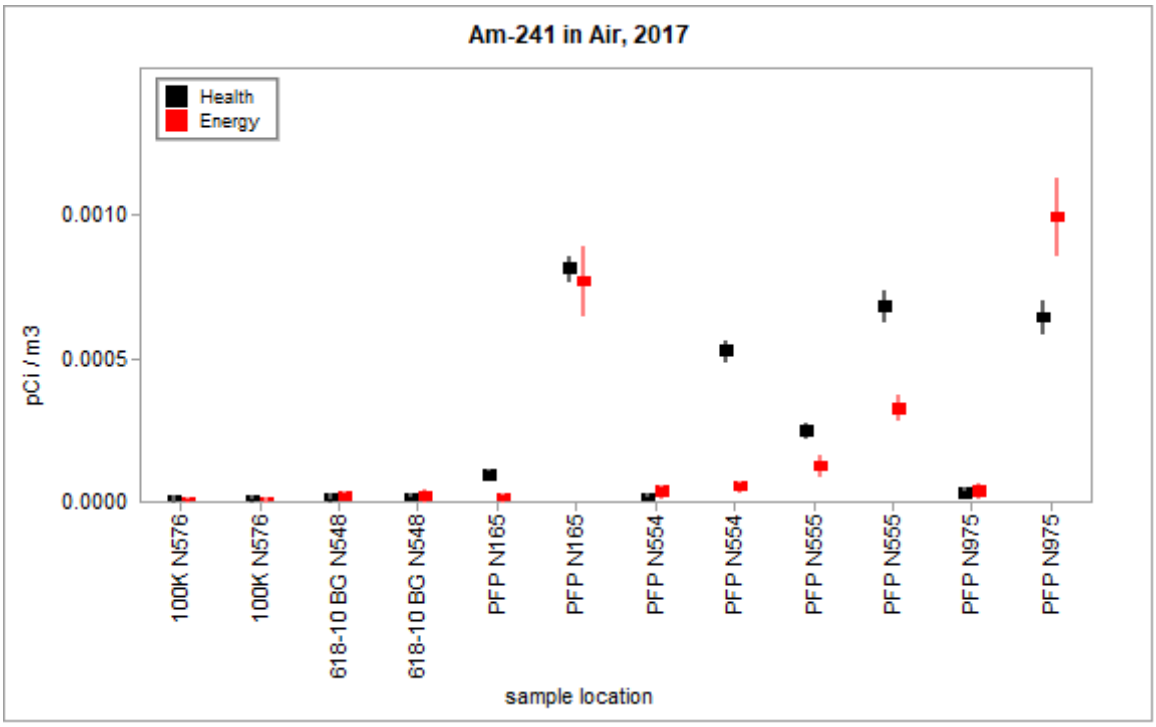


Figure 3.1.14 –

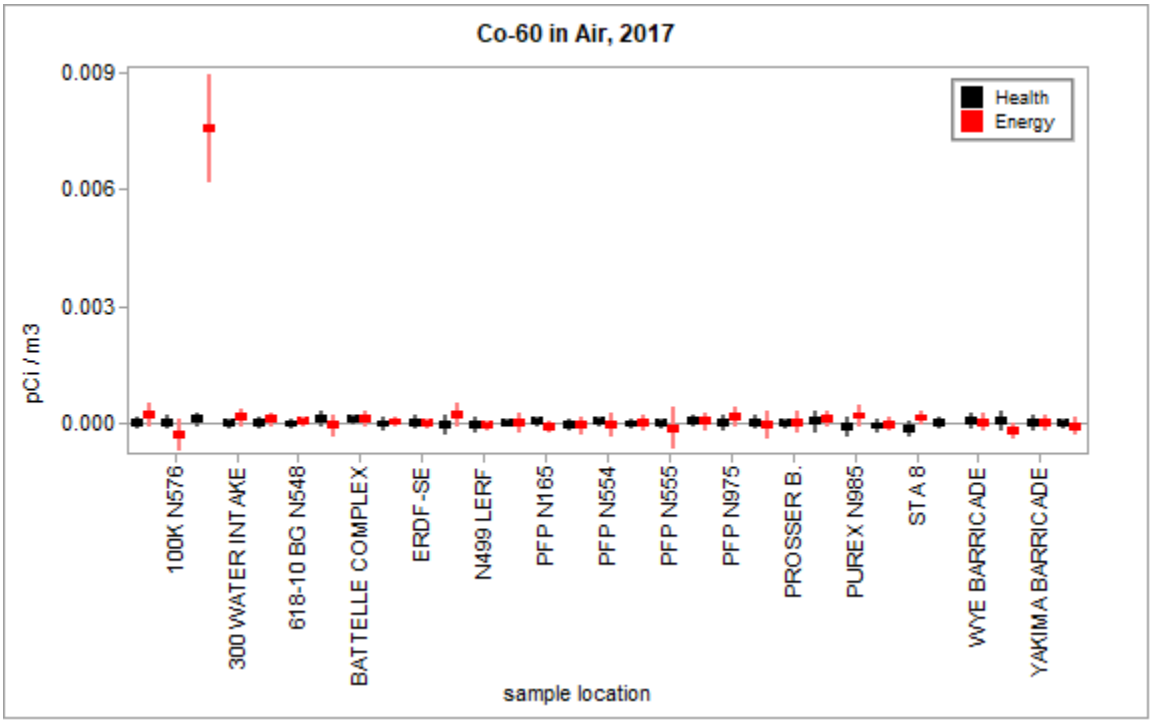


Figure 3.1.15 –

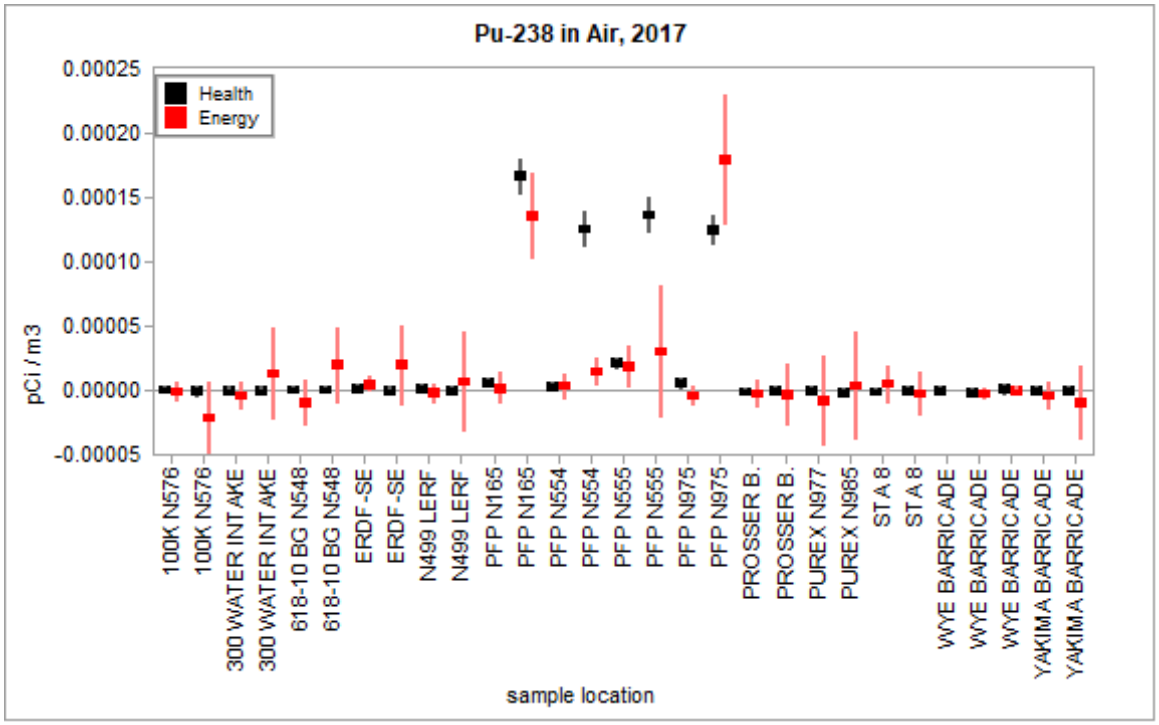


Figure 3.1.16 –

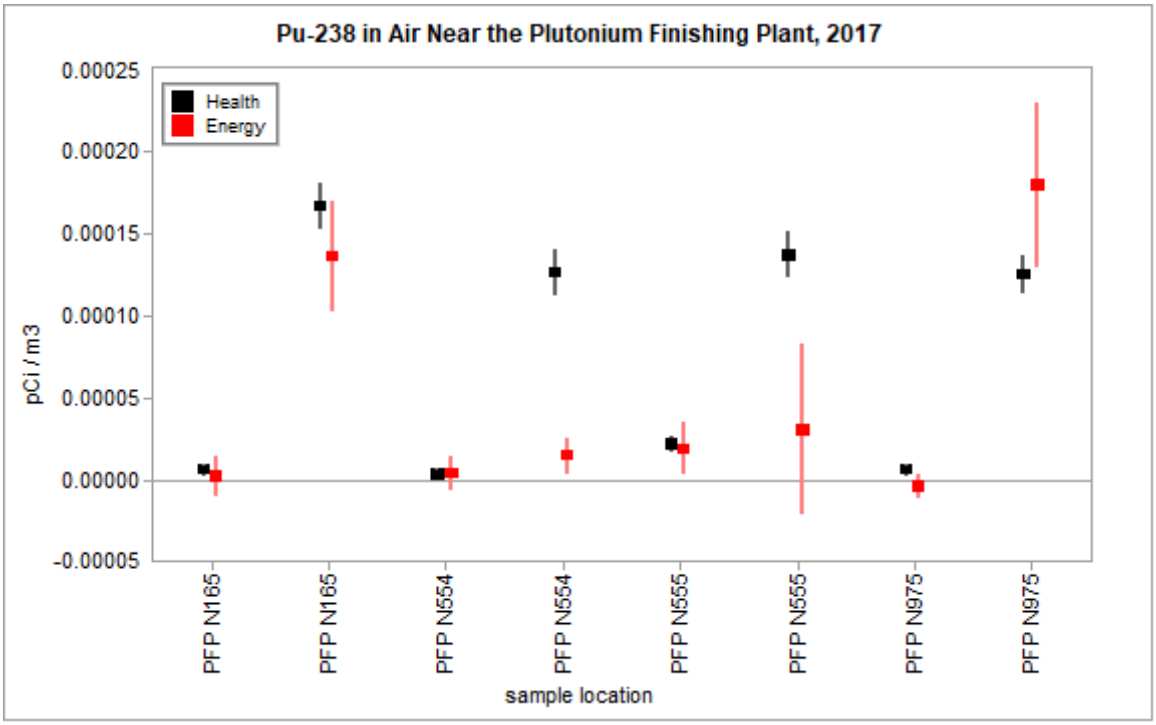


Figure 3.1.17 –

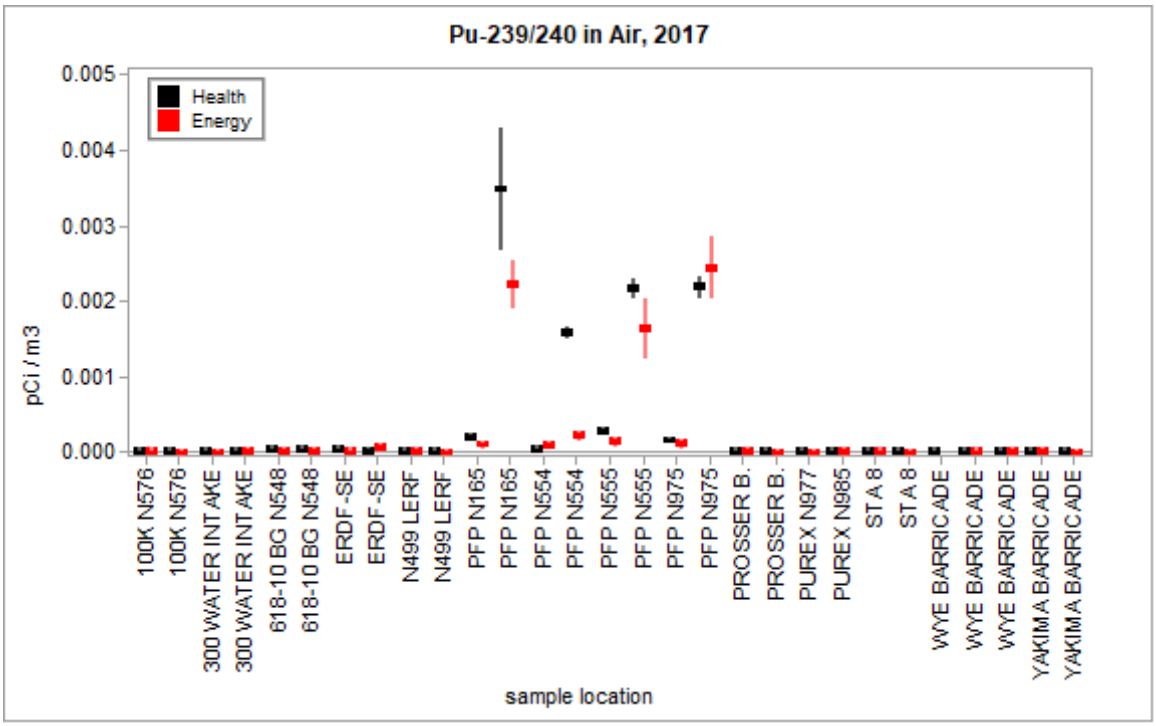


Figure 3.1.18 –

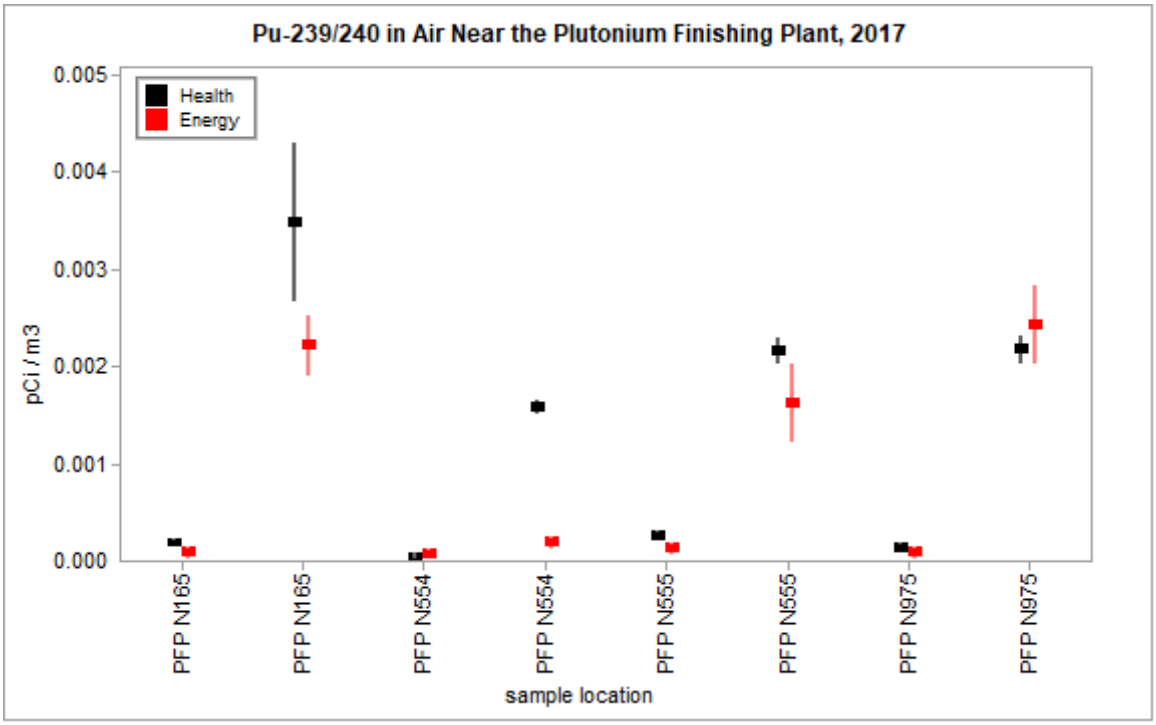


Figure 3.1.19 –

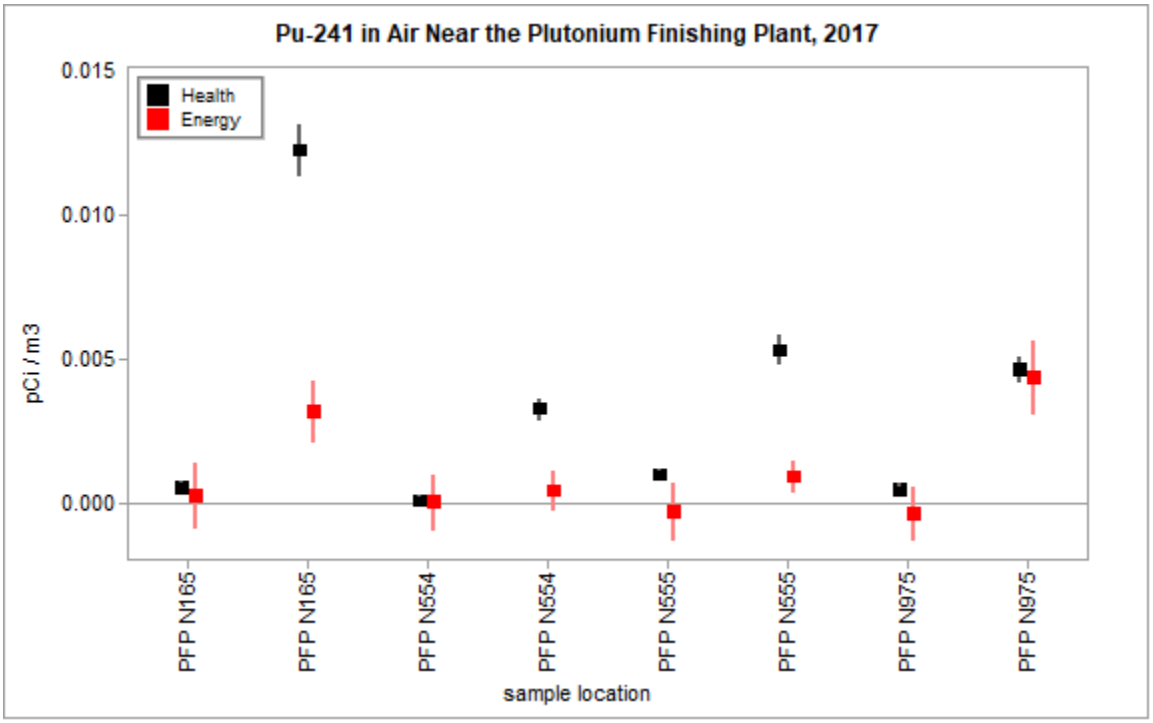
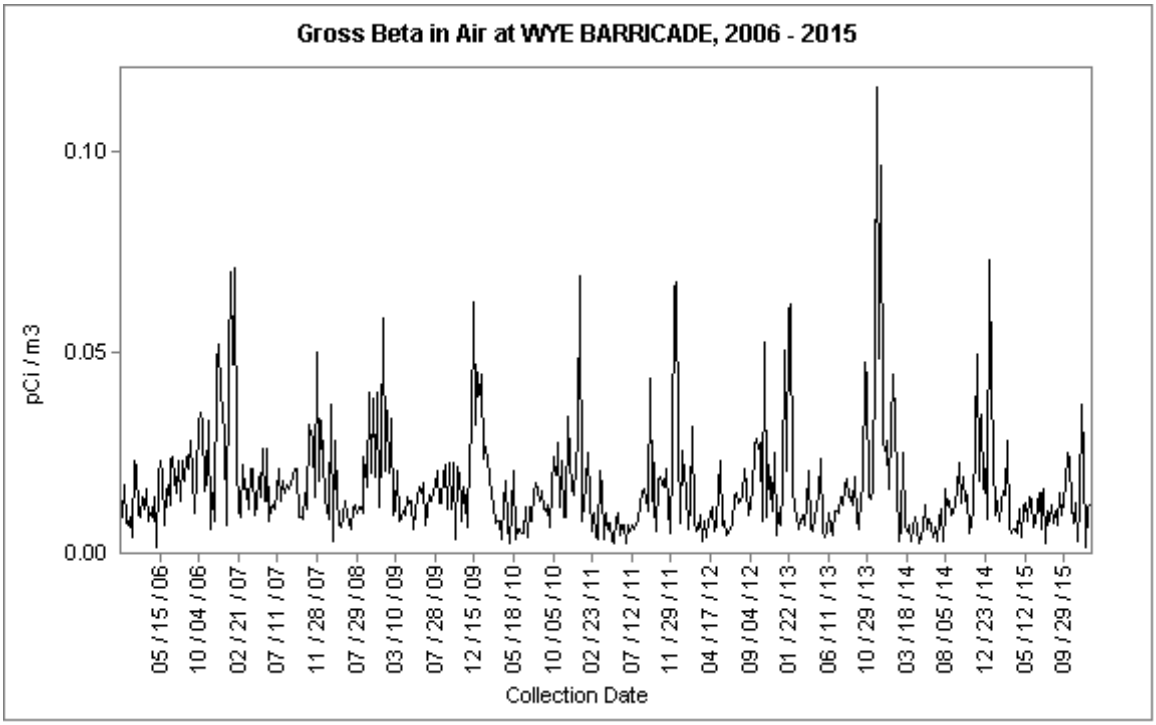


Figure 3.1.20 –


Gross Beta in Air at WYE BARRICADE, 2006 - 2015
pCi / m3
0.10
0.05
0.00
05 / 15 / 06
10 / 04 / 06
02 / 21 / 07
07 / 11 / 07
11 / 28 / 07
07 / 29 / 08
03 / 10 / 09
07 / 28 / 09
12 / 15 / 09
05 / 18 / 10
10 / 05 / 10
02 / 23 / 11
07 / 12 / 11
11 / 29 / 11
04 / 17 / 12
09 / 04 / 12
01 / 22 / 13
06 / 11 / 13
10 / 29 / 13
03 / 18 / 14
08 / 05 / 14
12 / 23 / 14
05 / 12 / 15
09 / 29 / 15
Collection Date

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 beta and C-14; 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 14 groundwater samples (one sample from each of 14 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. For this reporting period, six split samples came from 100 Area wells, five from the 200 Area, one from the 300 Area, and two from the 600 Area.

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 seven 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 (two split samples).

Surface Water

Health and the Energy contractor (MSA) split eleven surface water samples from nine different locations. Four samples were collected from the Columbia River upstream of Hanford (two from Priest Rapids Dam and two 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. Five samples were collected from the Columbia River (three 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. For this reporting period, Health collected one drinking water sample from the LIGO Facility.

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, and then split the sample. The samples are analyzed unfiltered 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.

Table 3.2.1 – Summary of Water Samples Split with Energy Contractors

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 23,000	**yes**
Co-60	annual	12	good	< 2 to 9	**yes**
Cs-134	annual	12	good	< 2	no
Cs-137	annual	12	good	< 2 to 640	no
Eu-152	annual	12	good	< 5	no
Eu-154	annual	12	good	< 5	no
Eu-155	annual	12	good	< 8	no
Gross Alpha	annual	20	good	<5 to 93	no
Gross Beta	annual	20	**fair**	< 2 to 24,000	no
H-3	annual	31	good	< 75 to 340,000	no
I-129	annual	2	good	< 0.6 to 14	no
Pu-238	annual	4	good	< 0.1	no
Pu-239/240	annual	4	good	< 0.05 to 12	no
Sr-90	annual	22	good	< 1 to 11,000	no
Tc-99	annual	15	good	< 4 to 11,000	no
U-234	annual	3	good	5 to 20	no
U-235	annual	3	good	0.2 to 1.3	no
U-236[(a)]	annual			0.6	no
U-238	annual	3	good	5 to 18	no

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

Health and Energy C-14 concentrations in water samples are in fair agreement. Figure 3.2.2 shows all 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. Three of the results are in good agreement, in that the Health and Energy error bars overlap; however, three of the results are in significant disagreement.

