

Hanford Environmental Radiation Oversight Program



2022 Data Summary Report

February, 2024



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Publication Number

DOH 320-135 2/24

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Acronyms and Abbreviations

DOH	Department of Health (Washington State)
ERDF	Environmental Restoration Disposal Facility
HMIS	Hanford Mission Integrated Solutions
LIGO	Laser Interferometer Gravitational-wave Observatory
LLD	Lower Limit of Detection
MAPEP	Mixed Analyte Performance Evaluation Program
MDA	Minimum Detectable Activity
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 and collocated samples collected from the field are not identical, and analytical methods may differ between programs. Health investigates and reports all unexpected discrepancies in split and collocated 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 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 70A.388 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. Section 4 provides a summary of results that are considered fair or poor. 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 contractors' 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 2022, the laboratory participated in two proficiency test programs and one pilot project:

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. Two rounds of MAPEP tests were performed in 2022; this is a National Institute of Standards and Technology traceable proficiency-testing program. 2) The laboratory participated in a Food Emergency Response Network exercise, in which samples of Romaine lettuce spiked with multiple radionuclides were analyzed by gamma spectroscopy. In addition, the laboratory participated in a pilot project conducted by the U.S. Centers for Disease

Control and Prevention to test potential screening methods for radioactive materials. This work was coordinated by the Federal Radiological Monitoring and Assessment Center.

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/m³); radioactivity in liquids such as water and milk is expressed as picocuries per liter (pCi/l); and radioactivity in solid material such as soil, vegetation, and food is expressed as picocuries per gram (pCi/g). Ambient gamma radiation is expressed as radiation exposure, measured in 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 combined standard uncertainties, in which the best estimates of the major contributors to random and systematic uncertainty are included to make a best estimate of the overall uncertainty. In radiation measurements these are counting uncertainties of the sample measurement itself, plus those of the background, and calibration measurements. Additionally, uncertainties related to the sample size and calibration standard preparation are included. There are also sources of uncertainty that the laboratory is not yet able to adequately account for and so these are not presently included.

The uncertainties are reported at a coverage factor of 2 ($k=2$, or two-standard deviation) confidence interval. A 2s uncertainty means there is approximately 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. The word

approximately is used because we realize that there are additional sources of uncertainty that we do not yet have a process to estimate.

2.2.2 Detection Limits

The laboratory can measure 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 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 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 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.

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 the collocated or split data are sorted by sample type and radionuclide. Then, for each sample type and radionuclide, all 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 enough 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 the 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 which are likely related to past Hanford operations are reported, regardless of whether the concentrations are above or below a detection limit. Concentrations of any man-made gamma emitting radionuclides are reported if they are detected.

Gamma spectroscopy is the method used to determine concentrations of many fission products. This method has the capability to measure concentrations of 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.

Gamma emitting radionuclides which may be related to Hanford include, but are not limited to, Co-60, Cs-137, 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 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 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 biweekly gross alpha concentrations are in poor agreement. There are many instances wherein Health reports elevated gross alpha in air and Energy does not.
- Health and Energy air concentrations are in good agreement for tritium.
- Health has not completed analysis for Sr-90 and alpha emitting radionuclides. These results will be presented in next year's report.

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. Hanford Mission Integrated Solutions (HMIS) is the Energy contractor for both programs.

Health collected air samples collocated with the Near Facilities and Operations program at ten locations, which include the Liquid Effluent Retention Facility (N499 LERF), the Environmental Restoration Disposal Facility (ERDF-SE), the Plutonium Finishing Plant (PFP N554, PFP N555, PFP

N975), and the PUREX facility (N985), all in the 200 Area; the 100K East Area near the fuel storage basins (100K N576), and the 100B Area near the cocooned reactor (100B Reactor), both in the 100 Area; and the Treated Effluent and Disposal Facility (300 TEDF) and the 300 S Gate N903 in the 300 Area.

Health collected air samples collocated with the Site-Wide and Offsite program at eight locations, which include the 300 Area Water Intake, LIGO, Rattlesnake Barricade, Wye Barricade, Prosser Barricade, and Yakima Barricade, which are all located throughout the Hanford Site; Station 8, which is located across the Columbia River from the Hanford perimeter; and Battelle Complex, which is 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.

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 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. 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.

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).

For some radionuclides, Health has not completed analysis for all the scheduled samples, or Energy has not provided results for all the scheduled samples, and in these cases the value in the “Number of Results” column represents the number of scheduled results followed by the number of actual results in parentheses.

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 Collocated Air Samples

Analyte	Collection Period	Number of Results	Quality of Agreement	Health’s Data Range (pCi/m ³)	Anomalous Data?
Gross Alpha	biweekly	422	poor	<0.0005 to 0.021	yes
Gross Beta	biweekly	425	fair	<0.0003 to 0.11	no
H-3	monthly	22	good	< 1.2 to 5.0	no
Am-241 ^(a)	semiannual	26 (0)			
Co-60	semiannual	36	good	< 0.0006	no
Cs-134	semiannual	36	good	< 0.0006	no
Cs-137	semiannual	36	good	< 0.0006	no
Eu-152	semiannual	36	good	< 0.0006	no
Eu-154	semiannual	36	good	< 0.0006	no
Eu-155	semiannual	36	good	< 0.0006	no
Pu-238 ^(a)	semiannual	36 (0)			
Pu-239/240 ^(a)	semiannual	36 (0)			
Pu-241 ^(a)	semiannual	8 (0)			
Sr-90 ^(a)	semiannual	34 (0)			
U-234 ^(a)	semiannual	32 (0)			
U-235 ^(a)	semiannual	32 (0)			
U-238 ^(a)	semiannual	32 (0)			

(a) Health has not completed analyte specific analysis for some or all the scheduled samples. The value in the “Number of Results” column represents the number of scheduled results followed by the number of actual results in parentheses.

Health and Energy collocated biweekly gross alpha concentrations are in poor agreement. Figures 3.1.2, 3.1.3, and 3.1.4 show the collocated data at Ligo Facility, Purex, and the Plutonium Finishing Plant, respectively (note that the y-axis scale is the same for all three graphs). These figures show that Health often reports higher concentrations than Energy. A more detailed inspection indicates the results are similar at low concentrations, but do not agree when Health reports higher concentrations. Figure 3.1.2 clearly shows this trend for the data at Ligo Facility. In addition, inspection of historical data from all sites indicates that the

higher concentrations detected at Ligo Facility (Figure 3.1.2) are higher than typical values, which is unusual since Ligo Facility is not near to sources of alpha radiation. The concentrations at Ligo Facility reported by Energy are similar to historical results.

The gross alpha scatter plot for 2022 data at all locations is shown in Figure 3.1.5. This plot, and the associated regression analysis, indicates the collocated concentrations are in poor agreement, in which the higher-range concentrations reported by Health are commonly two to ten times greater than those reported by Energy. Historically, the Health and Energy split gross alpha concentrations are in fair agreement, with Energy's results commonly being within 25% of those reported by Health.

Health and Energy biweekly gross beta concentrations are in fair agreement when considering data from all locations. The status of agreement falls into one of two categories, either good agreement, for example at PFP N554 (Figure 3.1.7); or fair agreement due to a small systematic bias, for example at Ligo Facility (Figure 3.1.6). The fact that the agreement is good at some locations and not at others is not understood currently.

The gross beta scatter plot for all locations is shown in Figure 3.1.8 and regression analysis indicates that on average a bias exists, where Energy reports concentrations approximately 45% of those reported by Health. Historically, the Health and Energy split gross beta concentrations are in fair agreement, with Energy's results commonly being within 25% of those reported by Health.

Health and Energy H-3 (tritium) concentrations in monthly atmospheric water vapor samples are in good agreement, as shown in Figure 3.1.9. The Health and Energy detection limits are significantly different. Health's detection limit is approximately 1 pCi/m³, and Health detects concentrations in the range from the detection limit to 5 pCi/m³. Energy's detection limit is much higher, ranging between 2 and 7 pCi/m³, and most of their results are considered below their sample specific detection limit. Considering the differing detection limits and uncertainty bars, most of the Health and Energy data are in good agreement for this reporting period, as the uncertainty bars overlap. Energy often reports slightly higher concentrations than Health, but the difference is less than the concentration's uncertainty value.

Health and Energy concentrations of the gamma emitting radionuclides Co-60, Cs-134, Cs-137, Eu-152, Eu-154, and Eu-155 are in good agreement, and all results are below the detection limit of approximately 0.0006 pCi/m³. Health and Energy occasionally detect Cs-137 in air samples, but this was not the case in 2022.

Health has not completed analysis for Sr-90 or the alpha emitting radionuclides Pu-238, Pu-239/240, Pu-241, U-234, U-235, or U-238 in 2022 air samples. The results will be discussed in next year's report.

Energy's background air location is in Yakima, Washington, approximately 50 miles west of the Hanford Site. Health does not have an air sampler at this location and thus does not have an

independent measurement of background air concentrations. Gross alpha and gross beta are screening tests used to help indicate anomalous activity. Gross alpha is used as a screening tool for alpha emitting radionuclides such as plutonium and americium. Gross beta screens for most beta emitting radionuclides but cannot efficiently detect weak beta emitters such as H-3 and C-14. Table 3.1.2 shows the range of Health’s data compared with background data reported by Energy for gross alpha, gross beta, and Sr-90. For gross alpha and gross beta, most of Health’s results are within the range of background; however, the highest Health results are greater than background.

Table 3.1.2 – Comparison of Health’s Air Sample Summary Data to Energy’s Data Reported for the Yakima Background Location^(a)

Analyte	Health’s Data Range (pCi/m ³) for 2022	Energy’s Data Range for Background Location (pCi/m ³)	Energy’s Average for Background Location (pCi/m ³)
Gross alpha	<0.0005 to 0.021	-0.00012 to 0.0042	0.00083
Gross beta	<0.0003 to 0.11	0.0043 to 0.095	0.018
Sr-90 ^(b)		-0.00013 to 0.00028	0.000036

(a) Data for Energy’s Yakima Background Location was summarized from the Hanford Environmental Information System database for the five-year period 2013 to 2017.

(b) Health has not completed analysis for Sr-90 for the 2022 air samples.