Historically, C-14 results for water samples have ranged from fair to poor agreement. Figure 3.2.4 shows the scatter plot for historical Health and Energy split C-14 results in water samples. The plot shows a systematic bias, where Energy consistently reports higher concentrations than Health.

The C-14 result reported by both Health and Energy at 199-K-106A is anomalously high compared to historical data at that well, as C-14 concentrations have been increasing over the last five years. Health's historical data at this groundwater well are shown in Figure 3.2.5.

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 3.2.6), 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 3.2.7 shows the split Cs-137 results. The two wells from the 200 Area (those whose names start with 299) have detectable concentrations of Cs-137 ranging up to 640 pCi/L.

Historically, Health and Energy gross alpha concentrations in water samples range from good to fair agreement. Figure 3.2.8 shows the split gross alpha concentrations. While the graph shows that the error bars overlap for most of the data, Health often reports slightly higher concentrations than Energy, and this trend in the 2017 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 3.2.9 and 3.2.10, 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 340,000 pCi/L. Figure 3.2.11 shows the H-3 split results for concentrations less than 50,000 pCi/L, and Figure 3.2.12 shows the results for concentrations less than 15,000 pCi/L. The split H-3 data are historically in good agreement.

Health and Energy I-129 concentrations in water samples are in good agreement for this reporting period, although historically the agreement is only fair. Health routinely detects I-129 in groundwater well 699-36-70A at concentrations ranging from 5 to 15 pCi/L.

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-239/240, Sr-90, Tc-99, and U-234 results are shown in Figures 3.2.13 - 3.2.17.

The Pu-238 concentrations are all below the detection limit, and detected concentrations of the other radionuclides are consistent with historical results. Pu-239/240 is typically detected in 200 Area groundwater wells, but is not detected at the background location near Vernita. Strontium-90 is typically detected at approximately 10,000 pCi/L at groundwater well 199-N-67 at the 100N Area, and is also detected at lower concentrations in groundwater wells at the 100K and 200 East Areas, and in riverbank seeps along the 100 Area. Technetium-99 is typically detected at 100 and 200 Area groundwater wells, while isotopes of uranium are detected in 200 and 300 Area groundwater wells.

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. Uranium - 236 is often detected in groundwater well 399-1-17A, at the 300 Area, at concentrations near 0.5 pCi/L. In addition, 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 6,500 pCi/L. No other radionuclides were detected. Health independently collected a drinking water sample from the LIGO Facility at Hanford's 600 Area, and all results were below detection limits.

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

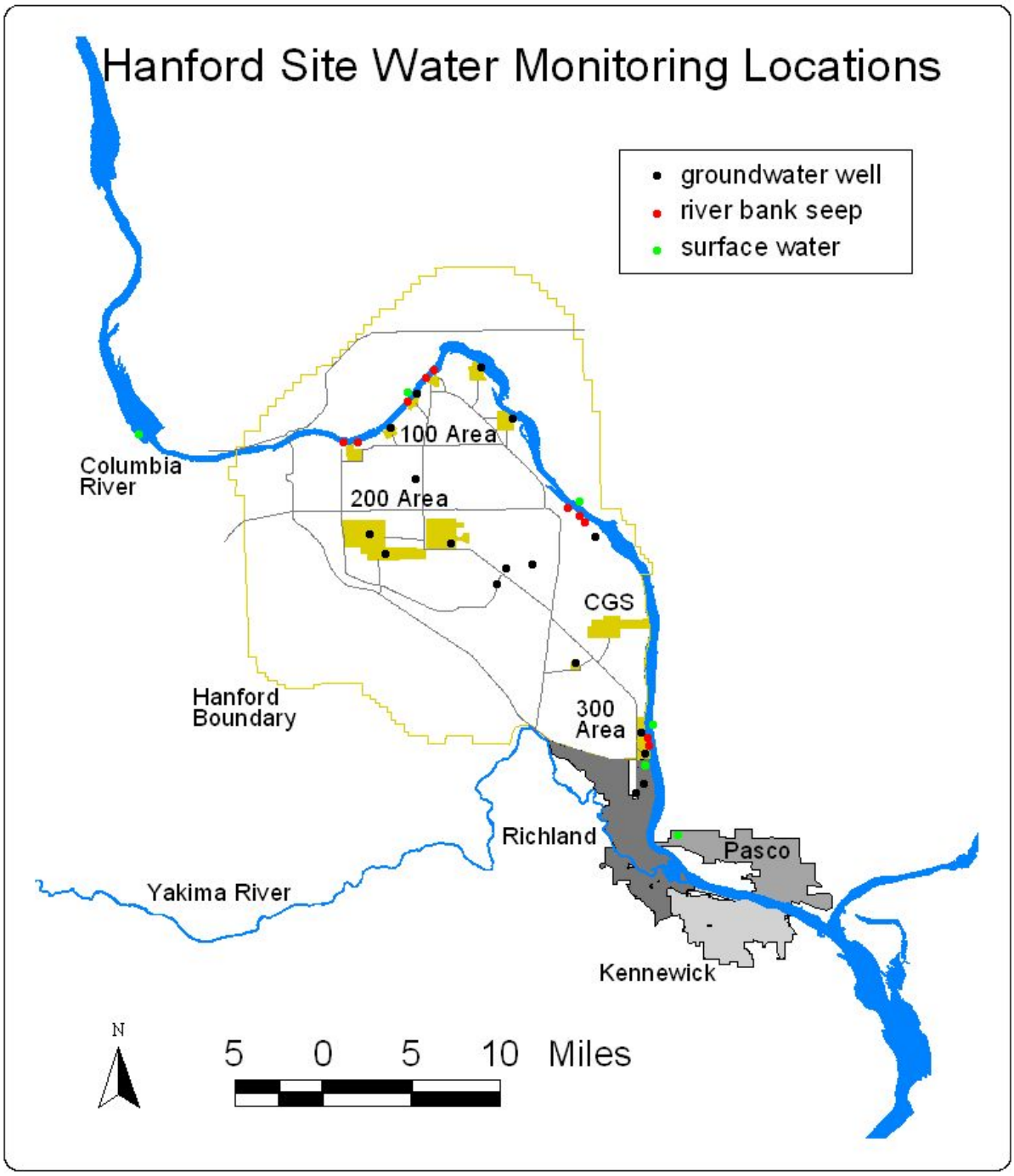
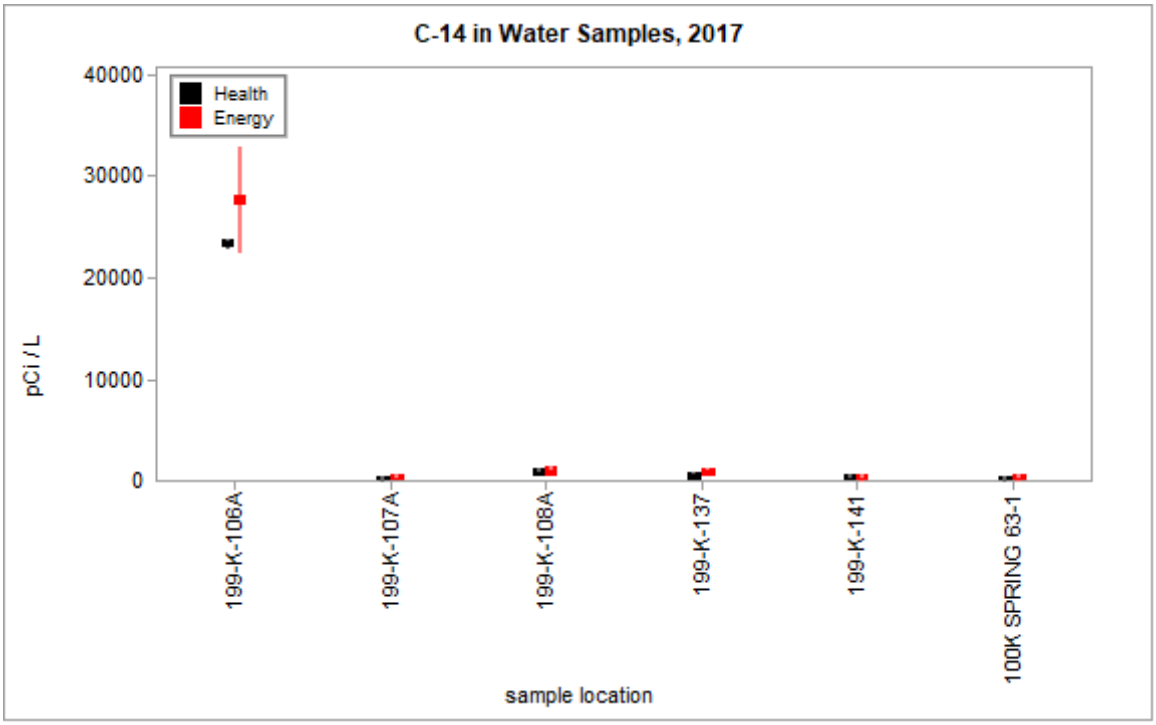