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

Figure 3.1.1 – Hanford Site Air Monitoring Locations

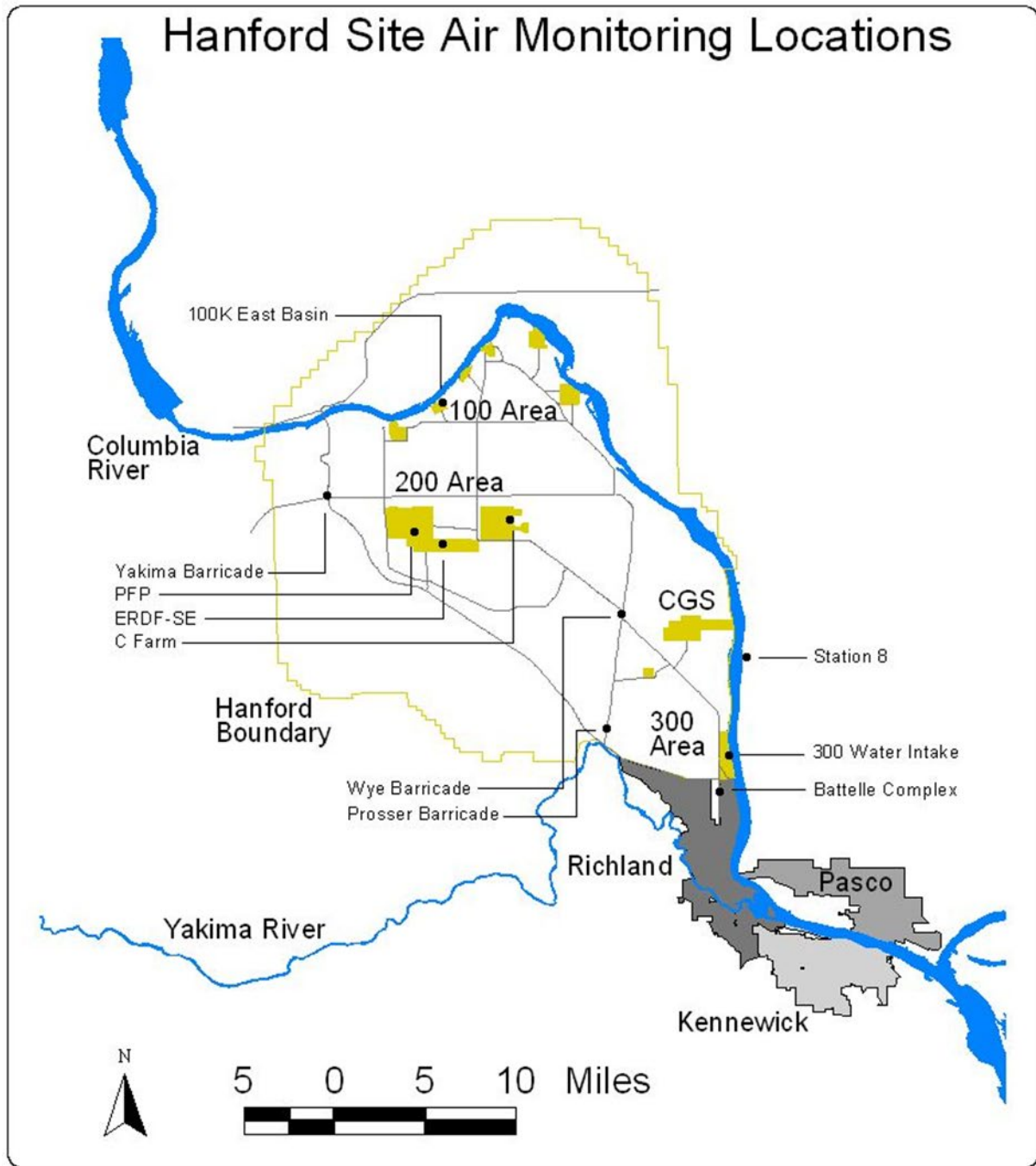


Figure 3.1.2 – Gross Alpha Concentrations in Air at Ligo Facility

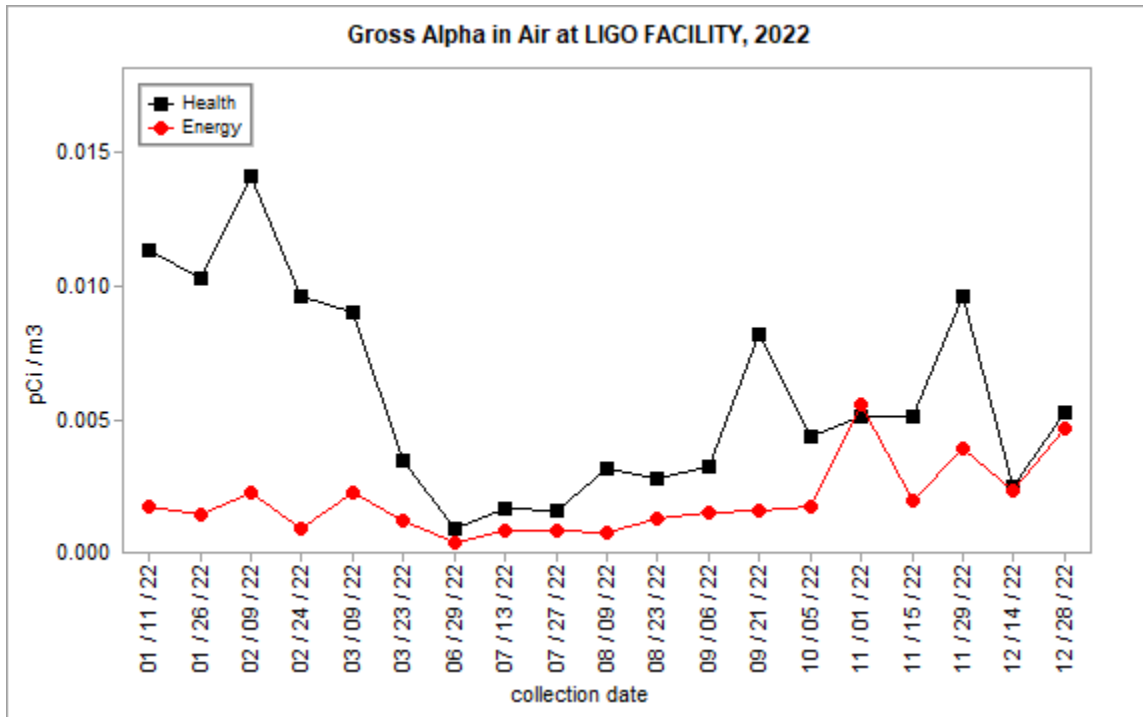


Figure 3.1.3 – Gross Alpha Concentrations in Air at Purex N985

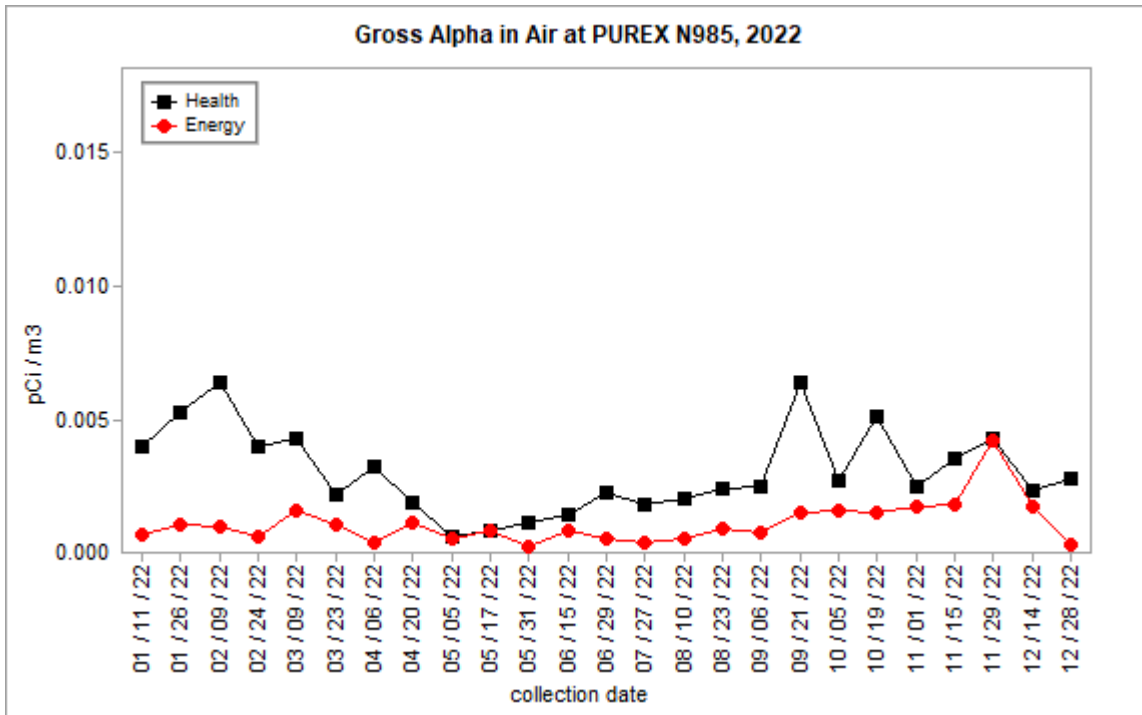


Figure 3.1.4 – Gross Alpha Concentrations in Air at PFP N975

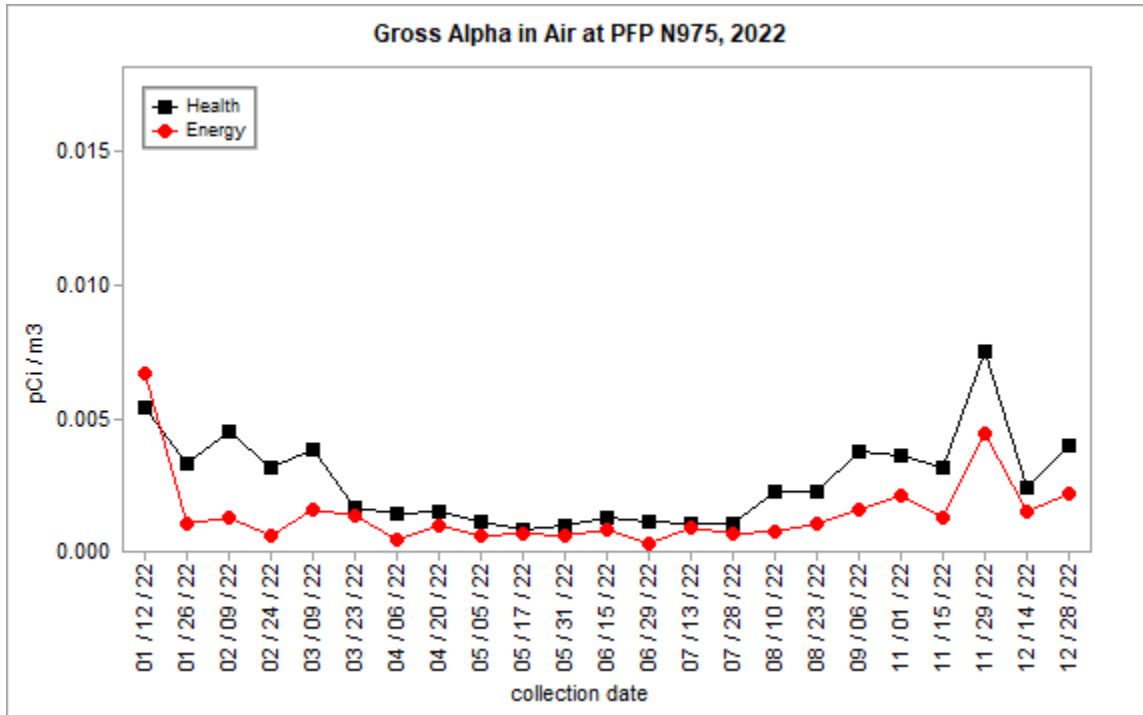


Figure 3.1.5 – Scatter Plot for Gross Alpha in Air

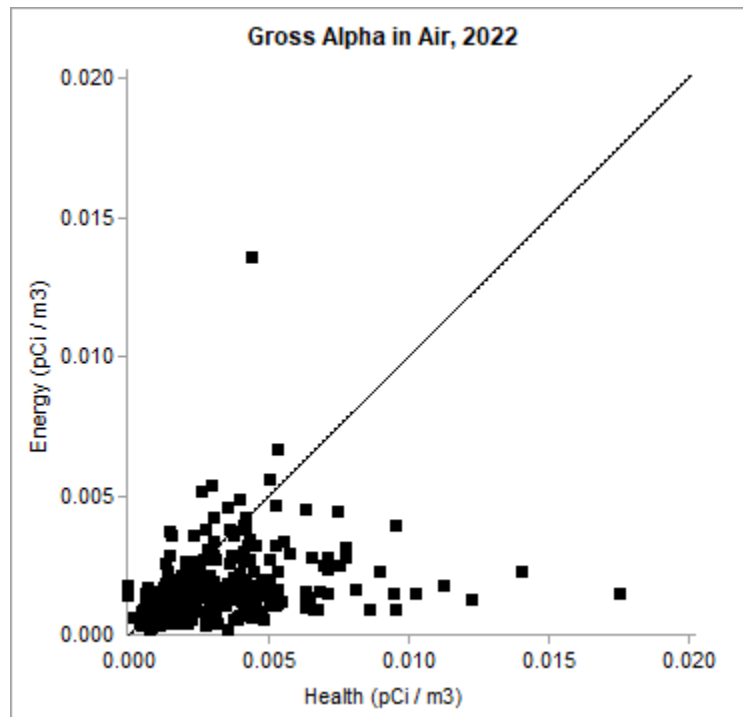


Figure 3.1.6 – Gross Beta Concentrations in Air at Ligo Facility

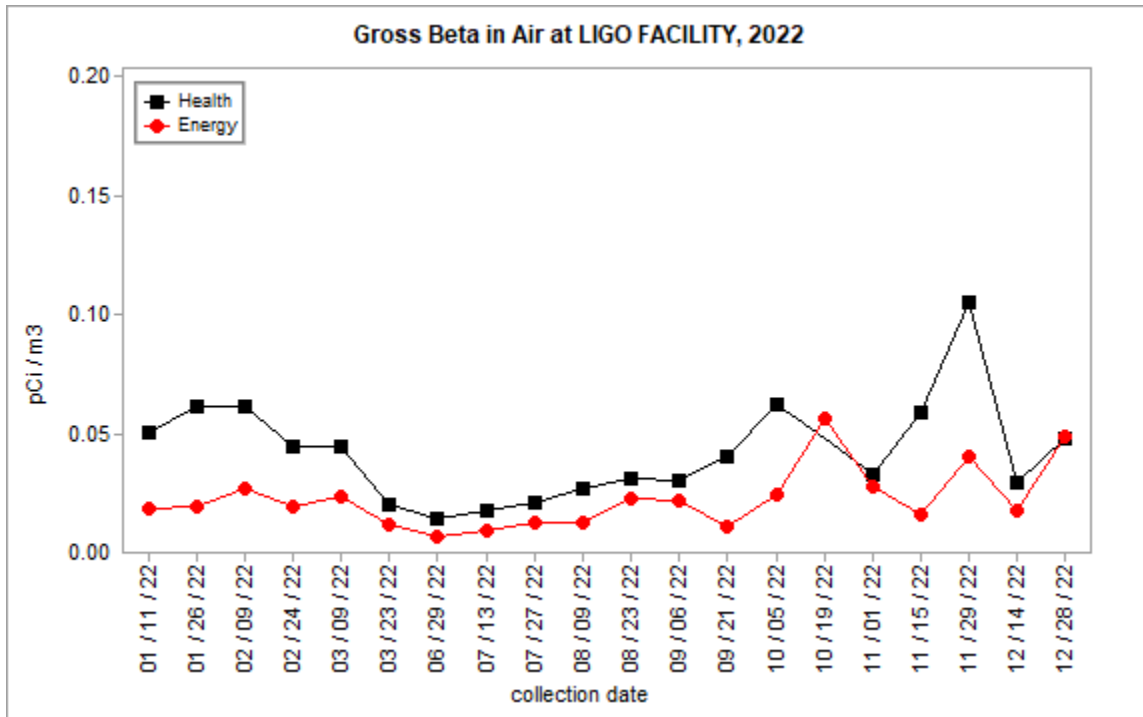


Figure 3.1.7 – Gross Beta Concentrations in Air at PFP N554

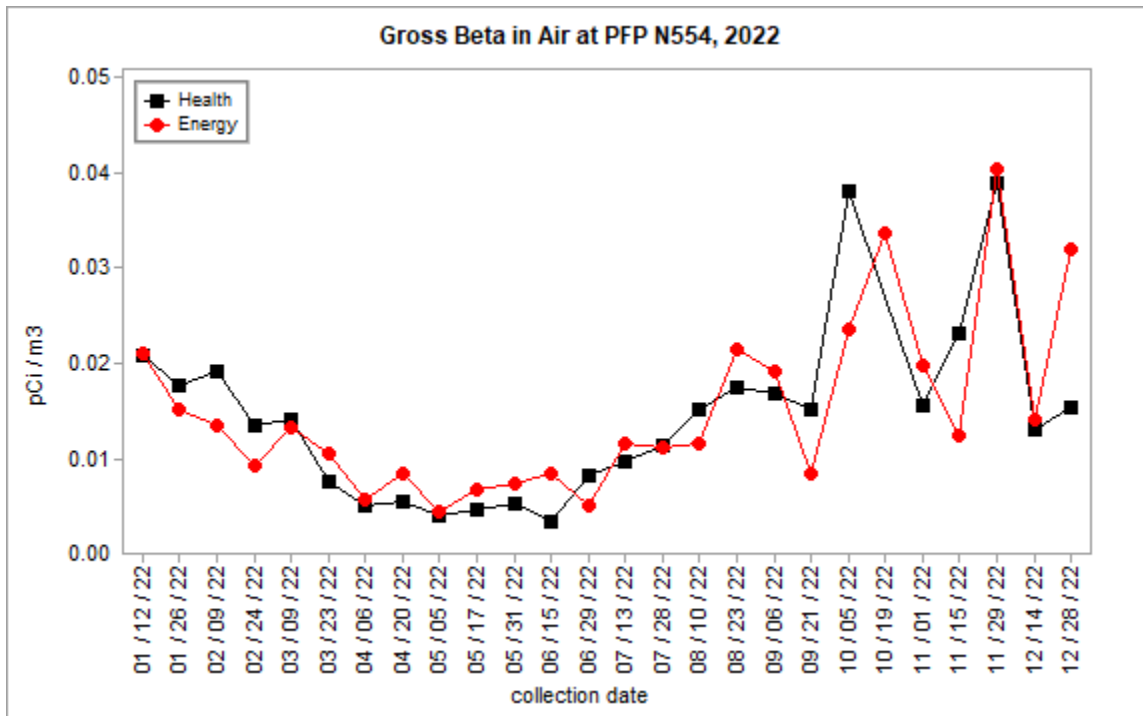


Figure 3.1.8 – Scatter Plot for Gross Beta Concentrations in Air

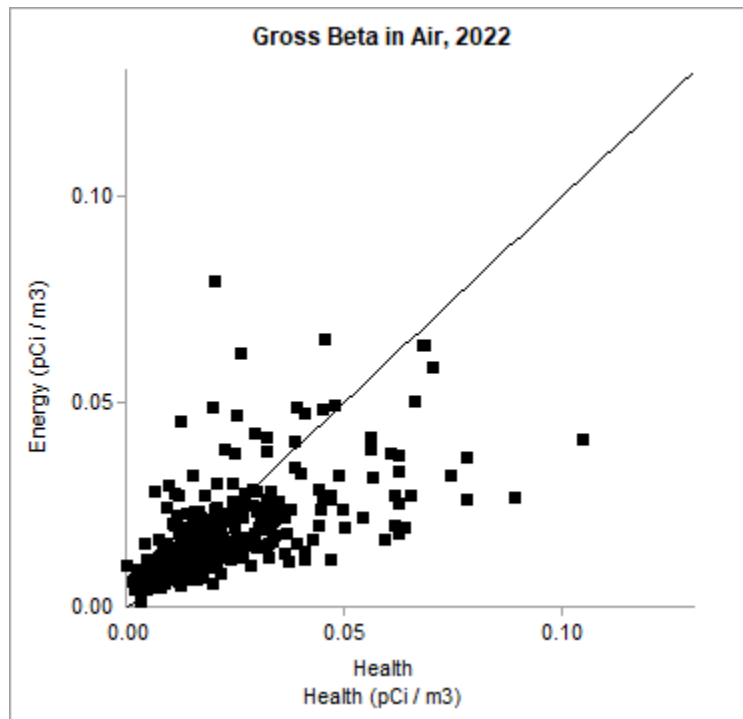


Figure 3.1.9 – Health and Energy H-3 Concentrations in Air

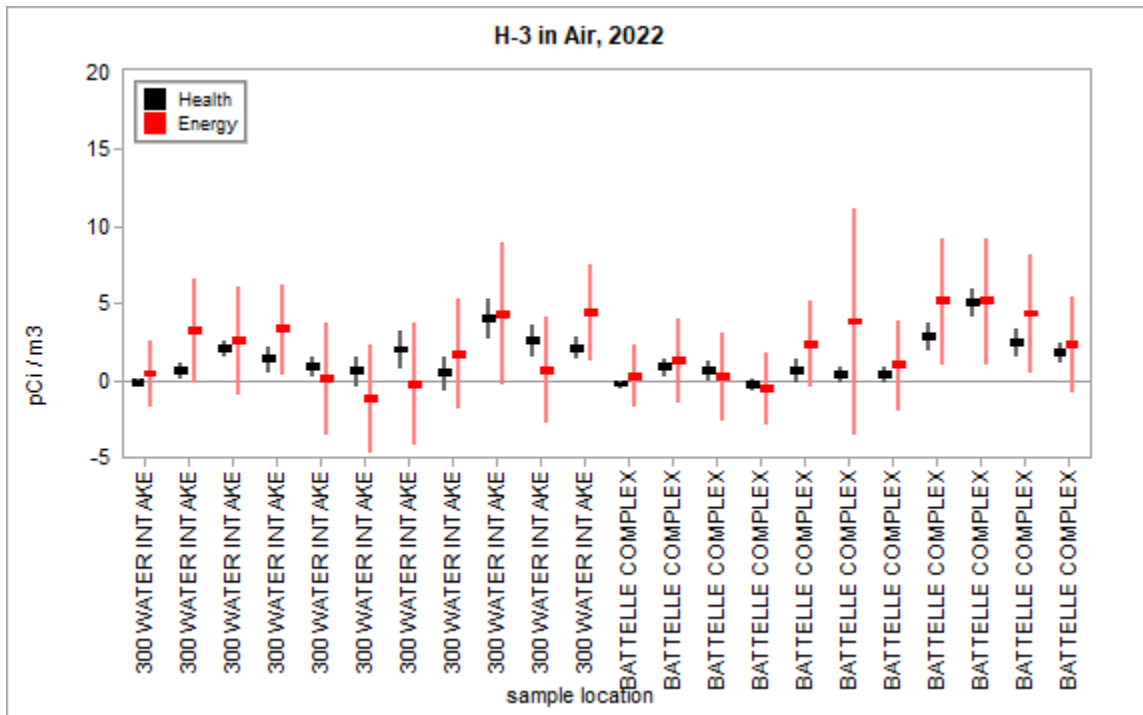
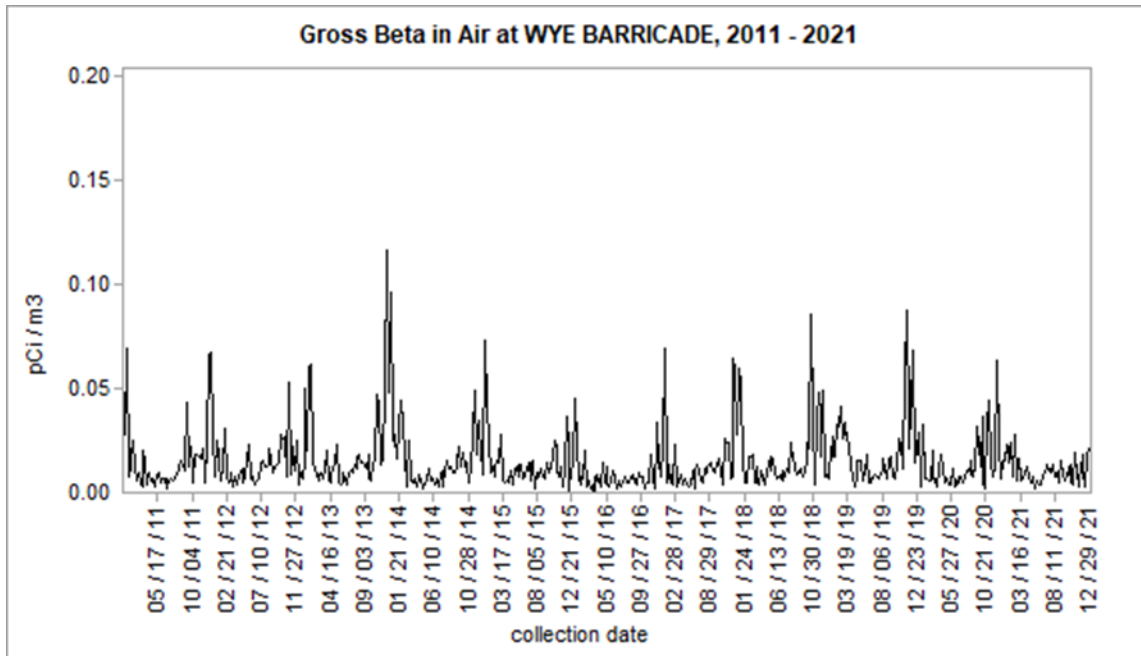


Figure 3.1.10 – Gross Beta in Air at Wye Barricade 2011 – 2021



3.2 Water Monitoring

Major Findings:

- Health and Energy split water concentrations are in fair agreement for C-14, gross beta, I-129, and Pu-239/240; and good agreement for all other radionuclides.
- Radionuclides were detected in groundwater near known groundwater plumes, and in riverbank seep water and Columbia River surface water from areas where known groundwater plumes enter 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.
- 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, irrigation returns 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 the current sampling locations. Locations may vary from year to year.

Groundwater

Health split 13 groundwater samples with the Energy contractor (Central Plateau Cleanup Company, CPCCo). 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, 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 H-3 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 (Hanford Mission Integrated Solutions, HMIS) 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 (HMIS) split eleven surface water samples from nine different locations. Four samples were collected from the Columbia River upstream of Hanford, two at the Vernita Bridge and two at Priest Rapids Dam. 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 program historically collects split samples from two locations upstream of the Hanford Site: at Priest Rapids Dam and at Vernita Bridge. The remaining surface water sites are downstream of areas that may be impacted by Hanford. A comparison of contaminant concentrations collected downstream of Hanford with those collected upstream of Hanford 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), traditionally used groundwater from the unconfined aquifer beneath the site. One composite drinking water sample from a water storage tank in the 400 Area was split with the Energy contractor (PNNL).

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.

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 times of high river flow. 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).

For some radionuclides, Health has not completed analysis for all the scheduled samples, or Energy has not provided results for all the scheduled samples, and in these cases the value in the “Number of Split Results” column represents the number of scheduled results followed by the number of actual results in parentheses.

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 Split Water Samples

Analyte	Collection Period	Number of Split Results	Quality of Agreement	Health’s Data Range (pCi/l)	Anomalous Data?
C-14	annual	6	fair	< 60 to 9,100	no
Co-60	annual	12	good	< 1.8 to 1.9	no
Cs-134	annual	12	good	< 1.6	no
Cs-137	annual	12	good	< 2.1 to 220	no
Eu-152	annual	12	good	< 5	no
Eu-154	annual	12	good	< 5	no
Eu-155	annual	12	good	< 5	no
Gross Alpha	annual	19	good	<5 to 23,000	no
Gross Beta	annual	19	fair	< 2 to 39,000	no
H-3	annual	31	good	< 80 to 212,000	no
I-129	annual	4	fair	< 0.5 to 17	no
Pu-238	annual	3	good	< 0.09	no
Pu-239/240	annual	3	fair	< 0.04 to 0.16	no
Sr-90	annual	21	good	< 0.6 to 19,000	no
Tc-99 ^(a)	annual	13 (11)	good	< 4 to 30,000	no
U-234	annual	14	good	0.18 to 16,000	no
U-235	annual	14	good	< 0.09 to 910	no
U-236	annual	3	good	< 0.05 to 0.23	no
U-238	annual	14	good	0.09 to 16,000	No

(a) Health has not completed analyte specific analysis for some or all the scheduled samples. The value in the “Number of Results” column represents the number of scheduled results followed by the number of actual results in parentheses.

Health and Energy C-14 concentrations in water samples are in fair agreement. Figure 3.2.2 shows all 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. For three of the six split samples, the difference in concentrations is significantly greater than the sum of Health's and Energy's uncertainty bars. Historically, C-14 results for water samples have ranged from fair to poor agreement.

Groundwater well 199-K-106A was targeted for split sampling because of the high C-14 concentrations in the area and because the concentrations have a wide range of values as a function of time. Figure 3.2.4 shows the split results at this well, where the sometimes-poor agreement between Health and Energy is evident.

Health and Energy concentrations for the gamma emitting radionuclides Co-60, Cs-134, Cs-137, Eu-152, Eu-154, and Eu-155 are all in good agreement, and most concentrations are below detection limits. Figure 3.2.5 shows the split Co-60 data. Both Health and Energy commonly detect Co-60 and Cs-137 from groundwater wells within Hanford's 200 Area. As an example, Figure 3.2.6 shows the historical Co-60 concentrations in groundwater well 299-E28-24 from Hanford's 200 East Area. For Cs-137, concentrations in 200 Area wells can reach several hundred picocuries per liter.

Health and Energy gross alpha concentrations in water samples are in good agreement, while the gross beta concentrations are in fair agreement. Most gross beta data are in good agreement; however, for a small percentage of the total data, approximately 10%, the Health and Energy error bars do not overlap. Because of the large range in concentration values, the lower concentration data for gross alpha and gross beta are shown in Figures 3.2.7 and 3.2.8, respectively. Not shown in these figures, higher concentrations of both gross alpha and gross beta, up to several tens of thousands pCi/L, are commonly measured at 200 East Area well 299-E33-344.