Figure 3.2.2 –



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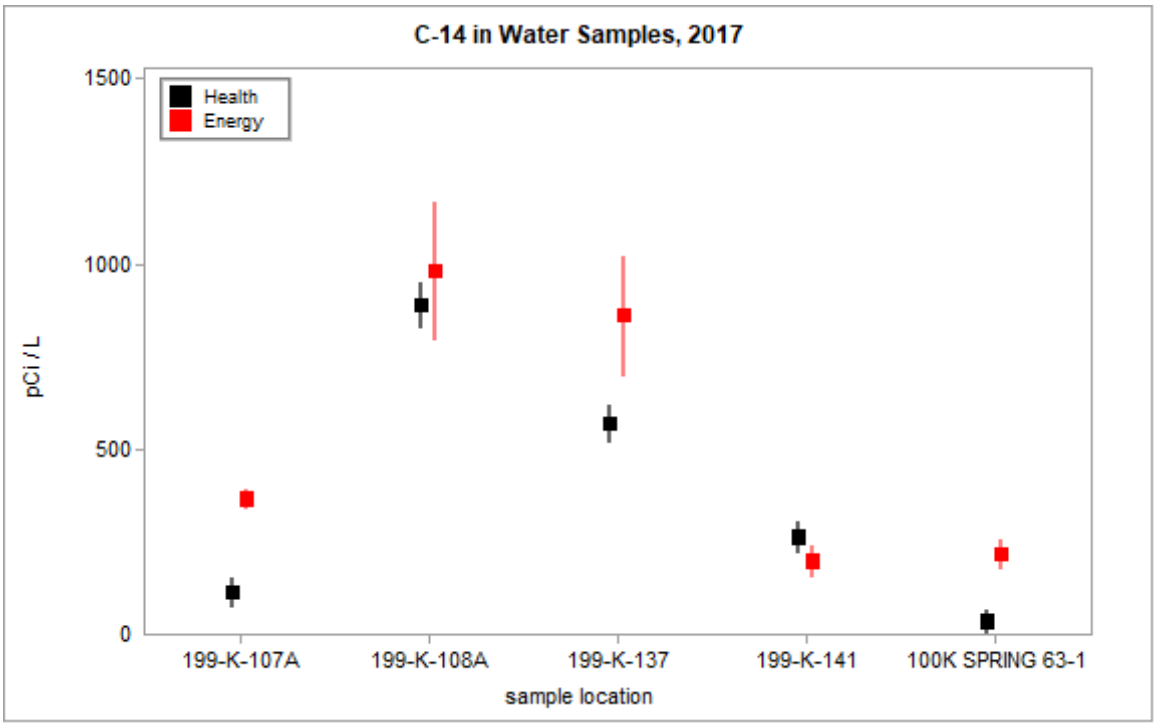


Figure 3.2.4 – Scatter Plot Historical C-14 Concentrations in Water

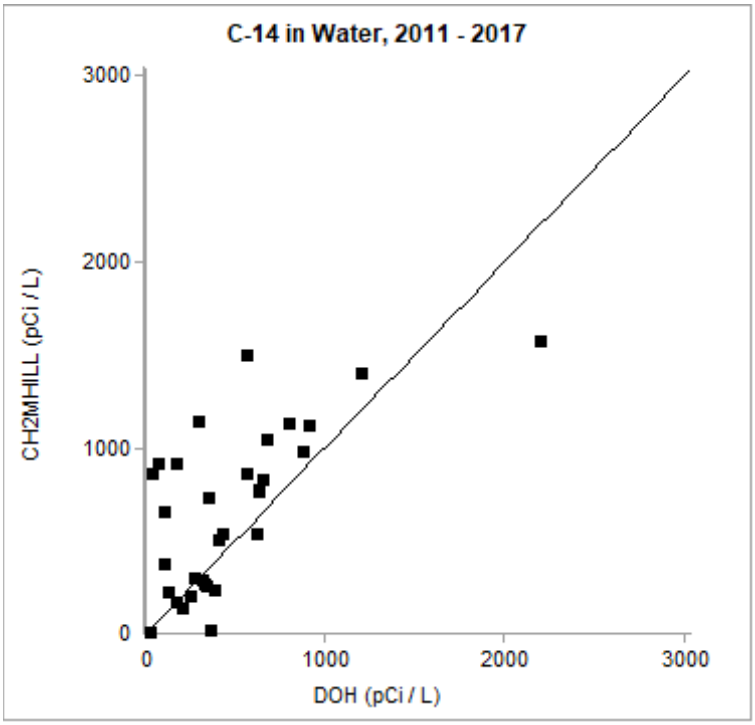


Figure 3.2.5 – Historical C-14 Concentrations

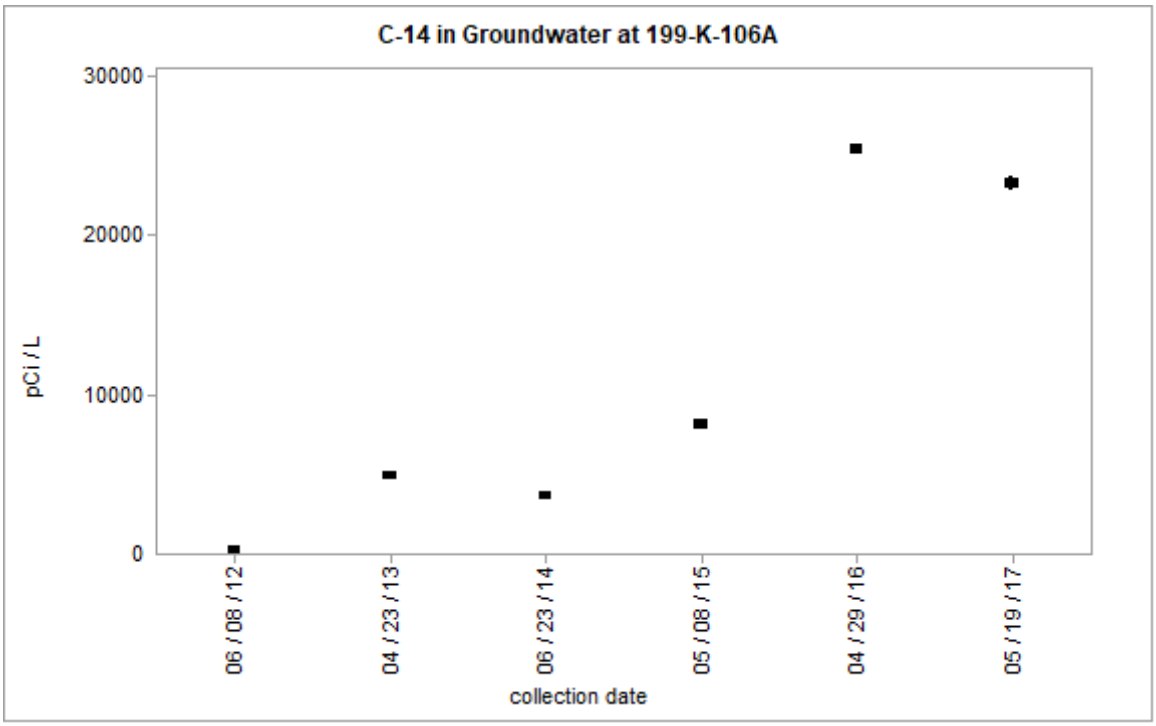


Figure 3.2.6 – Historical Co-60 Concentration

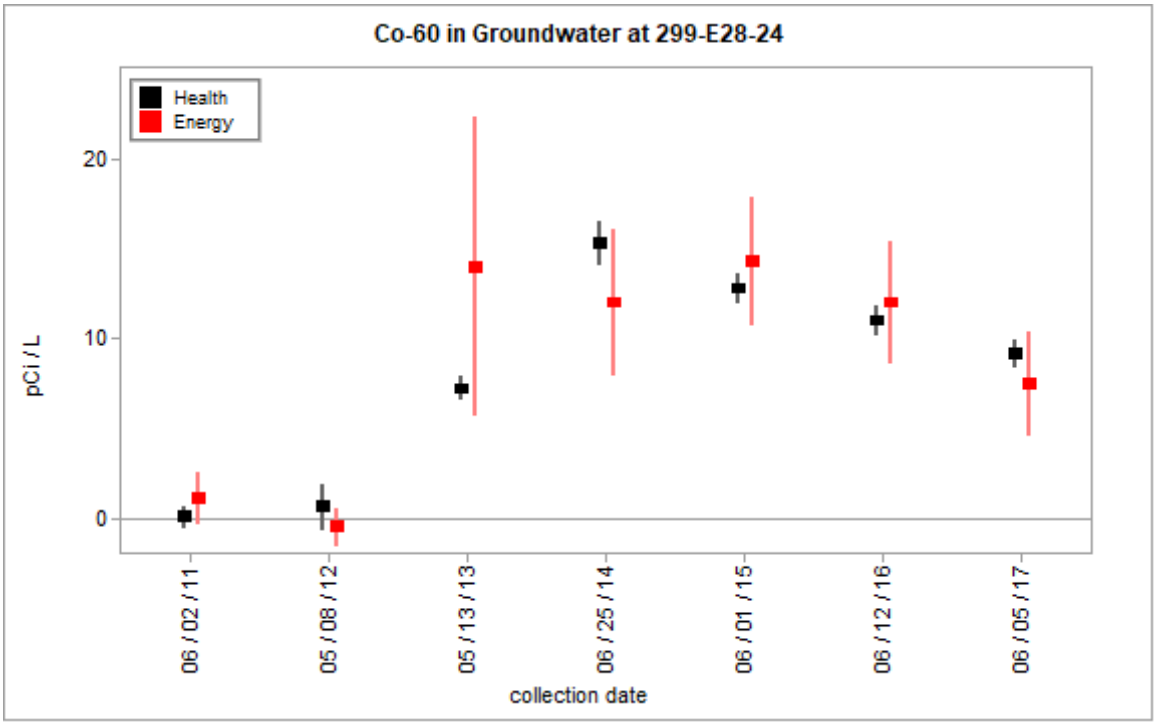


Figure 3.2.7 –

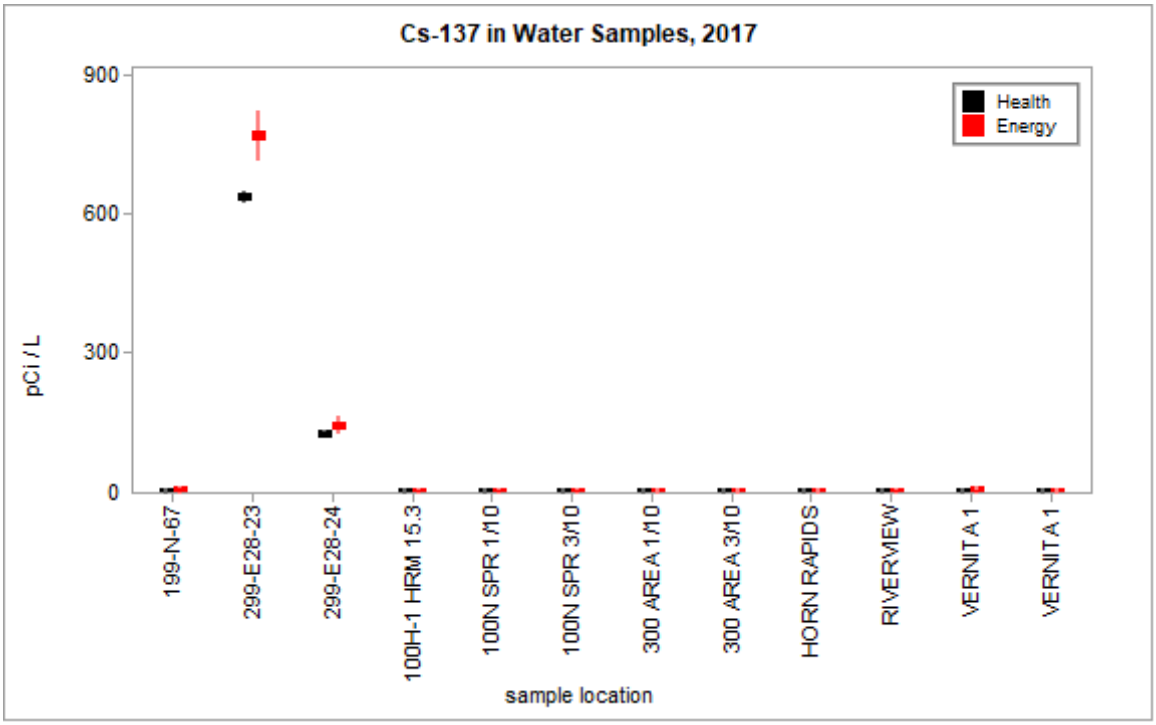


Figure 3.2.8 –

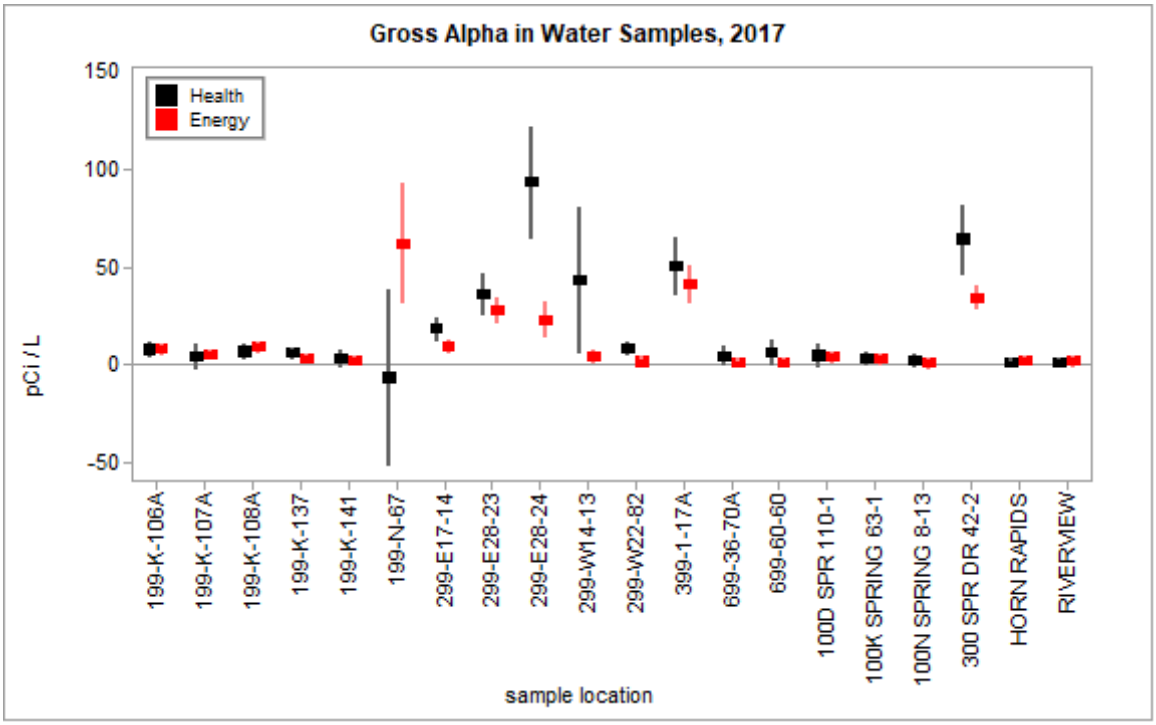


Figure 3.2.9 –

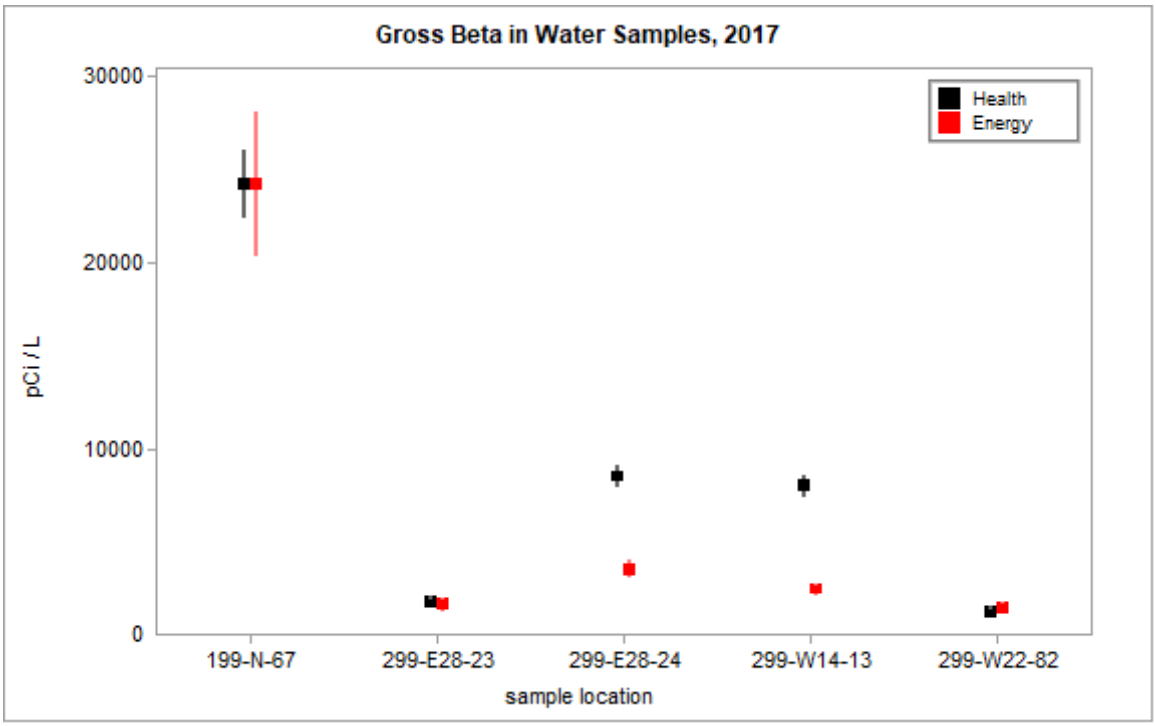


Figure 3.2.10 –

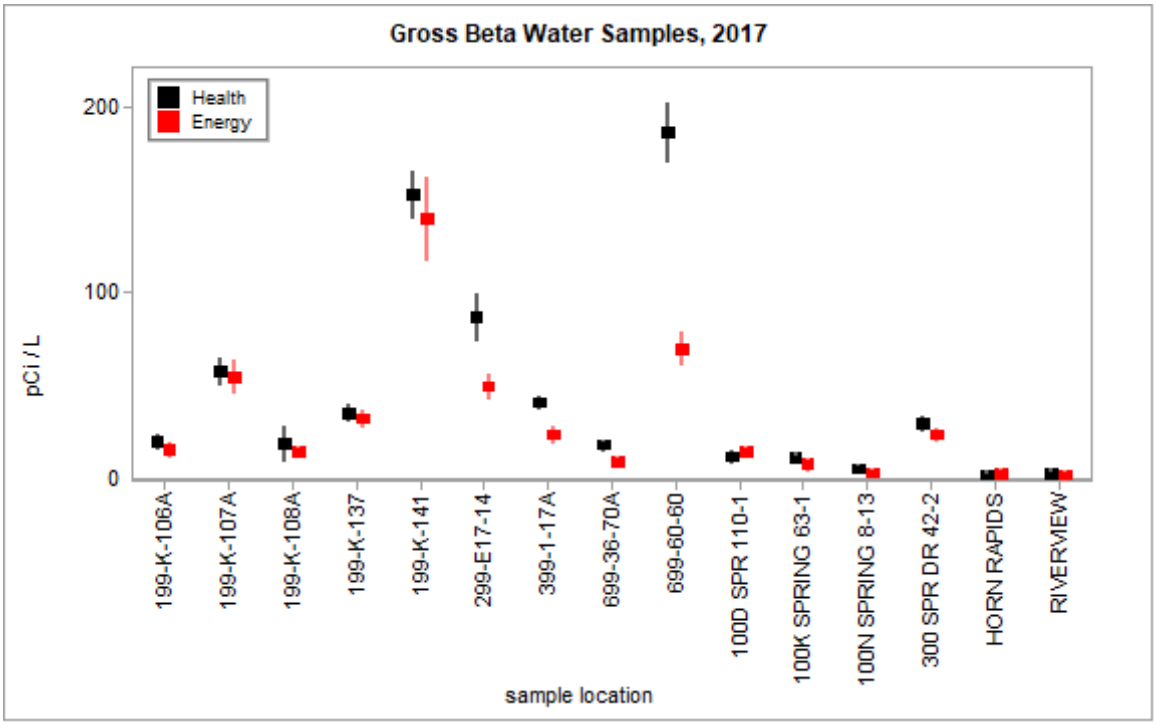


Figure 3.2.11 –

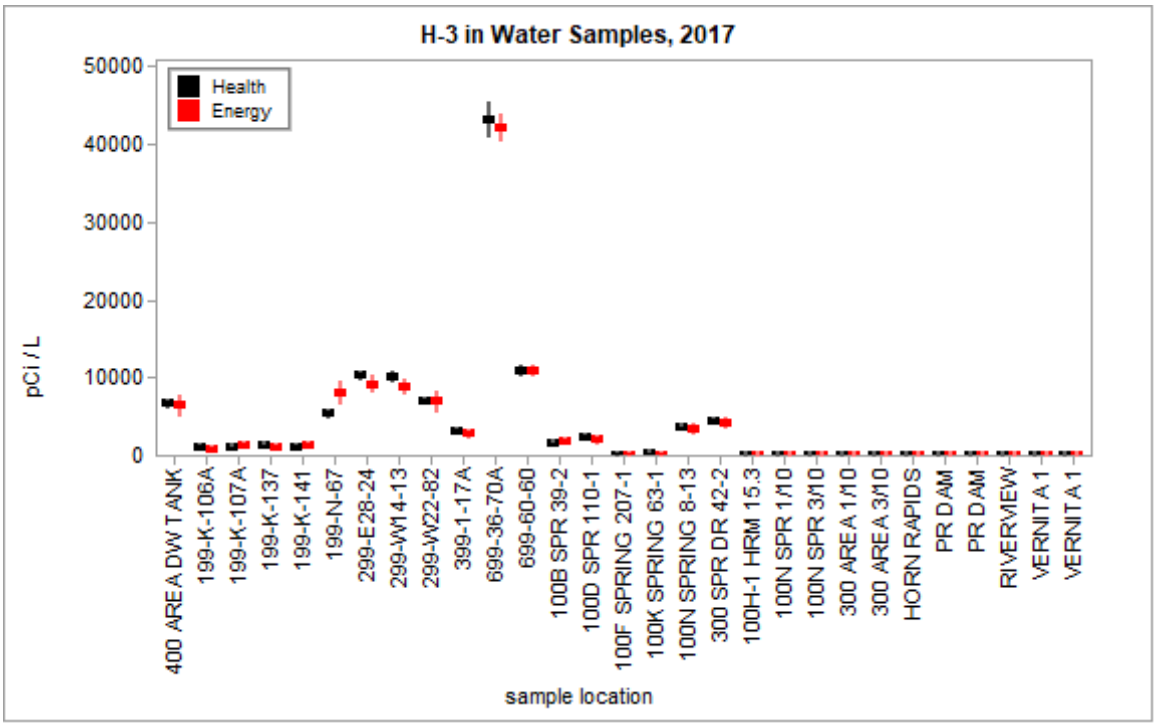


Figure 3.2.12 –

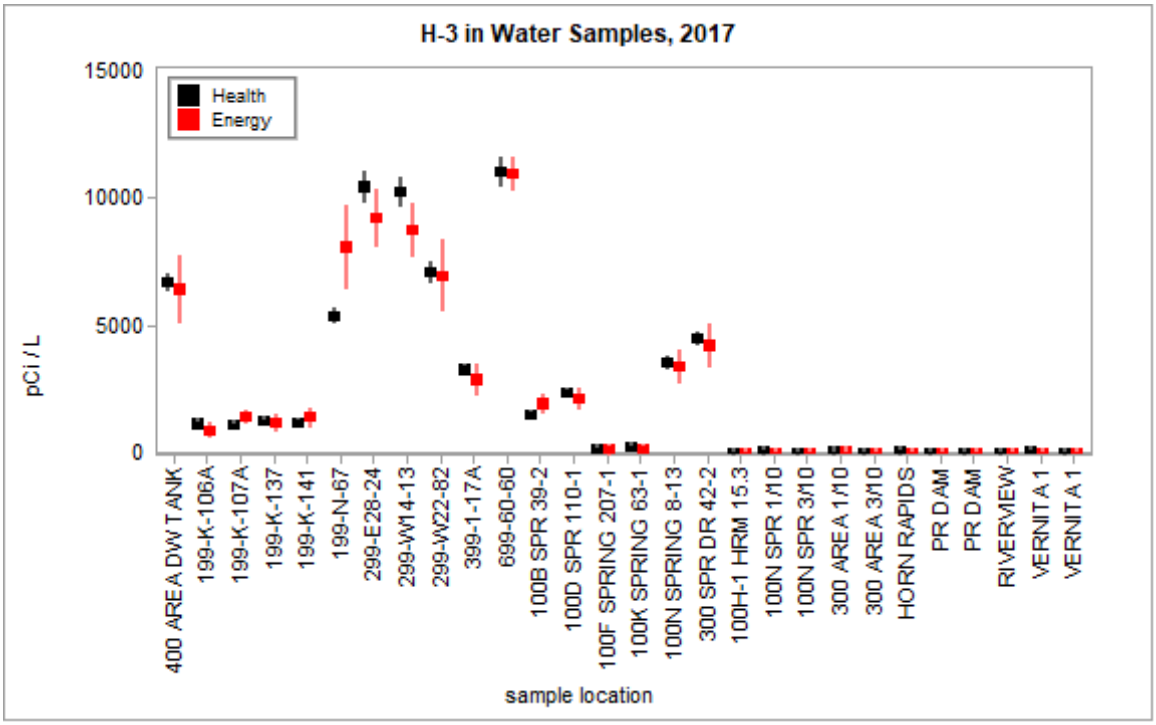


Figure 3.2.13 –

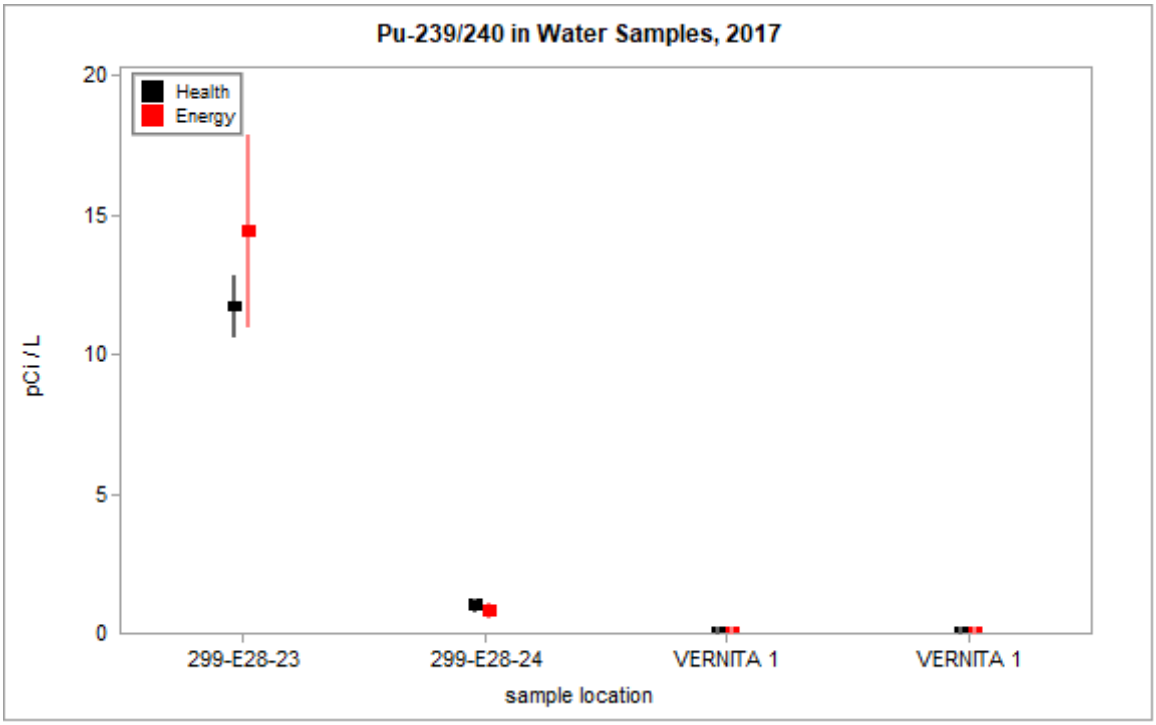


Figure 3.2.14 –

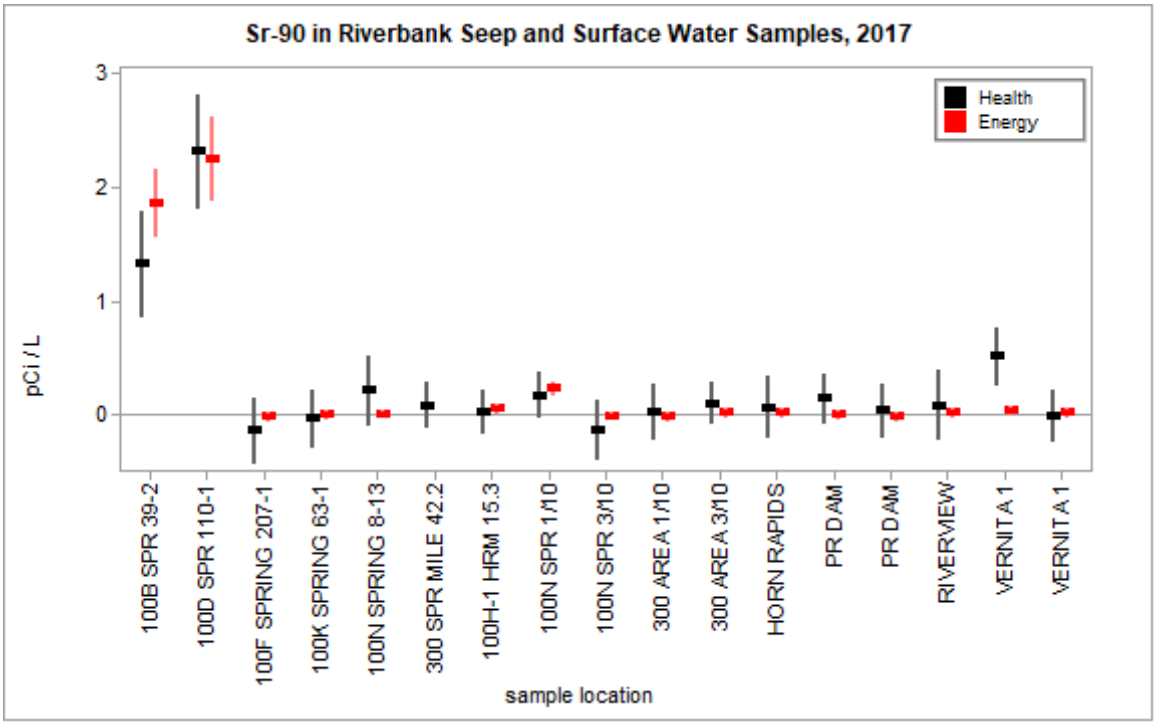


Figure 3.2.15 –

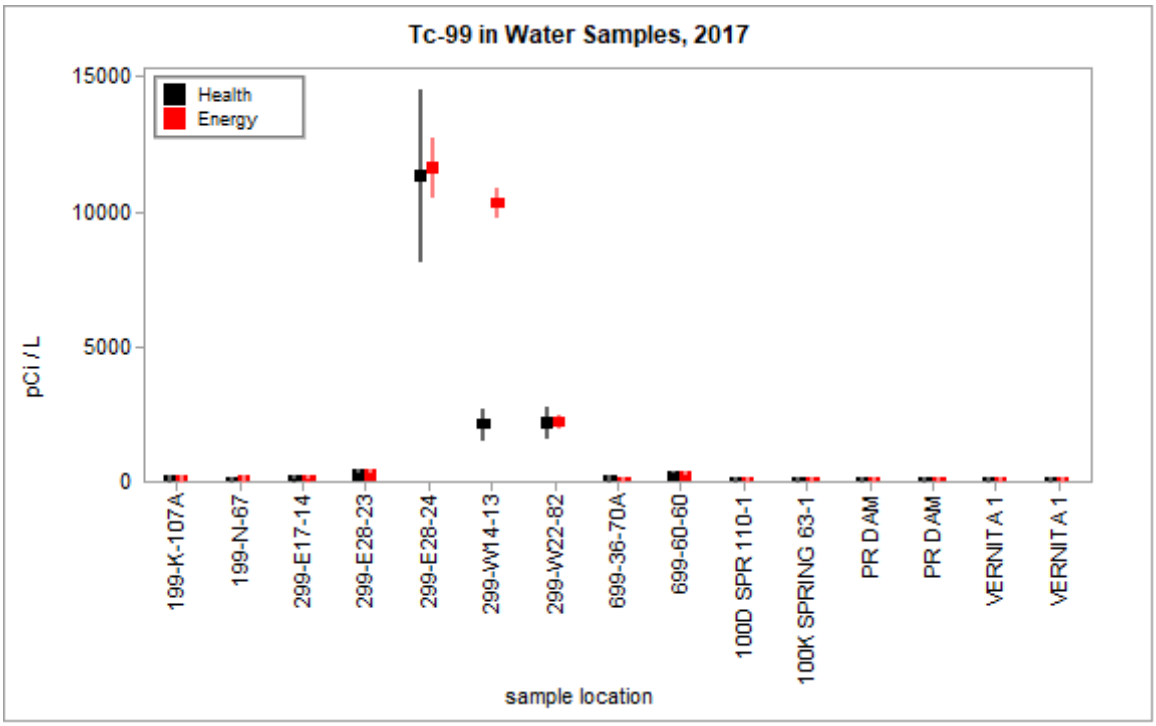
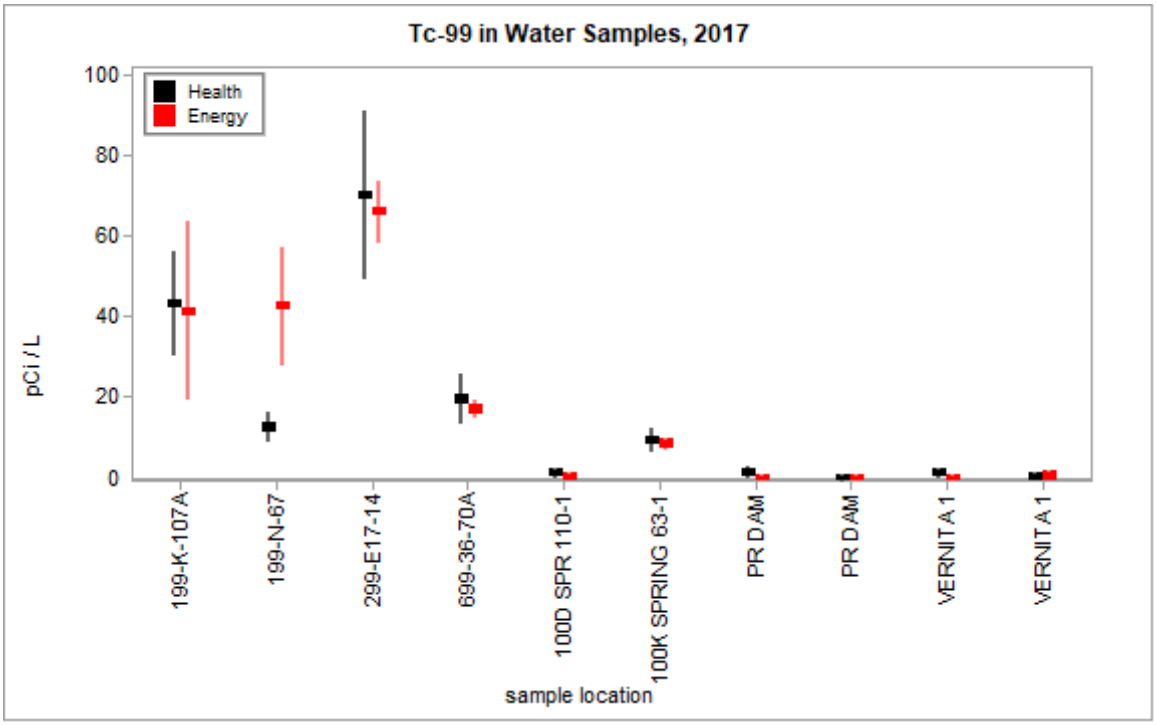


Figure 3.2.16 –



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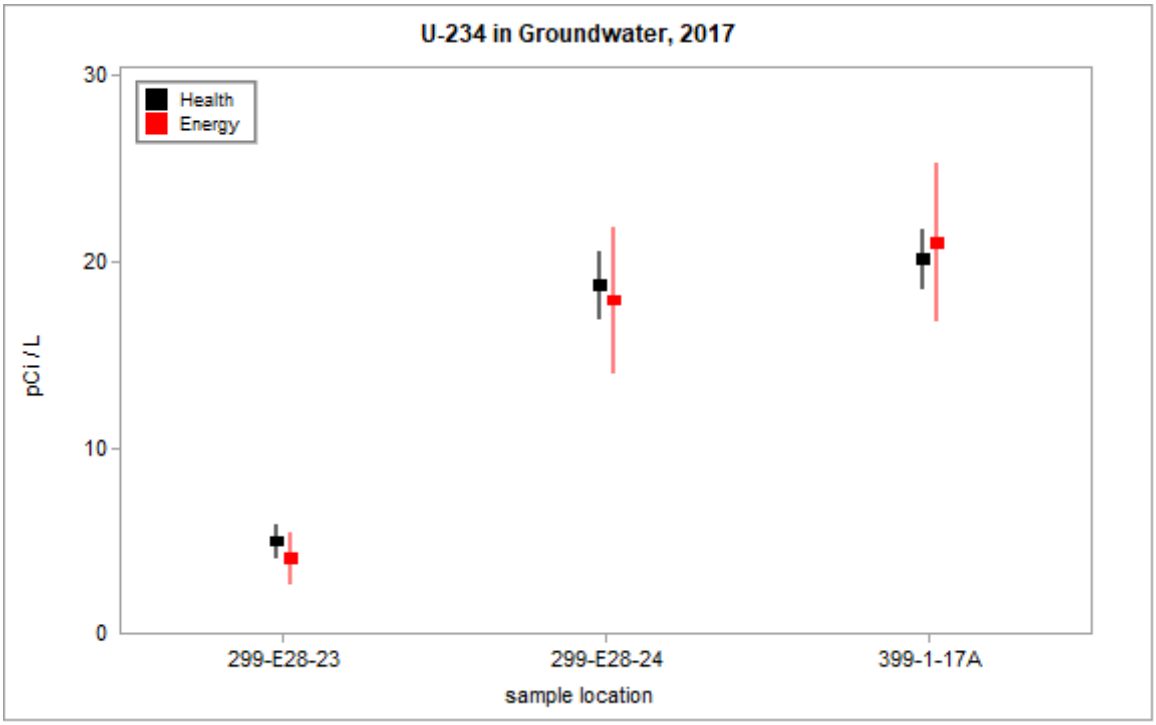


3.3 External Radiation Monitoring

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 external radiation monitoring program, Health compares on-site and off-site external radiation rates to determine if Hanford related contamination 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 55 external radiation monitoring locations that are relevant to the Hanford Site. Health's Hanford Environmental Radiation Oversight Program operates 47 of these sites, in which dosimeters from six sites are collocated with Energy's Near-Facilities and Operations program currently run by Mission Support Alliance (MSA), and Health independently monitors 41 sites. Nine sites are part of Health's Columbia Generating Station (CGS) Oversight Program, and they are included in this report because the sites are located along the Hanford perimeter. One of the 55 sites is operated for both the Hanford and CGS oversight programs.

Figure 3.3.1 shows most of Health's external radiation monitoring locations. Fifteen 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).

Table 3.3.1 –Summary of External Radiation Collocated Dosimeters

Analyte	Collection Period	Number of Results	Quality of Agreement	Health's Data Range (mR/day)	Anomalous Data?