Historically, the agreement for samples with gross beta concentrations above a few thousand pCi/L is only fair. For these higher concentrations, Health often reports higher concentrations than Energy, as can be seen in Figure 3.2.9 for historical gross beta concentrations at groundwater well 299-E33-344.

Health and Energy H-3 concentrations in water samples are in good agreement across a large range of concentrations from below the detection limit to several hundred thousand picocuries per liter. Figure 3.2.10 shows historical H-3 data in groundwater well 299-E17-14, where concentrations are typically above 200,000 pCi/L.

Health and Energy I-129 concentrations in water samples, shown in Figure 3.2.11, are in fair agreement, as the Health and Energy error bars do not overlap for half of the data. Health routinely detects I-129 in water from groundwater well 699-36-70A at concentrations ranging from 5 to 15 pCi/L.

Health and Energy Pu-238 concentrations in water samples are in good agreement, while the Pu-239/240 concentrations are in fair agreement (Figure 3.2.12). All Pu-238 results are below the detection limit. Historically, small quantities of Pu-239/240 are often detected in groundwater wells in the 200 Area, and this was the case in 2022.

Health and Energy Sr-90 concentrations in water samples are in good agreement. Strontium-90 is typically detected at approximately 10,000 - 15,000 pCi/L at groundwater well 199-N-67 in the 100N Area, at lower concentrations in groundwater wells at the 100K and 200 East Areas, and at low concentrations in riverbank seeps and near-shore surface water along the 100 and 300 Areas.

Health and Energy Tc-99 concentrations are in good agreement. Groundwater well 299-E33-344 is targeted for sampling due to its historically high concentrations of Tc-99 (Figure 3.2.13). Technetium-99 is typically detected at 100 and 200 Area groundwater wells.

Health and Energy U-234, U-235, and U-238 concentrations in water samples are in good agreement. The low concentration U-238 data are shown in Figure 3.2.14.

Health and Energy U-236 concentrations are in good agreement. In 2022, all U-236 split samples came from Columbia River surface water or riverbank seep water samples. The concentration at the 300 Area riverbank seeps is approximately 0.3 pCi/L, while the 300 Area Columbia River surface water samples are below the detection limit of 0.05 pCi/L.

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 Hanford groundwater, riverbank seeps, and Columbia River sediments and surface water samples. Uranium-236 is often detected in groundwater well 399-1-17A in the 300 Area at concentrations ranging from 0 to 2 pCi/L, in 300 Area riverbank seeps at concentrations approximately 0.5 pCi/L, and in groundwater well 299-E33-344 in the 200 Area at 250 pCi/L. In 2022, Health independently analyzed three 200 Area groundwater samples for U-236, with results ranging from below the detection limit of 0.05 pCi/L to 253 pCi/L.

Both Health and Energy analyzed a split drinking water sample from the 400 Area Drinking Water Tank. Both agencies detected tritium (H-3) at approximately 4,000 pCi/L, which is less than the federal drinking water standard. No other radionuclides were detected.

Health independently collected three other drinking water samples, one from the Ligo Facility on the Hanford Site, and two from the Edwin Markham Elementary School in Pasco. All results for gross alpha, gross beta, H-3 (tritium), Sr-90, and total uranium are below federal drinking water standards.