External Rad	quarterly	22	good	0.19 to 0.33	no

The Health and Energy quarterly collocated external radiation rate data are in good agreement. Figure 3.3.2 shows the collocated data for Health and Energy dosimeters collected in 2017, where the error bars overlap for most results. At each location, the graph first shows the fourth quarter data from 2016, followed by the first, second, and third quarter data for 2017. The prior year's fourth quarter results are included because the collection date for these dosimeters was in early January of 2017.

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. The scatter plot shows that on average, Health's measured radiation rates are slightly higher than those of Energy.

The frequency distribution for the relative percent difference (RPD) between the Health and Energy results, shown in Figure 3.3.4, quantifies this slight bias seen in the scatter plot. The RPD is defined as $(x - y)/((x + y)/2)$, where x is the Health result and y is the Energy result. Most of the results have a positive RPD between 0% and 20%, indicating that Health generally reports slightly higher radiation rates than Energy for the same sites.

3.3.5 Other Discussion

Including the six sites collocated with the Energy contractor discussed above; Health operates a total of 55 external radiation monitoring locations. Table 3.3.2 summarizes the data from these 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.

Table 3.3.2 – Summary of Independent Department of Health External Radiation Dosimeters

Analyte	Collection Period	Number of Results	Health's Data Range (mR/day)	Anomalous Data?
External Rad	Quarterly / Semiannual	170	0.16 to 0.37	no

Health categorizes its external radiation monitoring sites by their location type, as described in Section 3.3.2. Figure 3.3.5 shows the average, minimum, and maximum radiation rates for all of the sites in each location category. This graph includes data from all 55 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 at approximately 0.2 mR/day, which is consistent with exposure rates from locations away from contaminated areas.

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, approximately 0.2 mR/day. 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.

Figure 3.3.1 – DOH External Radiation Monitoring (TLD) Locations

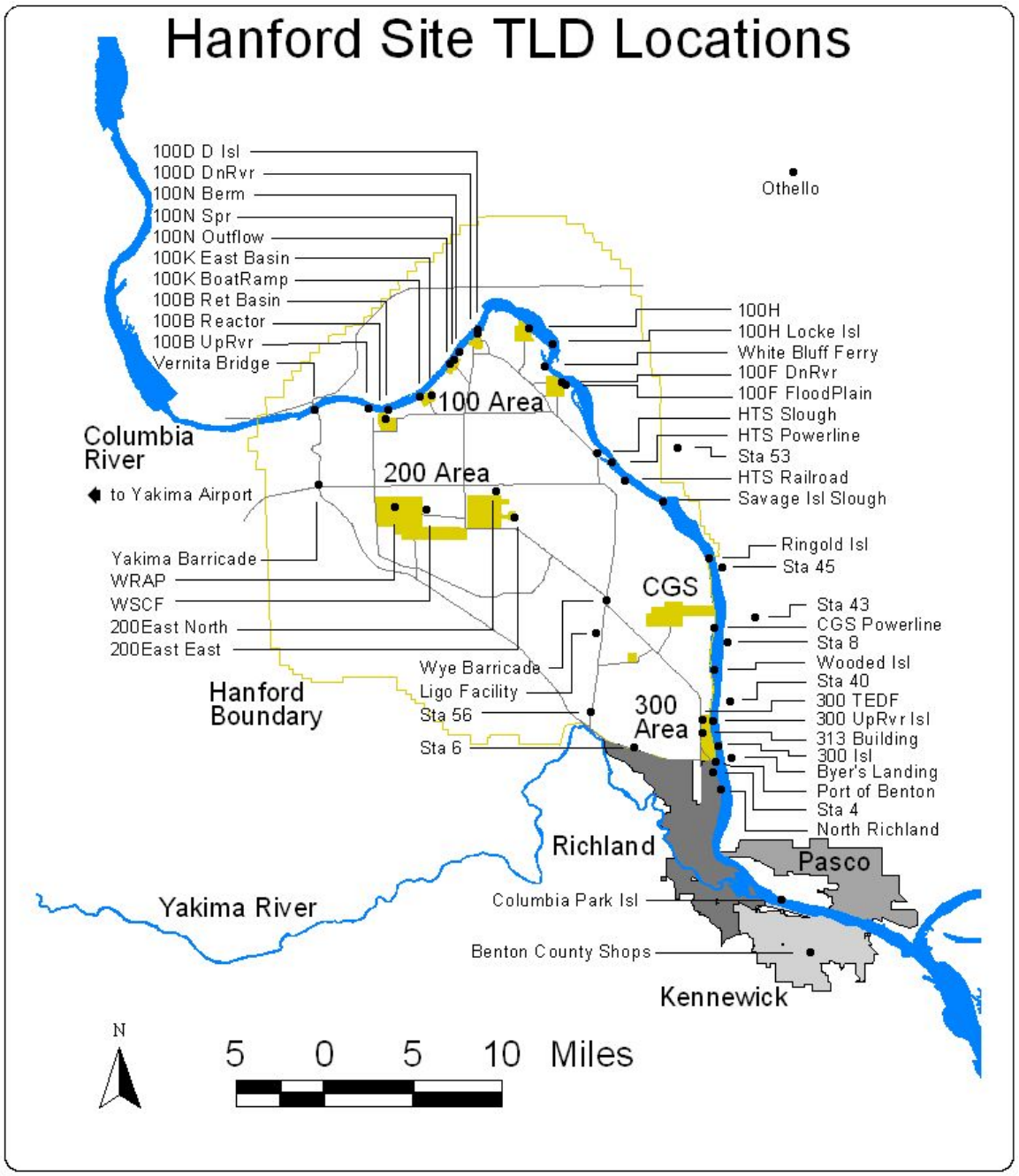


Figure 3.3.2 –

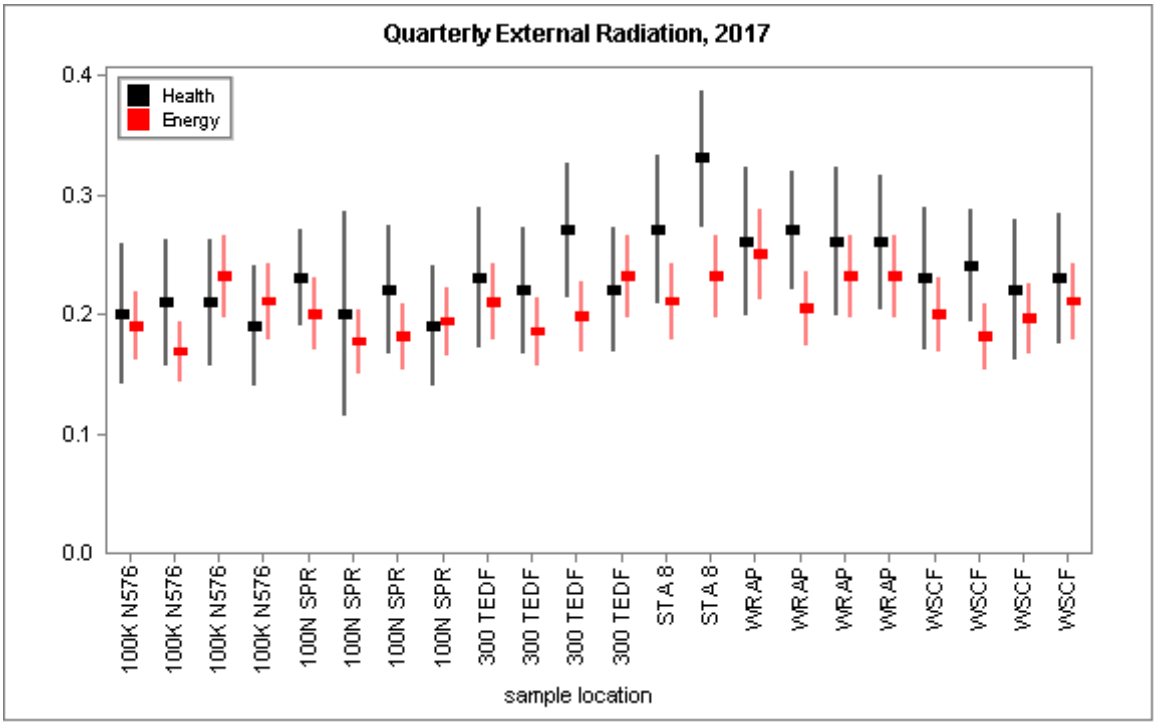


Figure 3.3.3 –

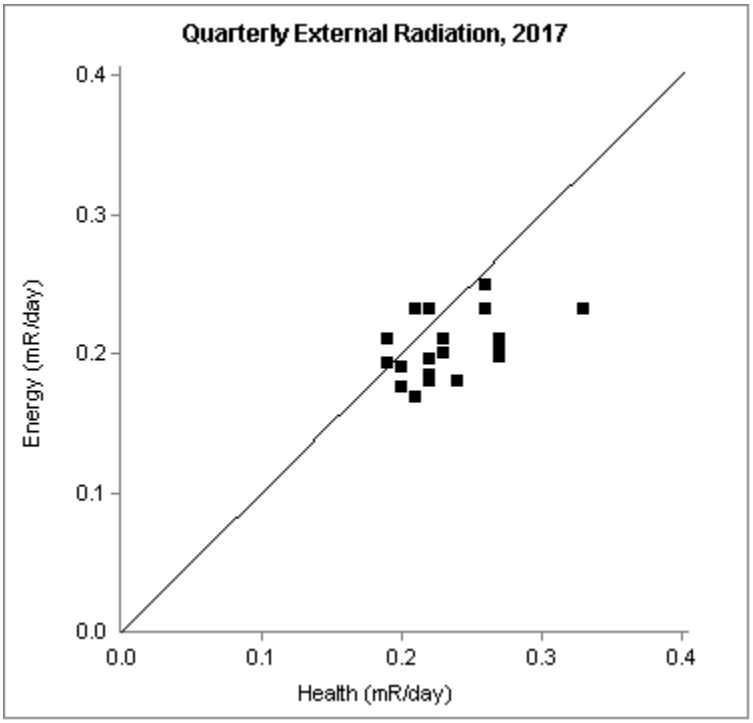


Figure 3.3.4 –

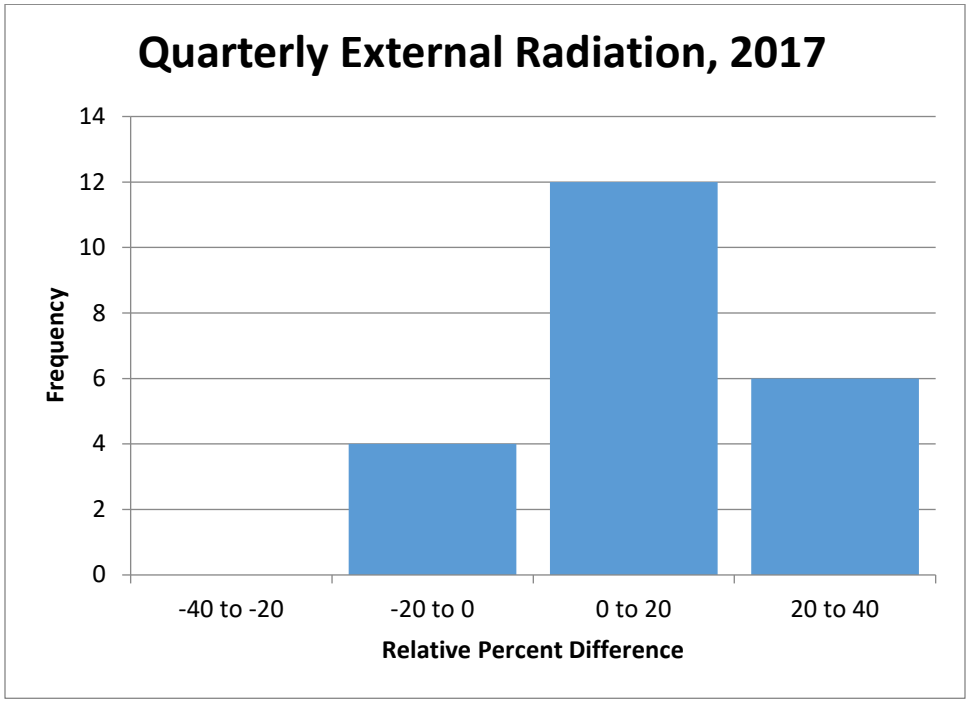
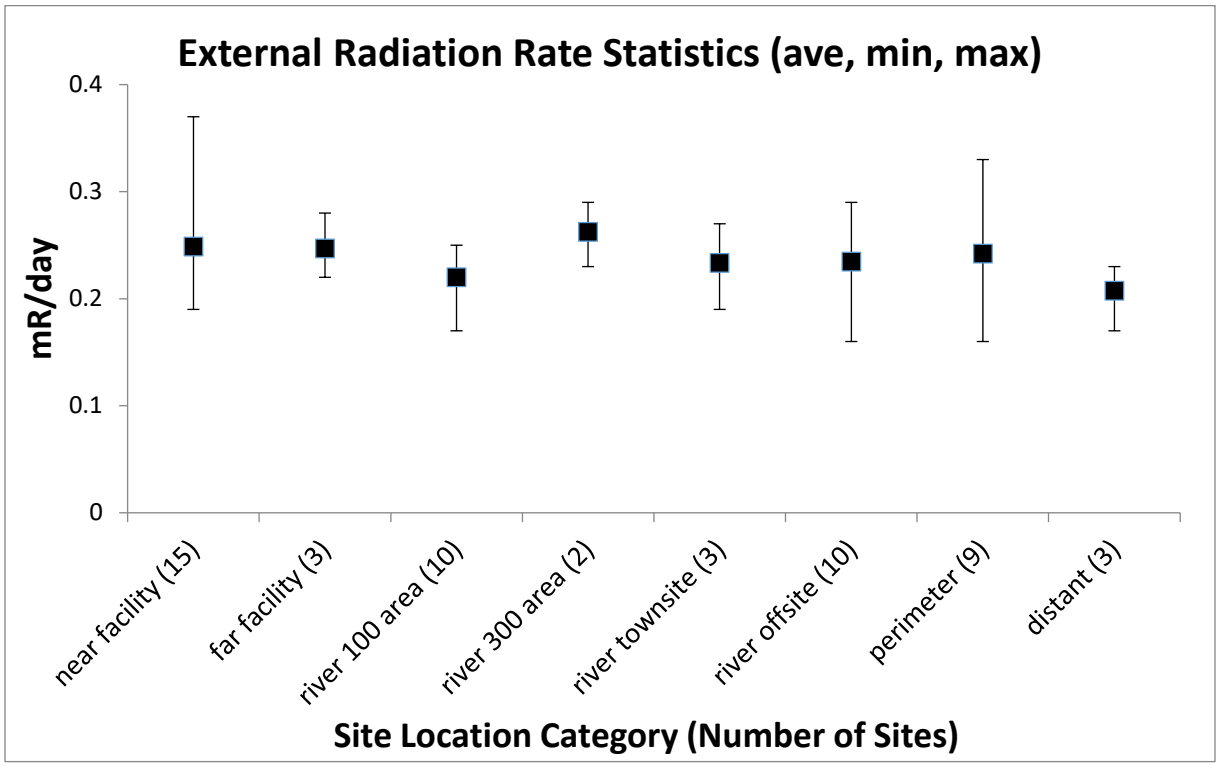


Figure 3.3.5 –



3.4 Soil and Sediment Monitoring

Major Findings:

- Health and Energy soil and sediment data are in poor agreement for C-14, fair agreement for U-234 and U238, and 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 from any potential Hanford releases. 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 five soil samples from locations on the Hanford Site; one sample each from the 200 East, 300, and 600 Areas, and two samples from the 200 West Area.

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).

Table 3.4.1 – Summary of Sediment Samples

Analyte	Collection Period	Number of Split Results	Quality of Agreement	Health's Data Range (pCi/g)	Anomalous Data?
C-14	annual	1	**poor**	15	no
Co-60	annual	13	good	< 0.02	no
Cs-134	annual	13	good	< 0.08	no
Cs-137	annual	13	good	< 0.01 to 2.7	no
Eu-152	annual	13	good	< 0.05 to 0.08	no
Eu-154	annual	13	good	< 0.05	no
Eu-155	annual	13	good	< 0.08	no
Pu-238	annual	13	good	< 0.04	no
Pu-239/240	annual	13	good	< 0.02 to 0.2	no
Sr-90	annual	8	good	< 0.007 to 0.011	no
U-234	annual	13	**fair**	0.5 to 1.4	no
U-235	annual	13	good	< 0.02 to 0.06	no
U-238	annual	13	**fair**	0.5 to 1.3	no

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.