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

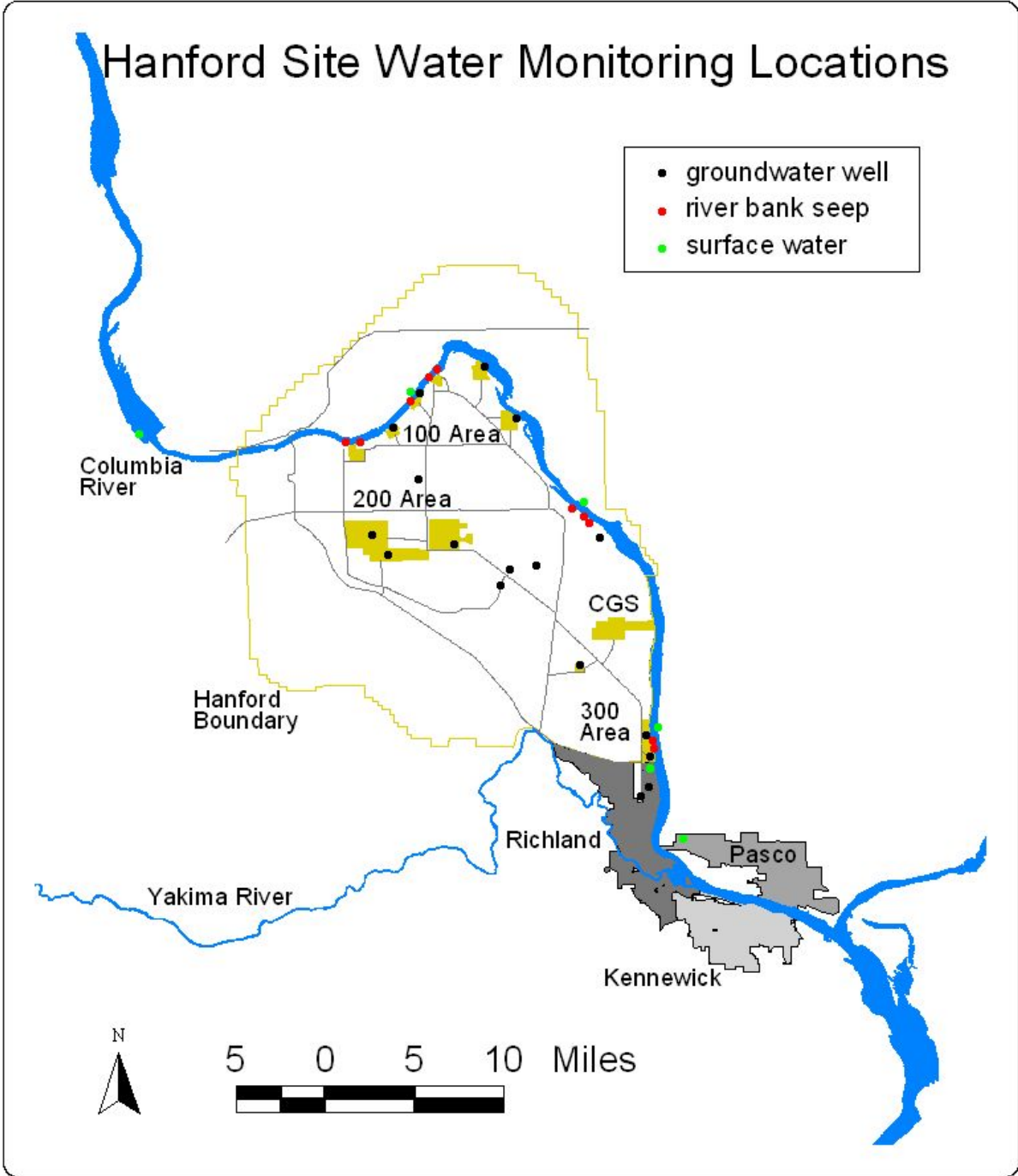


Figure 3.2.2 – C-14 Concentrations in Water

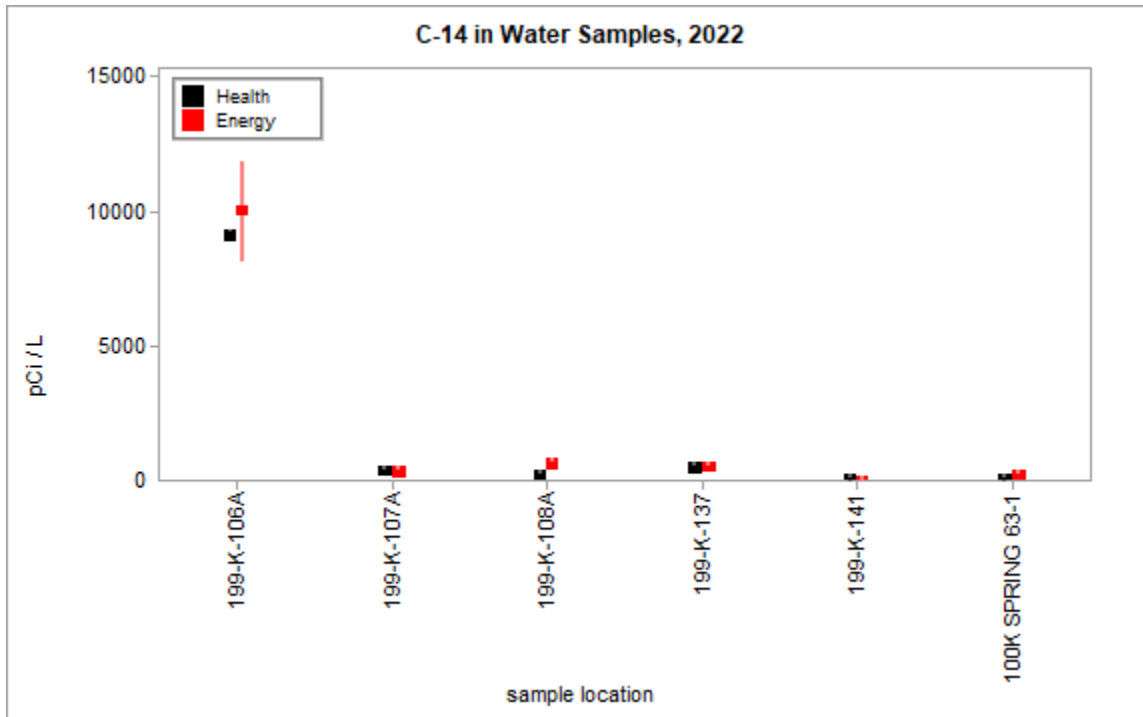


Figure 3.2.3 – C-14 Concentrations in Water, Low-Range Data

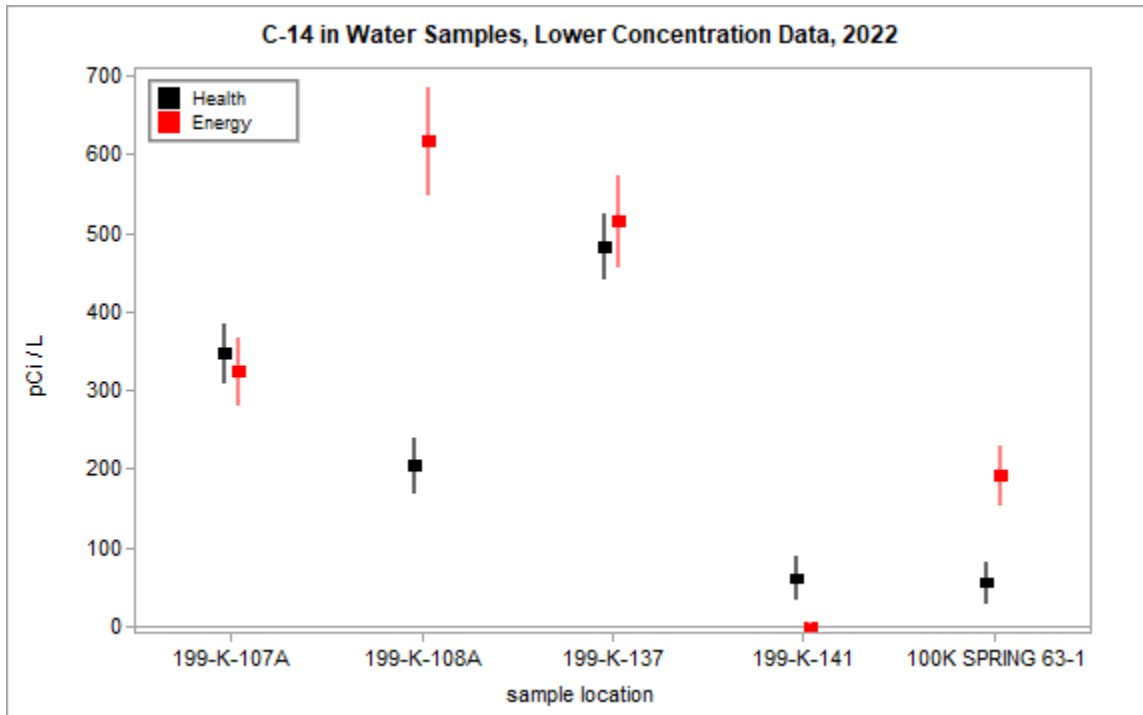


Figure 3.2.4 – C-14 Concentrations in Groundwater Well 199-K-106A

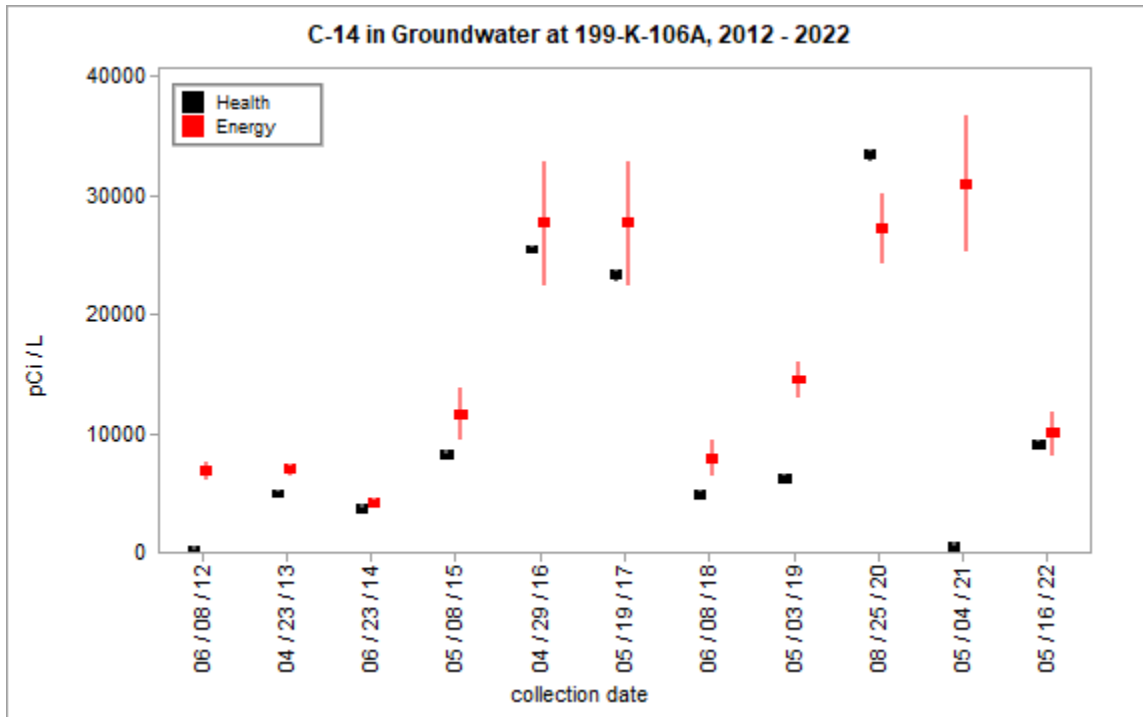


Figure 3.2.5 – Co-60 Concentrations in Water

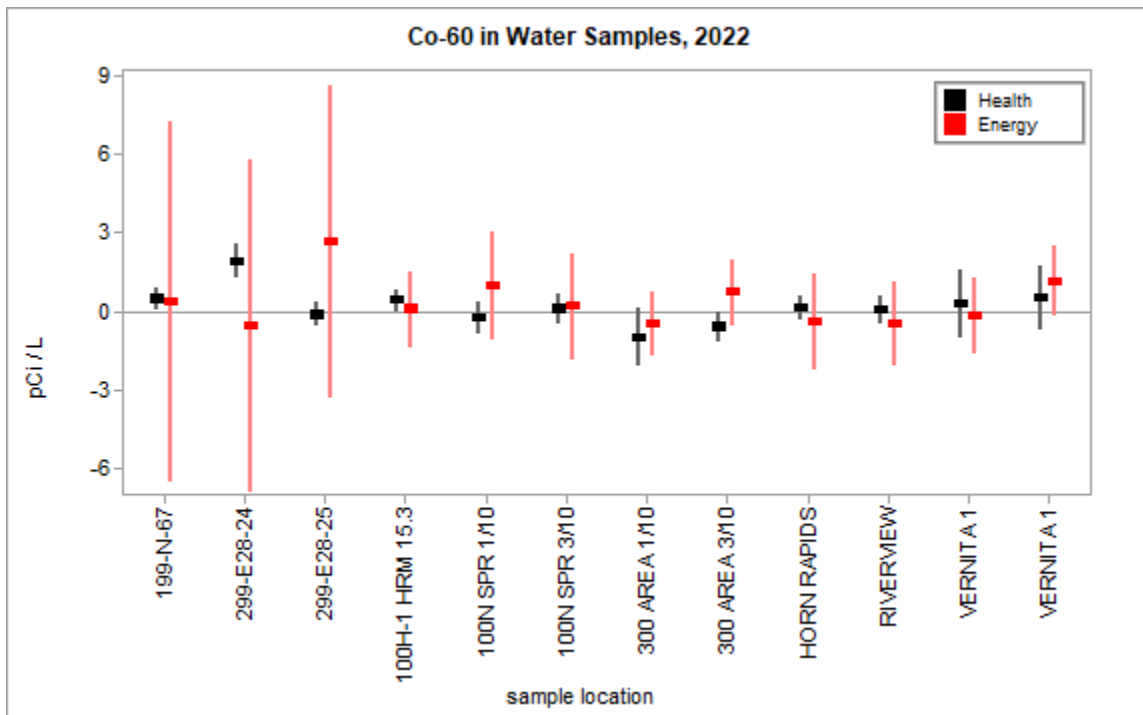


Figure 3.2.6 – Co-60 Concentrations in Groundwater Well 299-E28-24

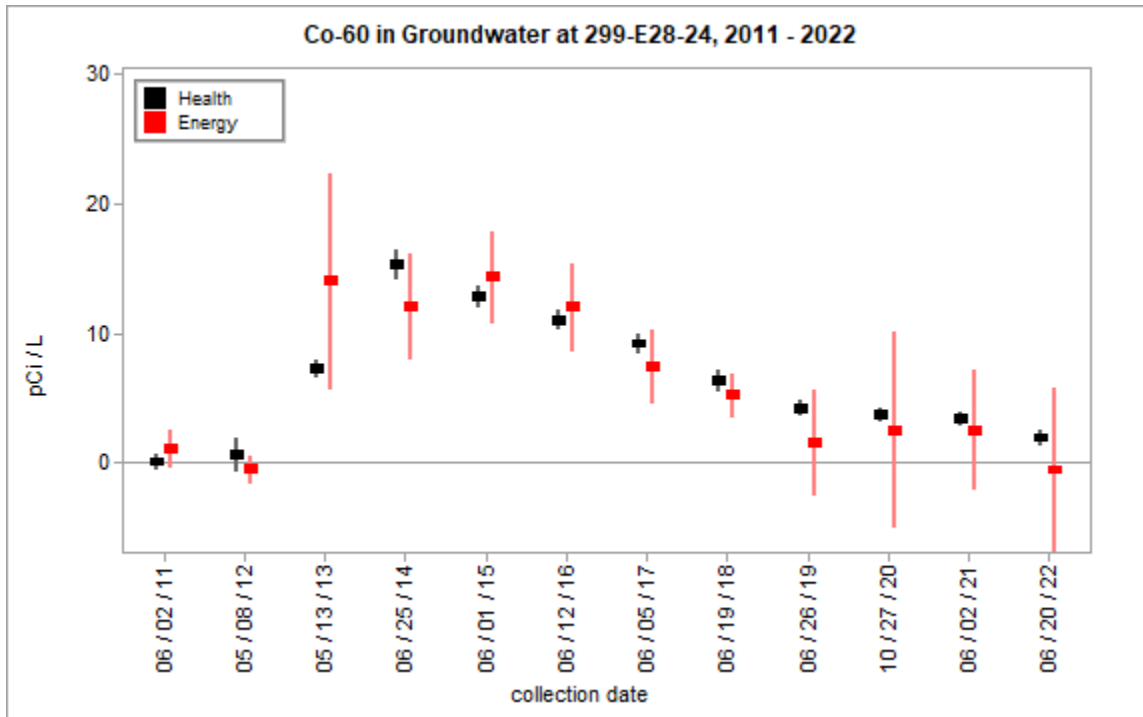


Figure 3.2.7 – Gross Alpha Concentrations in Water, Low-Range Data

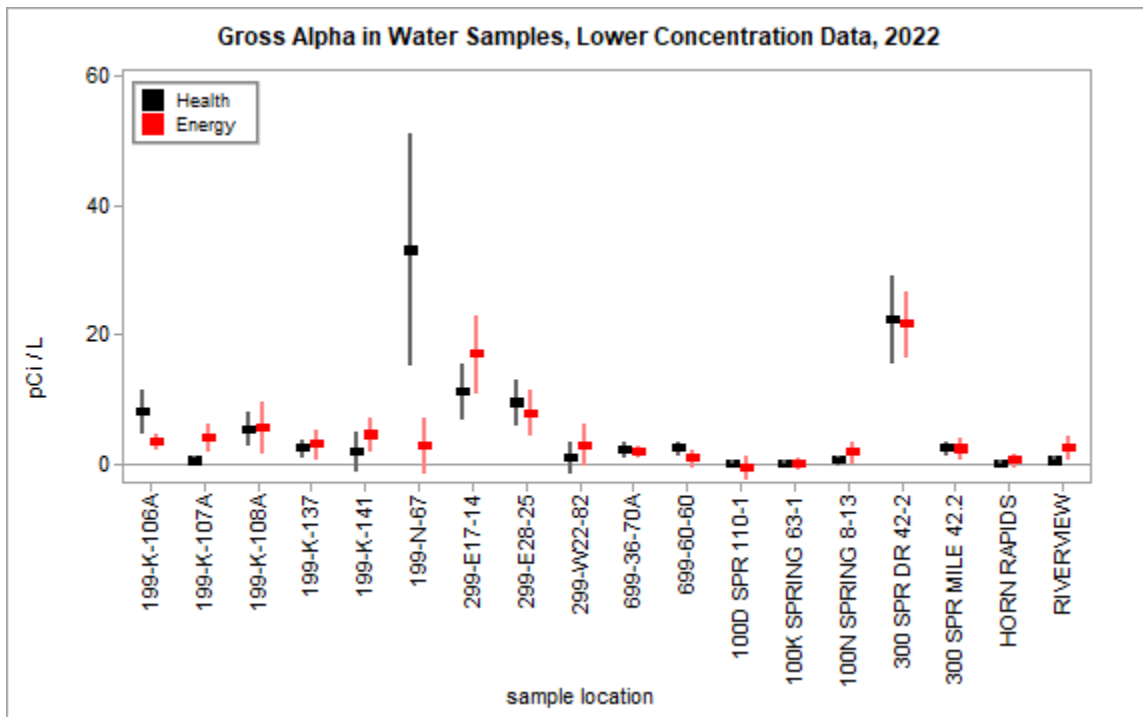


Figure 3.2.8 – Gross Beta Concentrations in Water, Low-Range Data

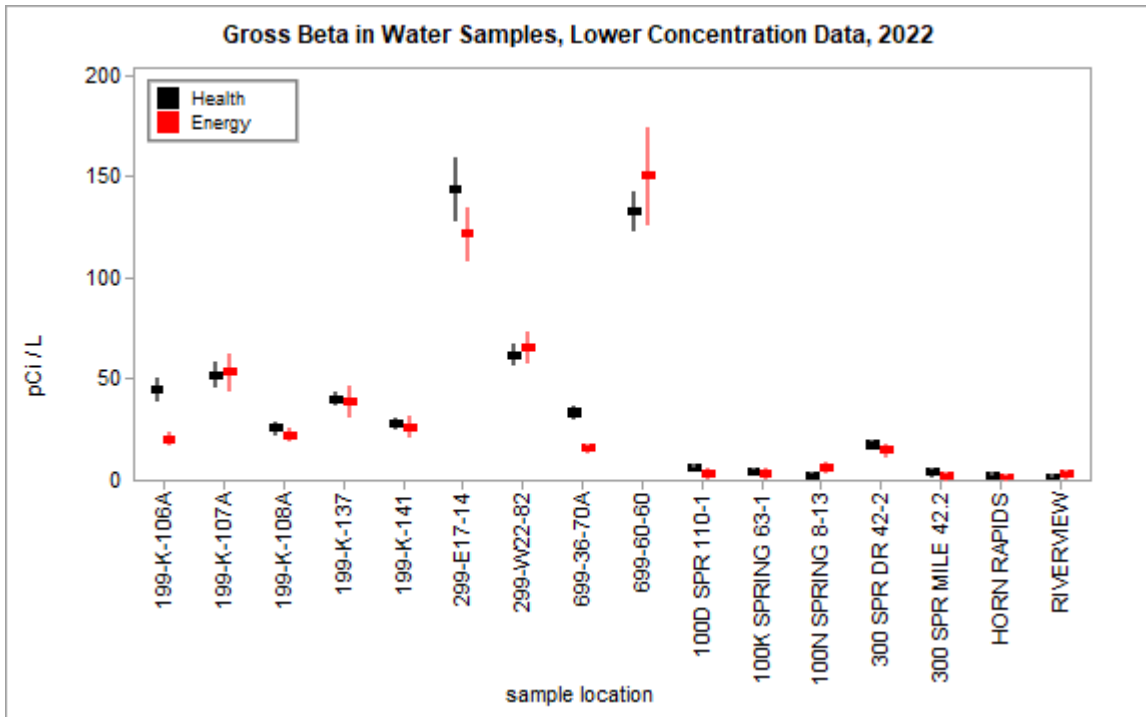


Figure 3.2.9 – Gross Beta Concentrations in Groundwater Well 299-E33-344