The single C-14 result from the 100K Area sample is in poor agreement (see Figure 3.4.2). Health detected 15 pCi/g, while Energy's result is less than their detection limit of approximately 1 pCi/g. The source of the significant discrepancy is not known, but it is possible that Health's split sample had a discreet C-14 particle whereas Energy's did not. Health has limited historical data for C-14 in sediment, with results from the Columbia River ranging from 1 to 15 pCi/g.

Figure 3.4.3 shows the Health and Energy split results for Cs-137. The Health and Energy results are in good agreement, and Health's results range from below the detection limit of 0.01 pCi/g to 2.7 pCi/g. Historically, the agreement in split results ranges from good to fair.

Figure 3.4.4 shows the Health and Energy split results for Pu-239/240, which are in good agreement. Health detected Pu-239/240 in soil samples from the 200 West Area at concentrations of 0.2 and 0.04 pCi/g.

The Health and Energy results for Sr-90 in sediment samples are in good agreement, as can be seen in Figure 3.4.5. Energy's detection limit (approximately 0.02 pCi/g) is an order of magnitude greater than Health's (approximately 0.001 pCi/g). For example, a concentration of 0.01 pCi/g would be considered detected by Health, and not detected by Energy. The larger error bars in the Energy data is a reflection of their higher detection limit.

The five soil samples were also analyzed for Sr-90; however, Health's laboratory has not completed the analysis at the time of this report, so those data will be discussed in a future annual report.

The Health and Energy U-235 results are in good agreement with most concentrations near the detection limit of approximately 0.04 pCi/g.

The Health and Energy U-234 and U-238 results are in good agreement for the sediment data, and in fair agreement for the soil data, as shown for U-234 in Figure 3.4.6 (the U-238 data are similar). Four of the five soil results indicate a systematic difference in which Energy reports concentrations approximately one-half those of Health. This same bias is not seen in the U-235 data.

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 3.4.3 through 3.4.6, the Cs-137, Sr-90, Pu-239/240, 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

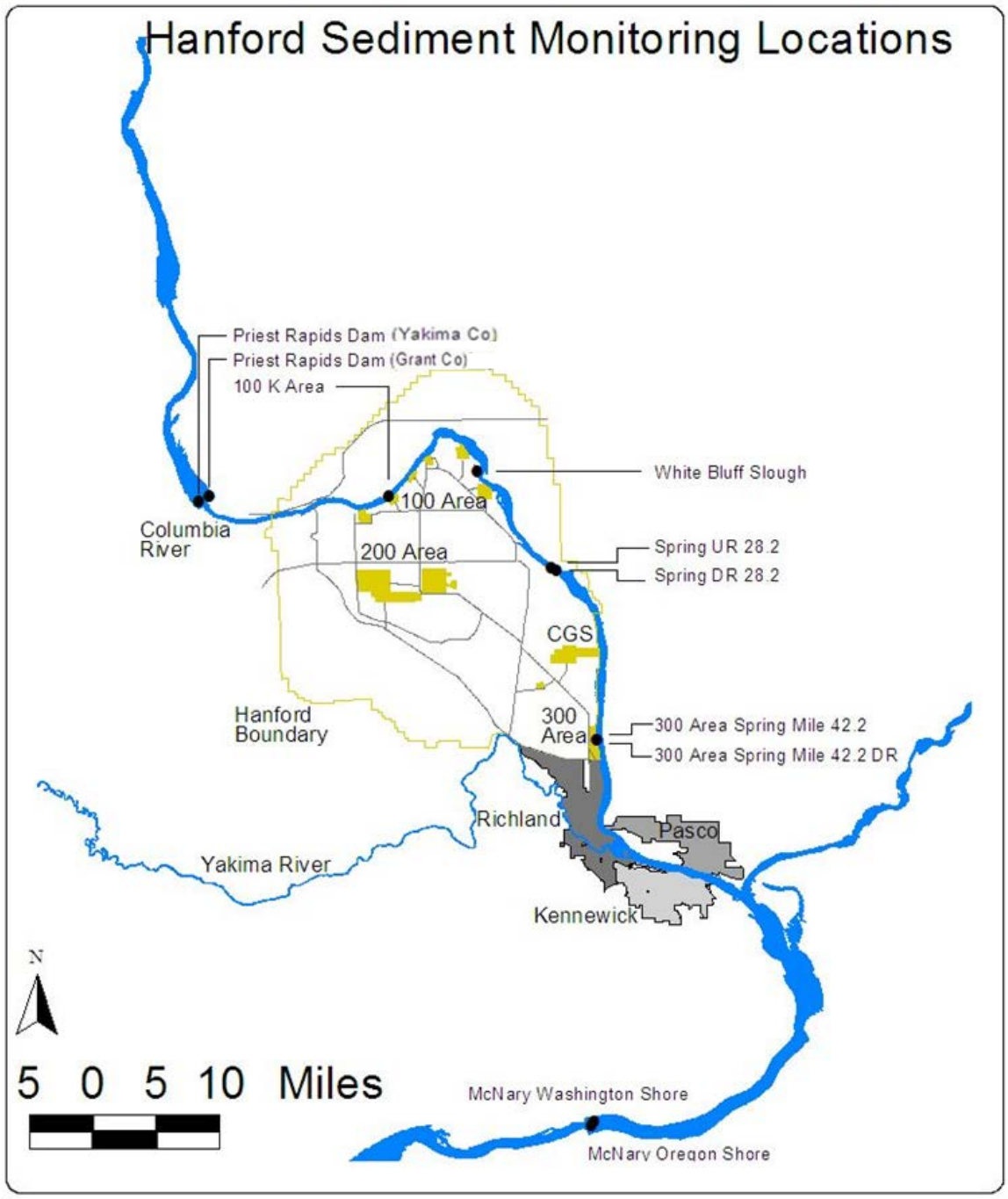


Figure 3.4.2 –

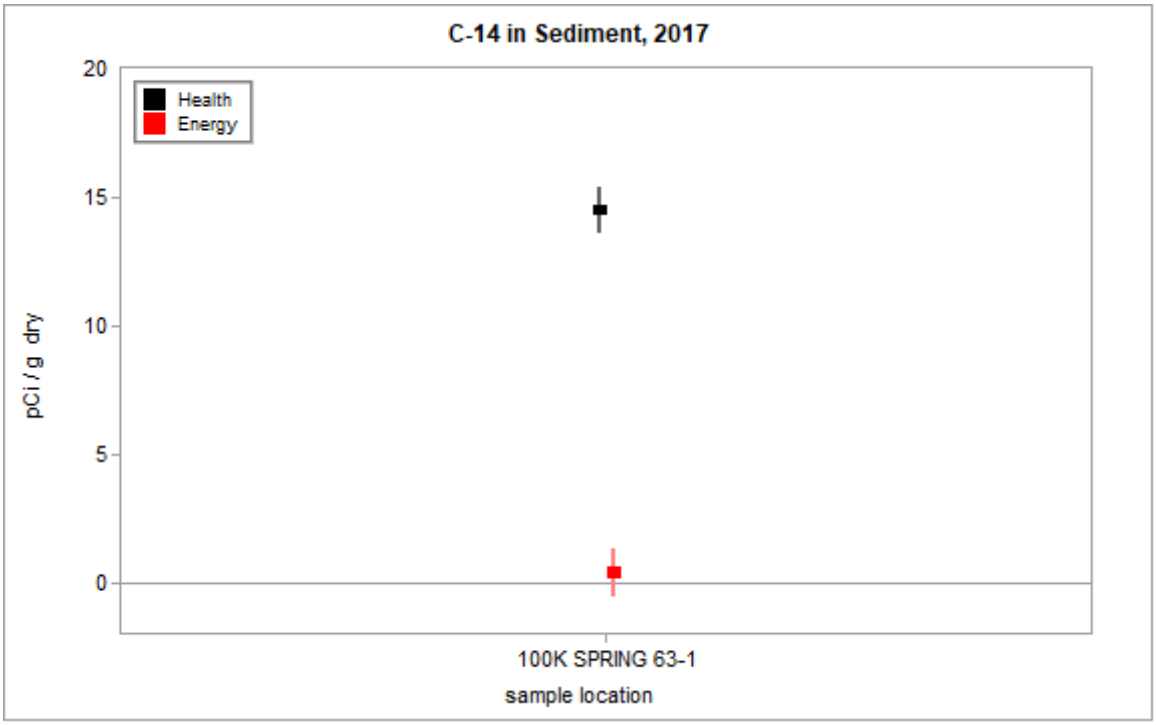


Figure 3.4.3 –

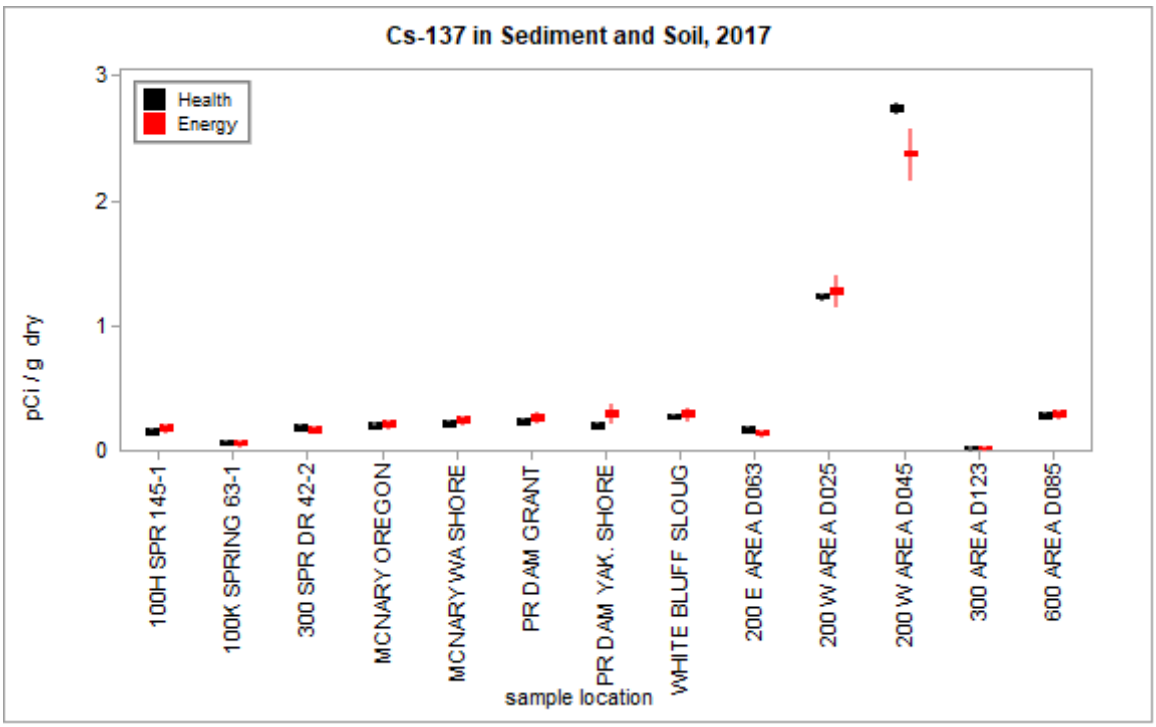


Figure 3.4.4 –

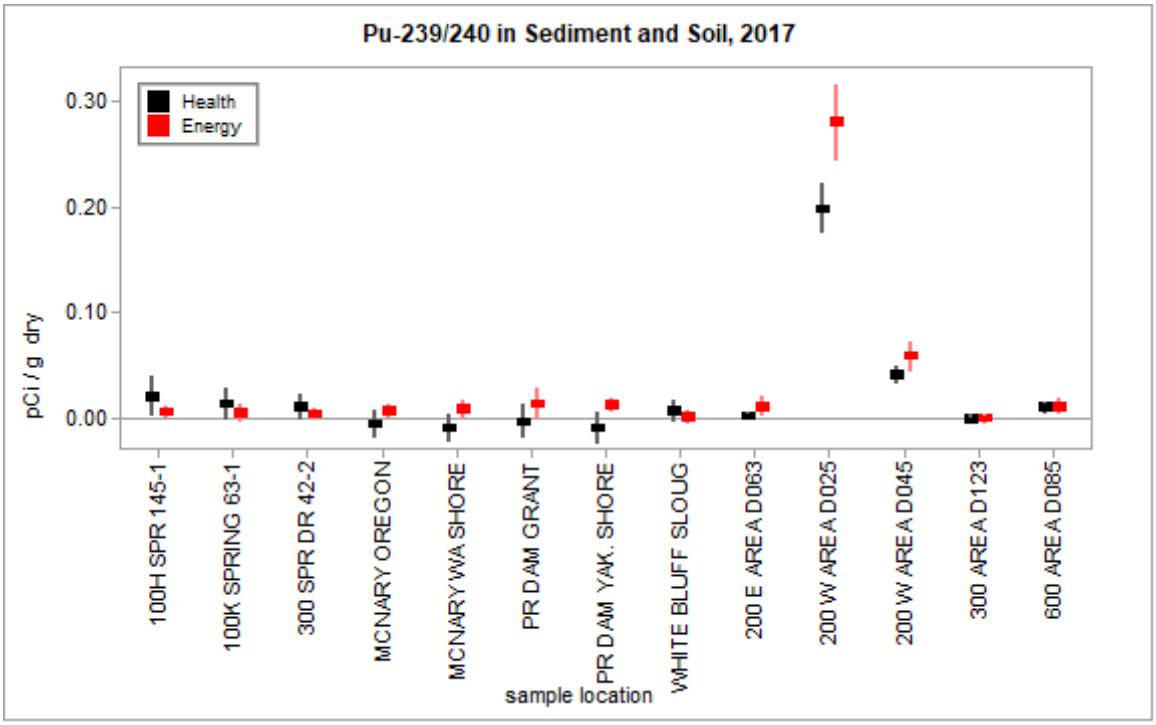


Figure 3.4.5 –

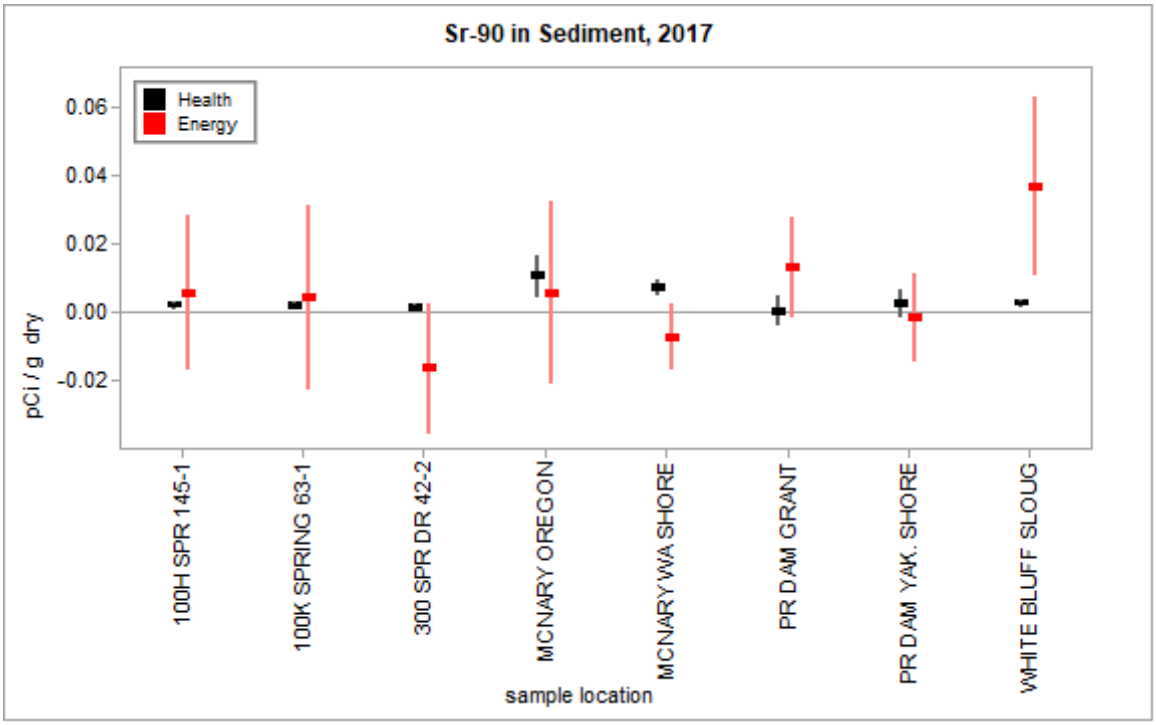
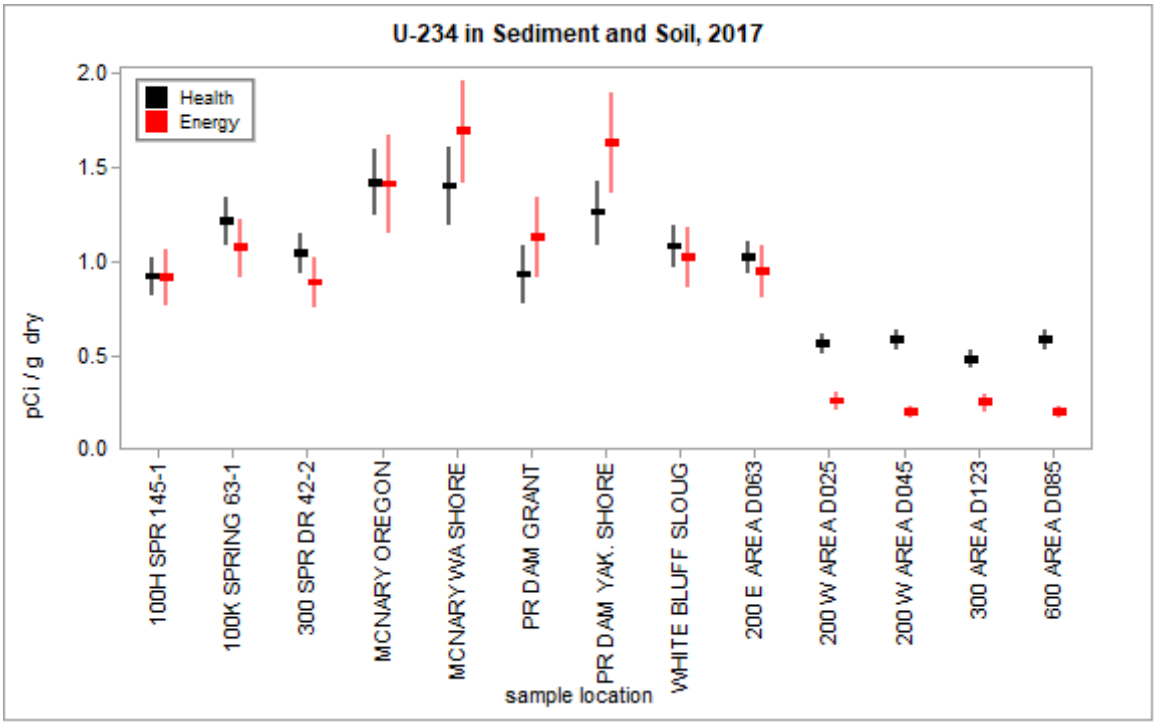


Figure 3.4.6 –


U-234 in Sediment and Soil, 2017
Health
Energy
pCi / g dry
2.0
1.5
1.0
0.5
0.0
100H SPR 145-1
100K SPRING 63-1
300 SPR DR 42-2
MCNARY OREGON
MCNARY WA SHORE
PR DAM GRANT
PR DAM YAK. SHORE
WHITE BLUFF SLOUG
200 E AREA D063
200 W AREA D025
200 W AREA D045
300 AREA D123
600 AREA D085
sample location

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 was 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 trees. 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 cherry samples, three corn samples, three leafy vegetable samples, two melon samples, two potato samples, and twelve wine samples.

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 collection of three fish from the Columbia River: one walleye from the 300 Area, one walleye from a background location at the Priest Rapids Dam pool, and one whitefish from the 100 Area. Three Canada geese samples were collected, one from Hanford's 100 Area, one from Hanford's 300 Area, and one from a background location at Wanapum Lake.

Five rabbit brush vegetation samples were collected on the Hanford Site, one from the 200 East Area, two from the 200 West Area, one from the 300 Area, and one from the 600 Area. These vegetation samples were collected from the same locations as the soil samples discussed in Section 3.4, to allow for correlations between soil and vegetation concentrations to be studied.

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. Some meat samples are analyzed for isotopes of uranium, and some for Sr-90. 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 plutonium, and for 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).

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?
C-14	annual	8	good	< 1	no
Co-60	annual	24	good	< 0.04	no
Cs-134	annual	24	good	< 0.04	no
Cs-137	annual	24	good	< 0.03	no
Eu-152	annual	24	good	< 0.05	no
Eu-154	annual	24	good	< 0.05	no
Eu-155	annual	24	good	< 0.05	no
Pu-238 (1)	annual	(8)			
Pu-239/240 (1)	annual	(8)			
Sr-90 (1)	annual	15 (27)	good	< 0.002 to 0.02	no
U-234 (1)	annual	(8)			
U-235 (1)	annual	(8)			
U-238 (1)	annual	(8)			

(1) Health has not completed the analysis for all or some of the samples.

Table 3.5.2 – Summary of Split Wine Samples

Analyte	Collection Period	Number of Results	Quality of Agreement	Health's Data Range (pCi/L)	Anomalous Data?
Co-60	annual	12	good	< 8	no
Cs-134	annual	12	good	< 8	no
Cs-137	annual	12	good	< 8	no
Eu-152	annual	12	good	< 20	no
Eu-154	annual	12	good	< 20	no
Eu-155	annual	12	good	< 20	no
H-3	annual	12	good	< 80 to 91	no

The Number of Results in parentheses in Table 3.5.1 represents the number of samples scheduled to be analyzed for the specific radionuclide. In these cases, Health has not completed analysis for all or some of the samples, and the data will be discussed in a future report.

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.

The split results for Pu-238, Pu-239/240, U-234, U-235, and U-238, as well as the Sr-90 results in fish and vegetation will be discussed in a future report, as the analysis of those data were not complete at the time of this report.

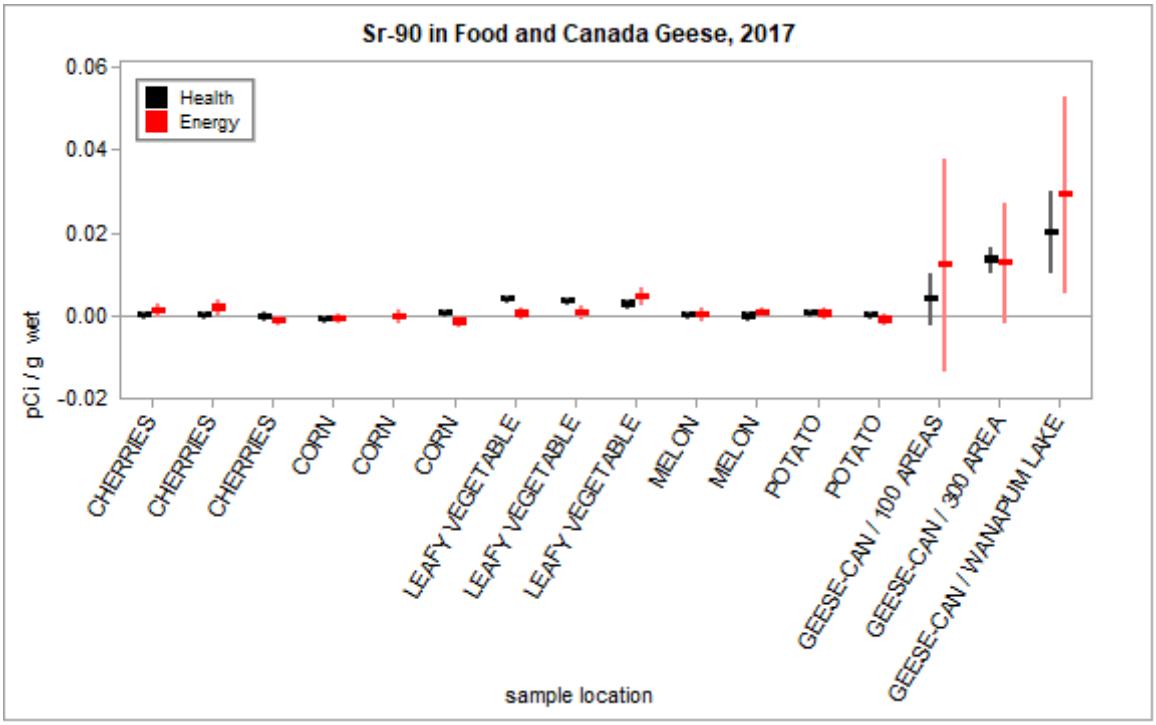
The Health and Energy results for Sr-90 in farm products and game birds are in good agreement, and these data are shown in Figure 3.5.1. Most results are below the detection limit of approximately 0.002 pCi/g. Strontium-90 was detected in the three leafy vegetable samples, at concentrations ranging from 0.003 to 0.004 pCi/g. Strontium-90 was also detected in two of the Canada geese samples, with the highest concentration of 0.02 pCi/g coming from the background sample.

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.

Figure 3.5.1 – Health and Energy Sr-90 Concentrations in Biota



4. Summary 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.

Categories of fair and poor do not necessarily indicate a problem with the laboratories' analyses but may demonstrate the influence of sampling error. In cases where samples are split (i.e., water, soil, sediment), effort is made to completely homogenize a sample before dividing, and there is significant likelihood each laboratory receives an indistinguishable sample.

For co-located air samples, there is no way to ensure that any present contamination is homogeneous in both samples, resulting in potential sampling error. In the case of an acute event that emits small quantities of individual contaminated particles, sampling error can become quite significant. In this case, the number of contaminated particles entering one air sampler, if any, may be different from the number entering the collocated sampler. For instance, demolition of the PFP discussed in Section 3.1 resulted in widespread particulate contamination. While both Health and Energy demonstrated capabilities to observe airborne contamination, the concentrations of radionuclides often did not agree. This may result simply from the fact that both samplers cannot detect a distinct discrete particle at the same time.

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 2017 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 Pu-238 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 plutonium and americium 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 and Am-241 concentrations in semiannual composite air samples are in poor agreement. For three of the eight 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 C-14 concentrations in water samples are in fair agreement. Concentrations in three of the six samples are in good agreement, but for three 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 beta concentrations in water samples are in fair agreement, as Health often reports higher concentrations than Energy.

Health and Energy results for C-14 in water samples are in poor agreement. There was only one sample split for this analysis. The source of the discrepancy is not known, but it is possible the difference was due to a discrete particle contaminated with C-14 in one of the split samples.

Health and Energy 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.

Table A.1 - Annual Effective Dose Equivalent (National Council on Radiation Protection and Measurements Report No. 93, *Ionizing Radiation Exposure of the Population of the United States, 1987*)

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

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)

	Nuclide	Volume (m3)	Method	Standard LLD (1000 min.)
Alpha	Nat U	10400	Alpha	1.25E-05
	U-234	10400	Alpha	1.25E-05
	U-235	10400	Alpha	5.00E-06
	U-238	10400	Alpha	1.25E-05
	Pu-238	10400	Alpha	5.00E-06
	Pu-239/240	10400	Alpha	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	2.00E-03
	U-234	20	Alpha	1.50E-02
	U-235	20	Alpha	1.00E-03
	U-238	20	Alpha	2.00E-03
	Pu-238	20	Alpha	3.00E-03
	Pu-239	20	Alpha	2.00E-03
	Th-230	20	Alpha	5.00E-03
	Th 232	20	Alpha	2.00E-03
	Am-241	20	Alpha	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

Milk (pCi/l)

	Nuclide	Volume (L)	Method	Standard LLD (100 min.)
Beta	Sr-90	1	Nitric Acid/ αβ Cntr	7.00E-01

Meat (pCi/g)

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

Shellfish (pCi/g)

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

Soil/Sediment (pCi/g)

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

Soil/Sediment (pCi/g)

	Nuclide	Mass (g)	Method	Standard (100 min.)
Beta	Sr-90	150	Nitric Acid/	1.80E-03
	Tc-99	10	3M/LS	2.00E-01
	Gross beta	0.4	$\alpha\beta$ Cntr	1.50E+00

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

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

	Nuclide	Volume (L)	Method	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)

	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

Appendix C - Formulas

A. **Random Uncertainty**

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

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

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

C. **Lower Limit of Detection (LLD)**

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

D. **Definitions**

2.22	=	conversion factor from dpm to picocuries
BKGCPM	=	background counts per minute
D	=	decay factor = $e^{-(\ln 2/T1/2)(t)}$
E	=	counting efficiency: counts per disintegration
LLD	=	the a priori determination of the smallest concentration of radioactive material sampled that has a 95 percent probability of being detected, with only five percent probability that a blank sample will yield a response interpreted to mean that radioactivity is present above the system background
n	=	number of samples analyzed (number of data points)
RU	=	random uncertainty at the 95 percent confidence level (sometimes referred to as counting error)
s	=	sample standard deviation
S	=	one standard deviation of the background count rate (which equals $(BKG/T_2)^{1/2}$)
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)

E. **Minimum Detectable Activity (MDA)**

The a posteriori determination of the activity level in a sample where there a 5% probability of making type I and type 2 errors,

MDA (pCi/unit) = (2.71 + (4.65 * sqrt(Bkg)) / (q*k*E*abn*T)) * (e^lambda Ts) * (lambda Tr) / (1 – e^-lambda Tr)

Where:

q = sample volume

k = 3.7E+07 (Bq/pCi)

E = Efficiency

abn = gamma ray abundance

T = Live time in seconds

e^ = natural log raised to the power of…

Tr = elapsed real time in seconds

Ts = difference between sample collection date and acquisition start time.

Bkg = sum of Compton continuum background counts under ROI for energy line of interest

Appendix D - 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 given a set of standard parameters (instrument counting efficiency, sample volume, counting time, background, etc).
Minimum Detectable Activity (MDA)	Minimum Detectable Activity, or MDA, represents the *a posteriori* determination of the activity level in a sample where there a 5% probability of making type I and type 2 errors

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.
mR	Milliroentgen, one thousandth of a Roentgen
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 E – 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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