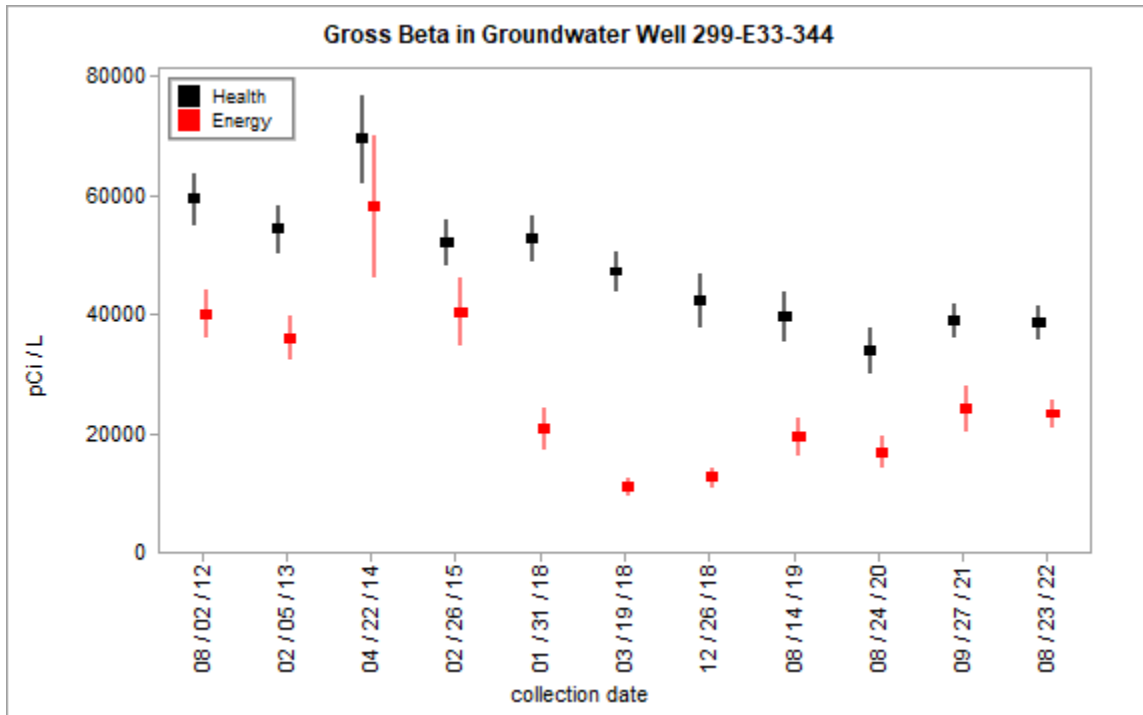


Figure 3.2.10 – H-3 Concentrations in Groundwater Well 299-E17-14

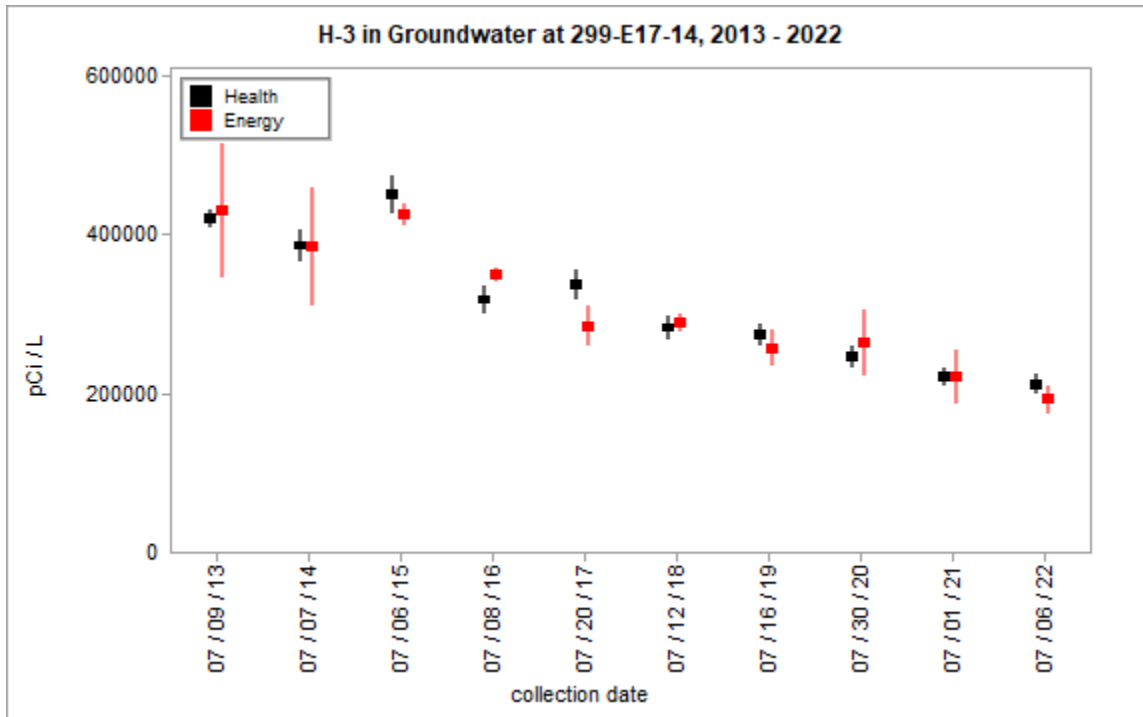


Figure 3.2.11 – I-129 Concentrations in Water

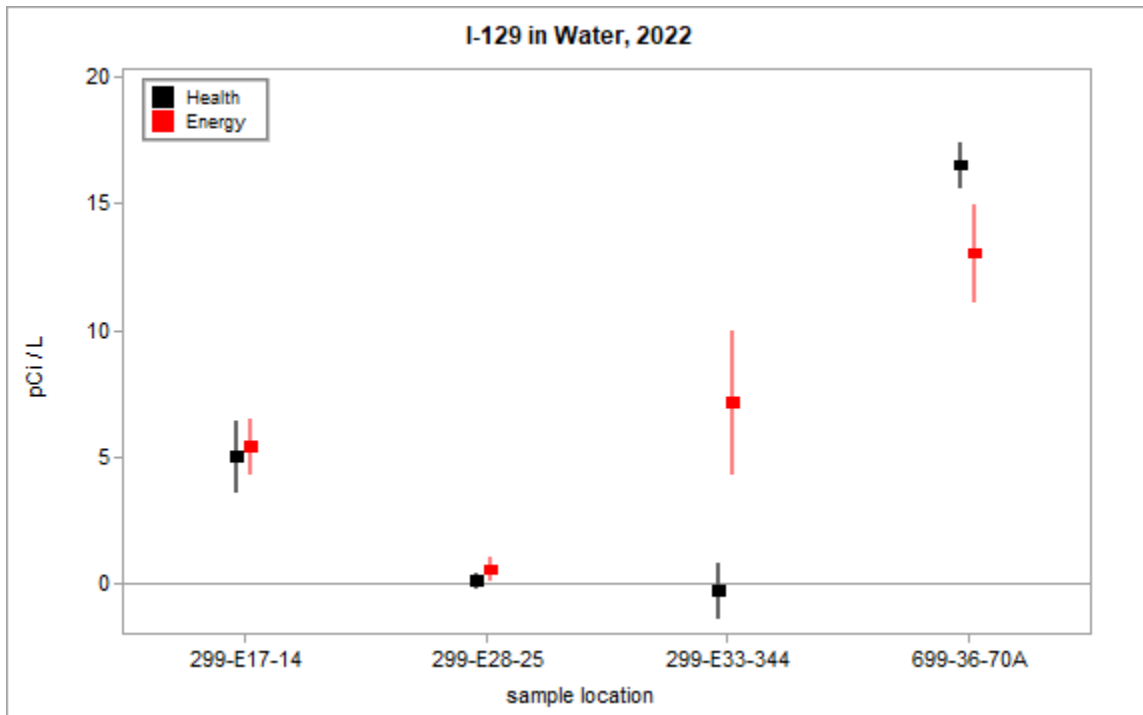


Figure 3.2.12 – Pu-239/240 Concentrations in Water

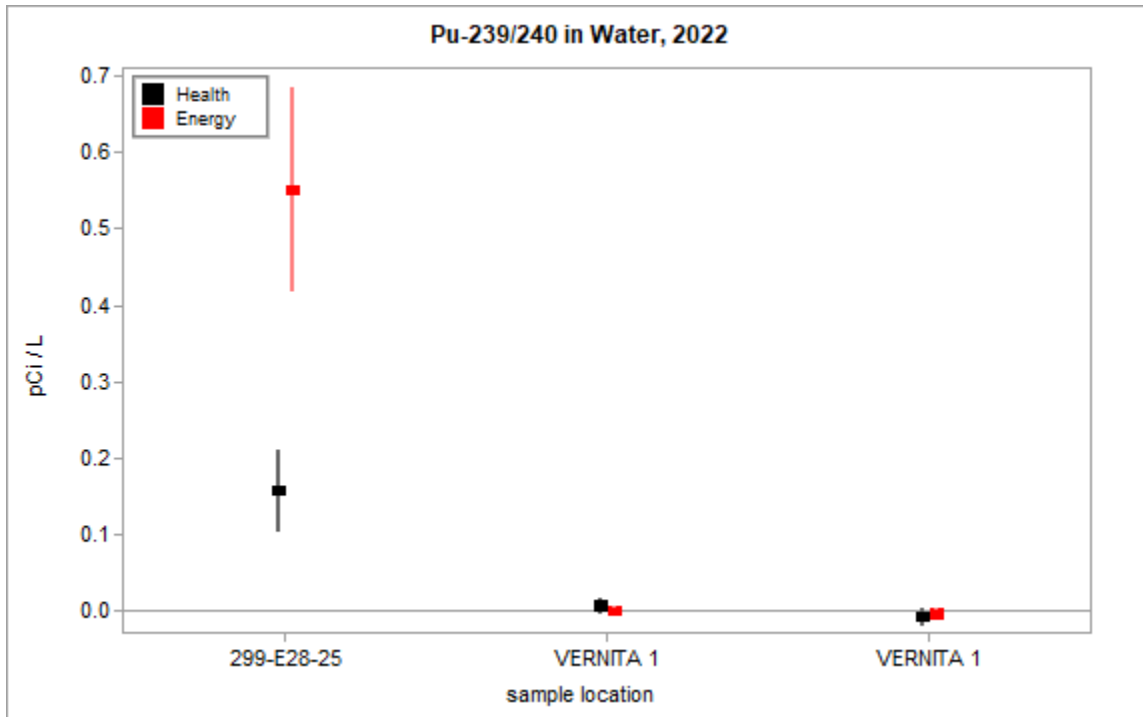


Figure 3.2.13 – Tc-99 Concentrations in Groundwater Well 299-E33-344

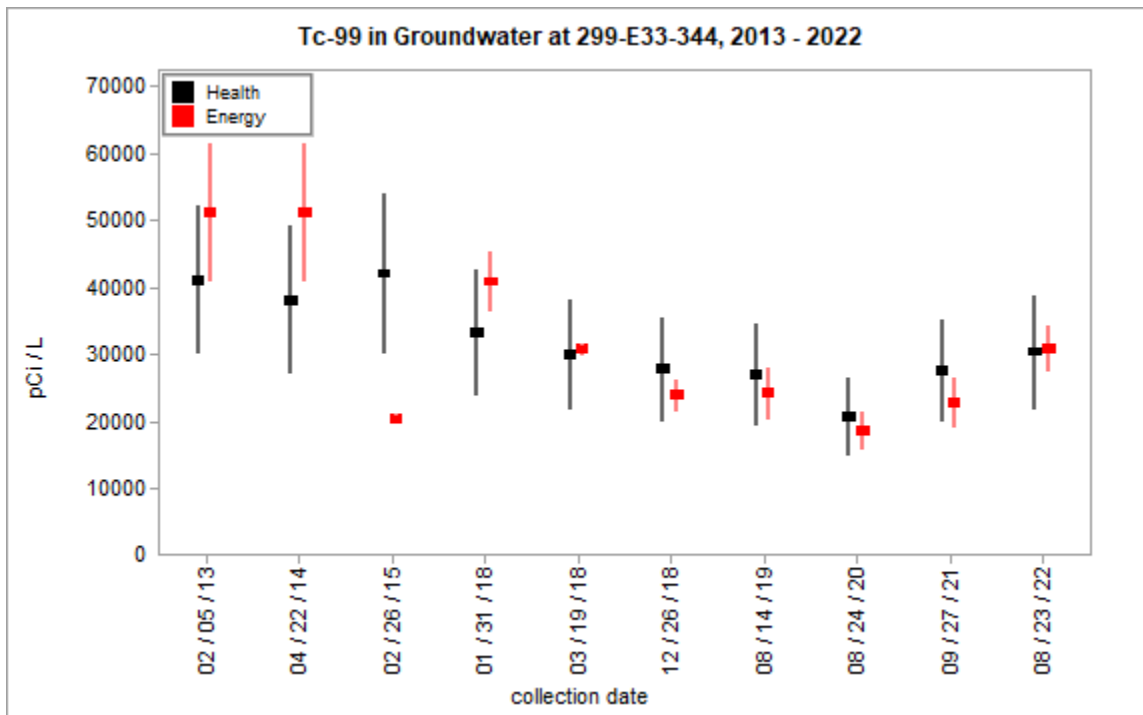
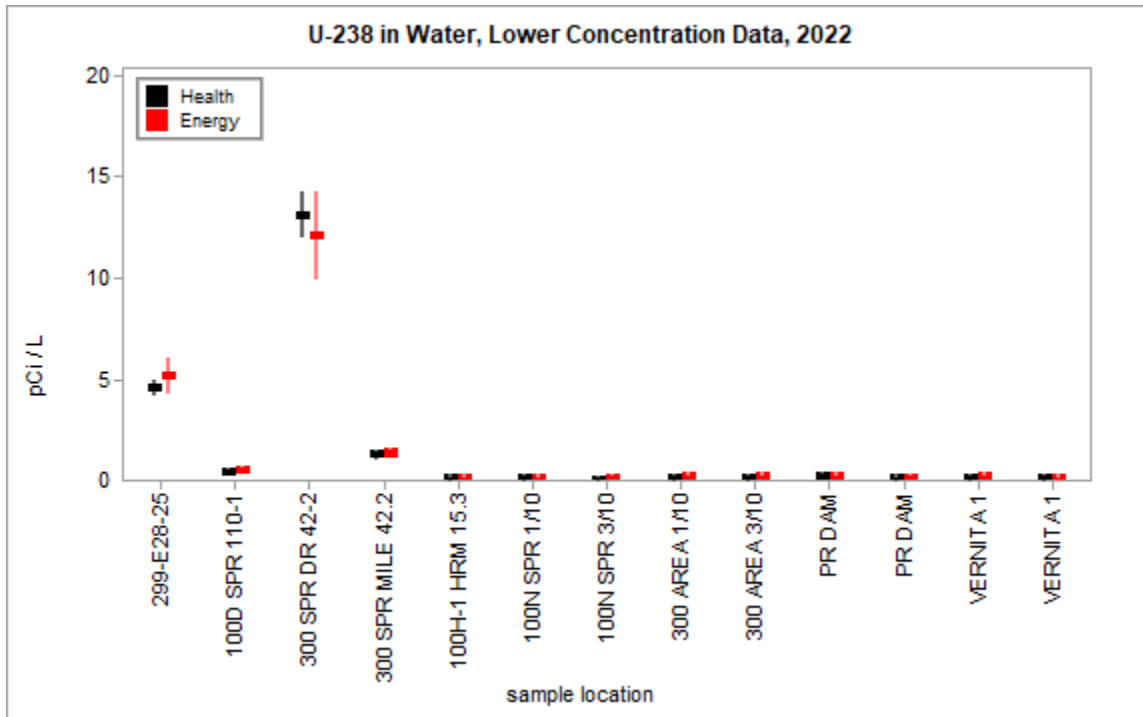


Figure 3.2.14 – U-238 Concentrations in Water, Low Range Data



3.3. External Radiation Monitoring

Major Findings:

- Health and Energy external radiation exposure rates are in fair agreement. For most data, Health reports exposure rates slightly lower than those reported by Energy.
- Exposure rates measured by Health are consistent with historical results.

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, or ambient, 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 numerous new monitoring sites, some on the Hanford Site and others 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. From 2006 forward, this report covers 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 54 external radiation monitoring locations that are relevant to the Hanford Site; 53 of these locations are considered environmental monitoring locations where the public

or workers or environmental receptors may have exposure, while one location is inside the 100B reactor with limited potential exposure to a worker. Nine of these sites are collocated with Department of Energy contractors, while Health independently monitors the remaining 45 sites. Of the nine collocated sites, one is inside the 100B reactor while the remaining eight are environmental monitoring locations.

Figure 3.3.1 shows most of Health’s external radiation monitoring locations. Fourteen 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.

Special Note: Due to limited sample collection operations, dosimeters from only 34 of the 45 independently monitored locations were collected in 2022, while dosimeters from all nine collocated sites were collected.

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, monitored independently by Health, 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 Collocated Dosimeters

Analyte	Collection Period	Number of Results	Quality of Agreement	Health’s Data Range (mR/day)	Anomalous Data?
External Rad	quarterly	35	fair	0.15 to 5.2	no

Health and Energy ambient radiation rates are in fair agreement. Figure 3.3.2 shows the data for the eight environmental locations (locations are discussed in Section 3.3.2). At each monitoring location in the figure, the graph first shows the fourth quarter data from the previous reporting year, followed by the first, second, and third quarter data for this reporting year. The prior year’s fourth quarter results are included because the collection date for these dosimeters was in early January of this reporting year.

The data in Figure 3.3.2 indicates a systematic bias, in which the radiation rates reported by Energy are on average 0.05 mR/day higher than those reported by Health. The scatter plot in Figure 3.3.3 more clearly shows this bias. Interestingly, in some years, Energy’s results are systematically higher than Health’s (as in the current year 2022), while in other years, Health’s results are higher than Energy’s (as seen in Figure 3.3.4, which shows the collocated data from the year 2019).

Figure 3.3.5 shows the collocated results from inside the 100 B Reactor, which does not represent an environmental monitoring location. Radiation rates inside 100B Reactor are approximately 40 times higher than for the environmental sites. This location was chosen to represent the maximum exposure possible for a worker inside the building; it is unlikely a member of the public would access this area.

Inside the 100 B Reactor, Health reports radiation rates approximately 50% greater than those reported by Energy. These results are consistent with previous years in which Health reports radiation rates significantly greater than those reported by Energy at this site.

The bias for the higher radiation rates inside the 100 B Reactor contrasts with the bias at the environmental monitoring sites where radiation rates are lower. At lower radiation rates, Energy reports higher values, while at higher radiation rates, Health reports higher values.

Inspection of Figures 3.3.2 and 3.3.5 indicates that Energy reports anomalously small error bars, or no error bars, for some of the data they provided to Health.

3.3.5 Other Discussion

Health operates a total of 54 external radiation monitoring locations, 53 of which are environmental monitoring locations, and one location is inside the 100B Reactor building. As discussed in Section 3.3.2, Health collected dosimeters from only 42 of the environmental

monitoring site locations in 2022 (eight collocated sites and 34 independent sites), and Table 3.3.2 summarizes these data.

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 external radiation rates reported by Health are consistent with historical results, and Health did not encounter anomalous data.

Table 3.3.2 – Summary of Health’s Independent Dosimeters

Analyte	Collection Period	Number of Results	Health’s Data Range (mR/day)	Anomalous Data?
External Rad	Quarterly / Semiannual	125	0.14 to 0.29	no

Health categorizes its external radiation monitoring sites by their location type, as described in Section 3.3.2. Figure 3.3.6 shows the average, minimum, and maximum external radiation rates at the environmental monitoring sites for each location category. As can be seen, the average radiation rates are similar for all location categories, except for the distant sites where the average is slightly lower. The rates are lower at distant sites most likely because these sites are covered by concrete, which shields natural radiation from the earth’s crust to a greater degree 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 since 2007 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 – Health External Radiation Monitoring Locations

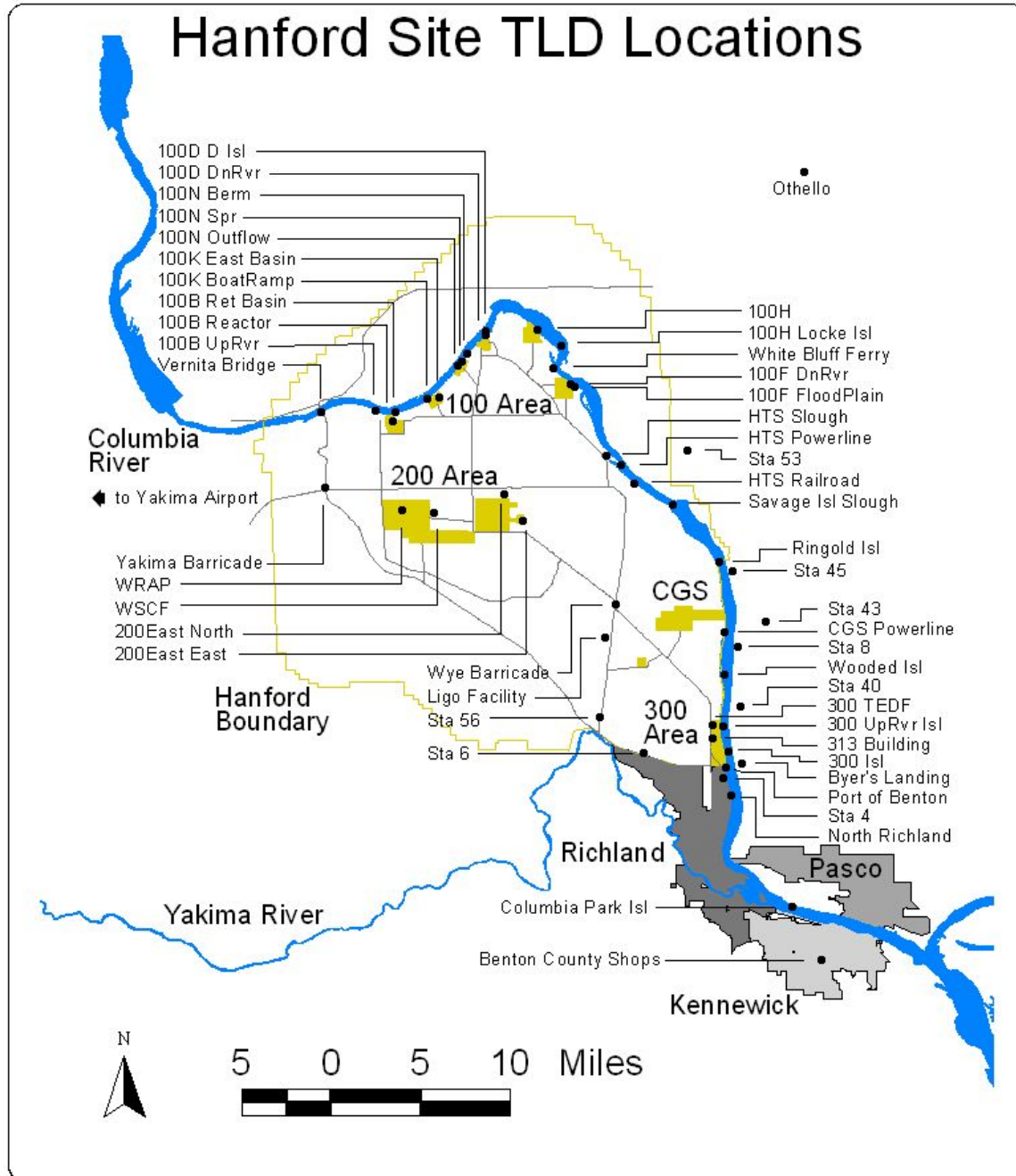


Figure 3.3.2 – Quarterly Ambient Radiation Rates

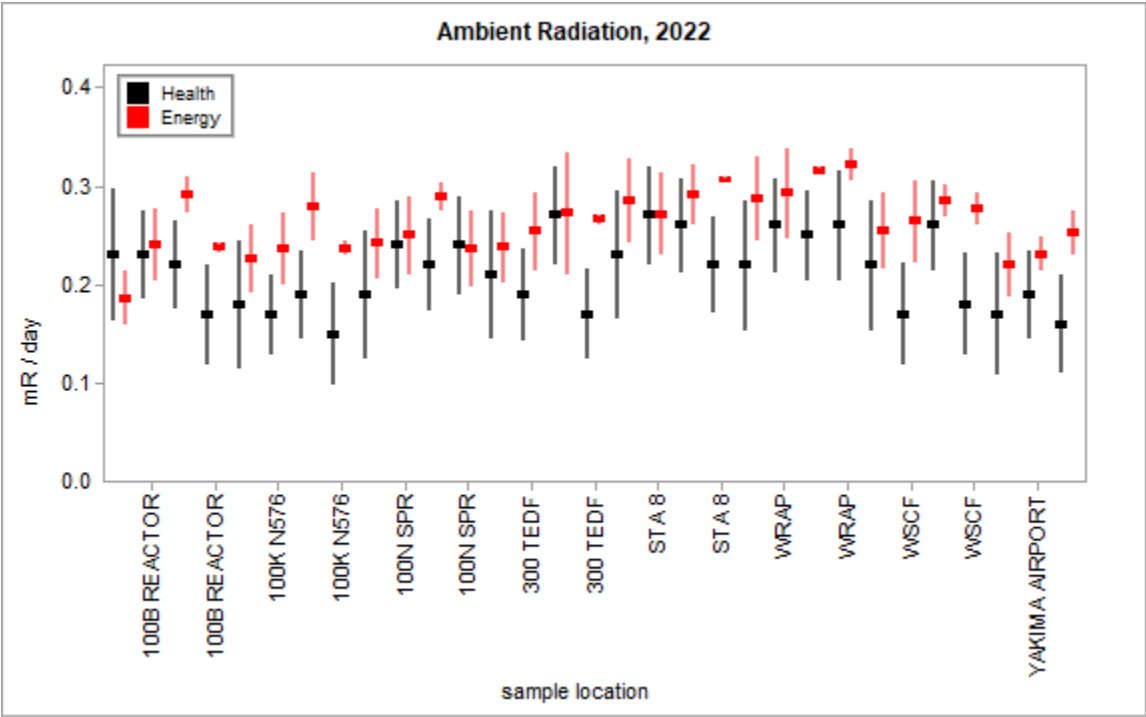


Figure 3.3.3 – Quarterly Ambient Radiation Rates

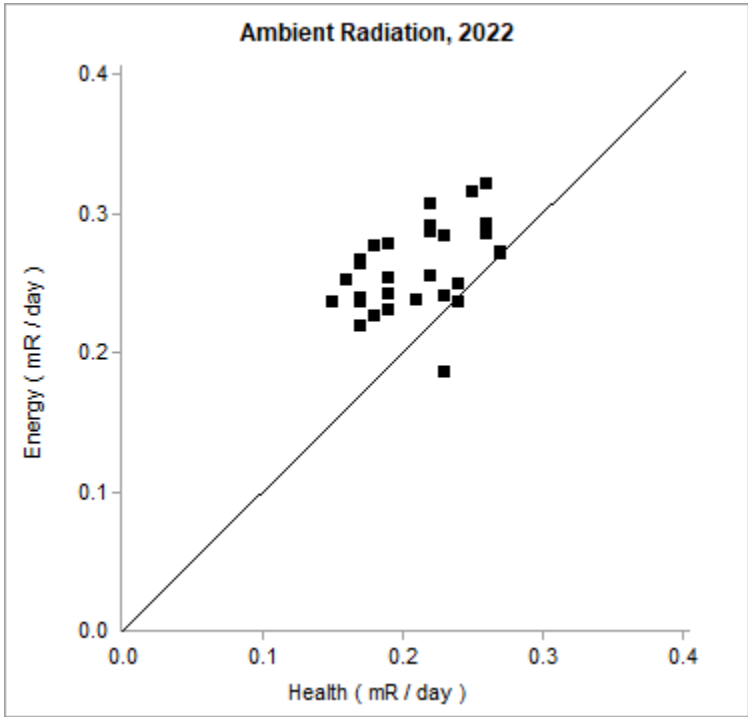


Figure 3.3.4 – 2019 Quarterly Ambient Radiation Rates

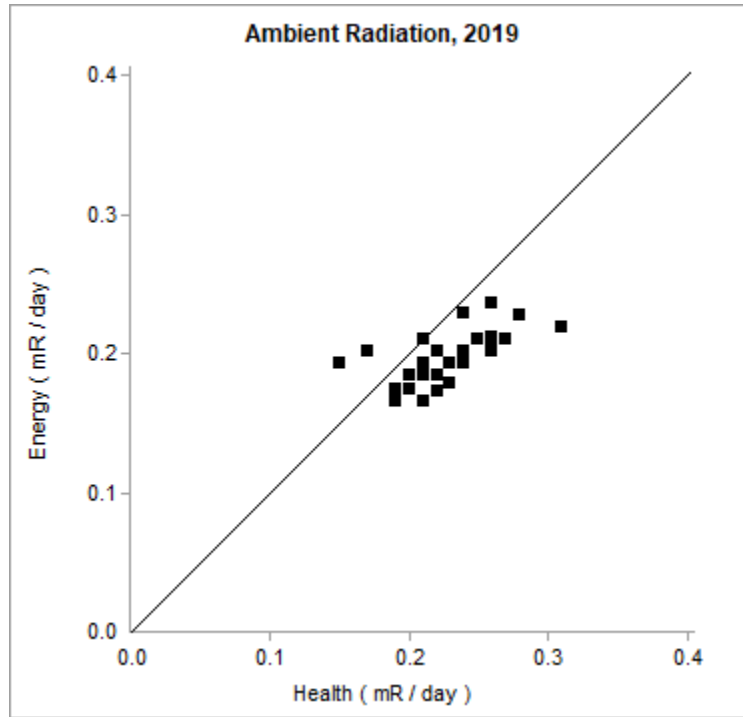


Figure 3.3.5 – Quarterly Ambient Radiation Rates Inside 100B Reactor

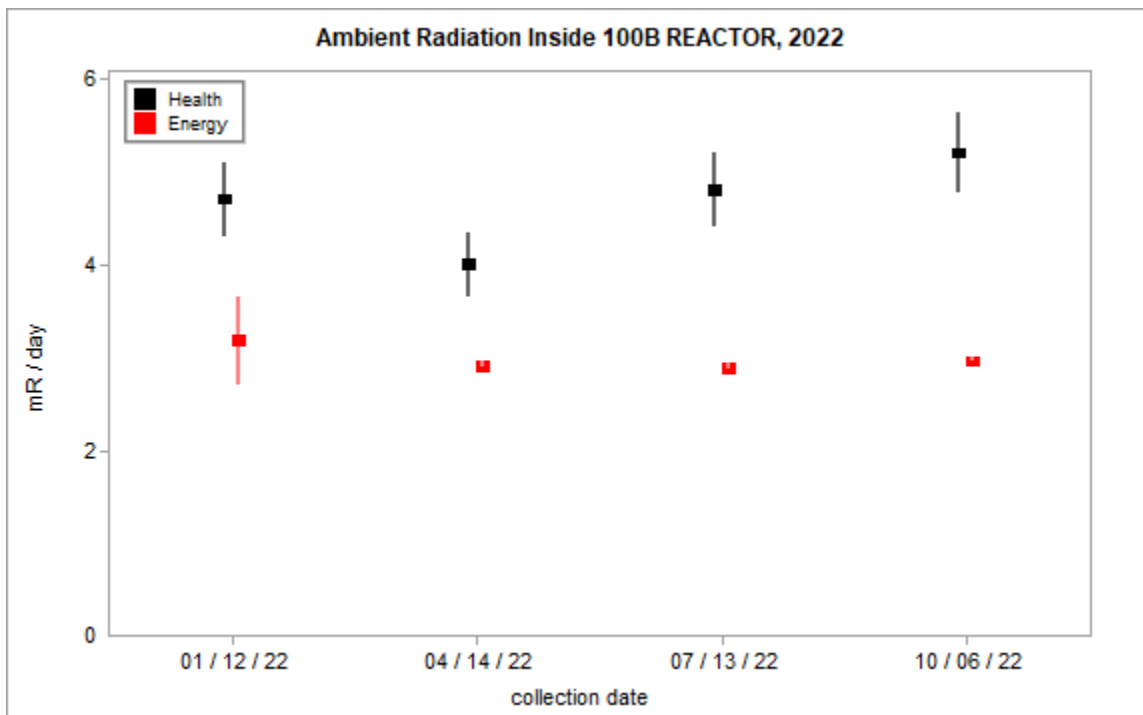
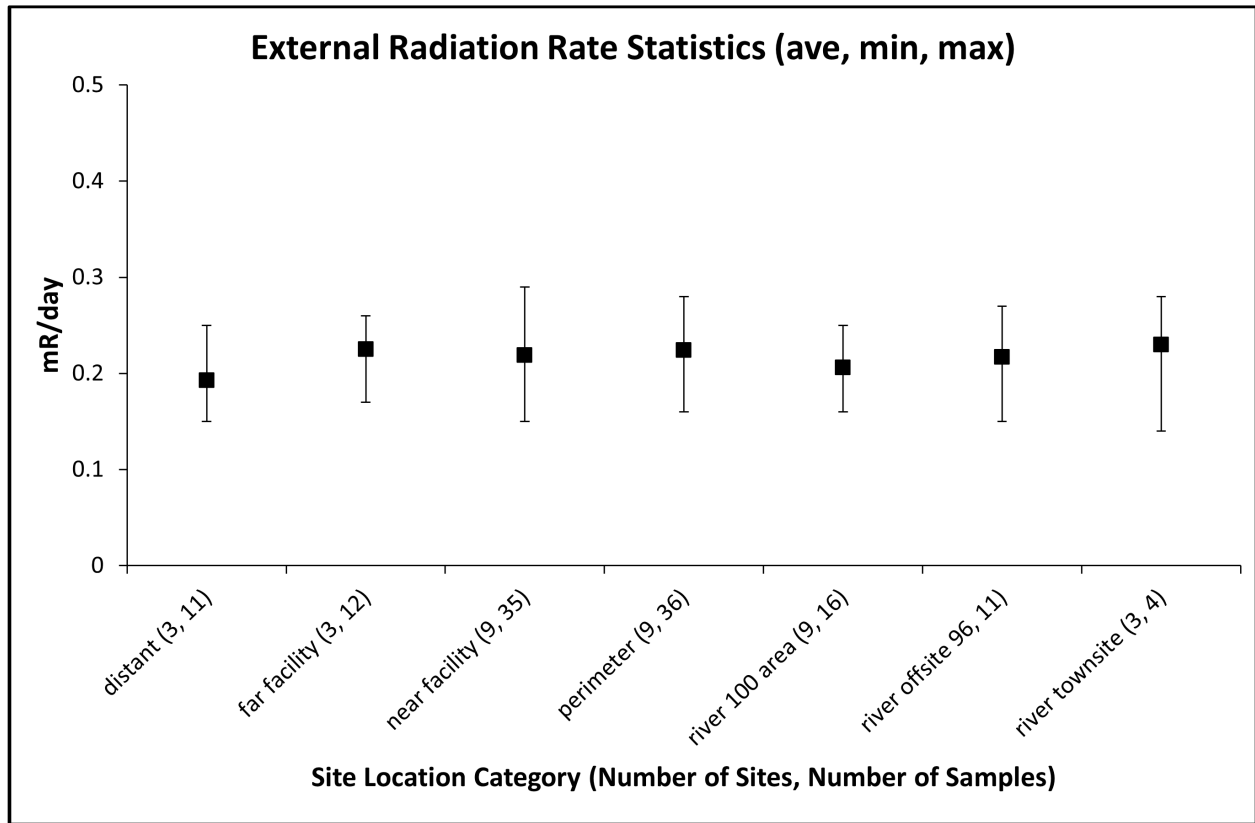


Figure 3.3.6 – External Radiation Rates by Location Category



3.4 Sediment and Soil Monitoring

Major Findings:

- Health and Energy sediment and soil concentrations are in fair agreement for Sr-90, U-234, and U-238, and are in good agreement for all other radionuclides.
- Health's reported radionuclide concentrations are either 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 from Hanford. 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 of all downriver dams 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; three soil samples from the 200 Area, and one each from the 300 and 600 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. In addition, two of the samples from the 200 West Area were analyzed for Am-241, as this area may have transuranic isotope contamination.

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. In addition, the sample from the 100 K Area was analyzed for C-14 as this isotope has historically been detected in various media from this location, and the sample from the 300 Area was analyzed for U-236.

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).

For some radionuclides, Health has not completed analysis for all the scheduled samples, or Energy has not provided results for all the scheduled samples, and in these cases the value in the “Number of Results” column represents the number of scheduled results followed by the number of actual results in parentheses.

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 3.4.1 – Summary of Split Soil and Sediment Samples

Analyte	Collection Period	Number of Split Results	Quality of Agreement	Health’s Data Range (pCi/g)	Anomalous Data?
Am-241	annual	2	good	0.021 to 0.06	no
C-14	annual	1	good	< 1.8	no
Co-60	annual	13	good	< 0.02	no
Cs-134	annual	13	good	< 0.07	no
Cs-137	annual	13	good	< 0.01 to 9.5	no
Eu-152	annual	13	good	< 0.04	no
Eu-154	annual	13	good	< 0.05	no
Eu-155	annual	13	good	< 0.06	no
Pu-238	annual	13	good	< 0.01 to 0.011	no
Pu-239/240	annual	13	good	< 0.005 to 0.02	no
Sr-90 ^(a)	annual	13 (8)	fair	< 0.002 to 0.02	no
U-234	annual	13	fair	0.52 to 1.7	no
U-235	annual	13	good	0.02 to 0.07	no
U-236	annual	1	good	< 0.01	no
U-238	annual	13	fair	0.55 to 1.5	no

(a) Health has not completed analyte specific analysis for some or all the scheduled samples. The value in the “Number of Results” column represents the number of scheduled results followed by the number of actual results in parentheses.

Health and Energy sediment and soil concentrations are in good agreement for Am-241, C-14, isotopes of plutonium, and for the gamma emitting isotopes of Co-60, Cs-134, Cs-137, Eu-152, Eu-154, and Eu-155, with concentrations either below detection limits or consistent with historical values. As examples, the Co-60, Pu-238, and Pu-239/240 data are shown in Figures 3.4.2, 3.4.3, and 3.4.4. In Figure 3.4.3 for Pu-238, the minimum detectable activity (MDA) for Health’s results are also shown. A few of Health’s results are slightly above the MDA of approximately 0.01 pCi/g.

Historically, Eu-152 is not typically detected in Columbia River sediments; however, Health has detected this isotope in sediments at White Bluffs Slough for nearly 25 years. The average

concentration for Health's historical data at this site is 0.06 pCi/g, and in 2022 Health's result was less than the minimum detectable activity of 0.04 pCi/g.

For Sr-90 in sediments, the Health and Energy concentrations are in good agreement, with results ranging from < 0.002 to 0.02 pCi/g. Results for Sr-90 in soil samples are incomplete and will be reported in the following annual report.

The Health and Energy U-234 and U-238 concentrations are in fair agreement (see Figure 3.4.5 [the U-238 are similar]). While the split results are similar, the Health and Energy error bars do not overlap for many of the samples. In addition, there is a systematic bias in which Energy reports lower concentrations than those reported by Health. Historically, Energy's U-234 and U-238 concentrations can differ by as much as one-half of the value reported by Health.

Historically, the Health and Energy U-235 concentrations are also in fair agreement, with a similar bias discussed above for U-234 and U-238. However, in 2022 the U-235 data are in good agreement, as shown in Figure 3.4.6.

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 Am-241, C-14, Eu-152, Pu-238, and Sr-90. The range of detected results reported in Table 3.4.1 is consistent with expected results.

Americium-241 is often detected in 200 Area soil samples, with concentrations near 0.1 pCi/g. Carbon-14 is often detected in Columbia River sediment samples near the 100K Reactor Area, at concentrations ranging from 0 to 15 pCi/g, due to a C-14 groundwater plume in that area.

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 these isotopes may be transported through the environment into sediment.

In addition to the single split U-236 sediment sample, Health independently analyzed two soil samples from the 200 West Area for U-236, with results ranging from below the detection limit to 0.009 pCi/g.

Typically, radionuclide concentrations in sediment at locations downriver from Hanford at McNary Dam are not significantly different from those at the upstream background location at Priest Rapids Dam. For example, as can be seen in Figures 3.4.2, 3.4.3, and 3.4.4, the Co-60, Pu-238, and Pu-239/240 concentrations at McNary Dam (downriver location) are similar to the concentrations at Priest Rapids Dam (upriver location). From Figure 3.4.5, the U-234 concentrations are slightly higher downriver than upriver. Analysis of Health's data at McNary

Dam for samples collected from the years 2000 through 2022 indicates an average U-234 concentration of 1.42 pCi/g with a standard deviation of 0.2 pCi/g, while the average at Priest Rapids Dam is 1.22 pCi/g with a standard deviation of 0.17 pCi/g, indicating a very small increase in concentrations downriver.

Figure 3.4.1 – Typical Sediment Monitoring Locations

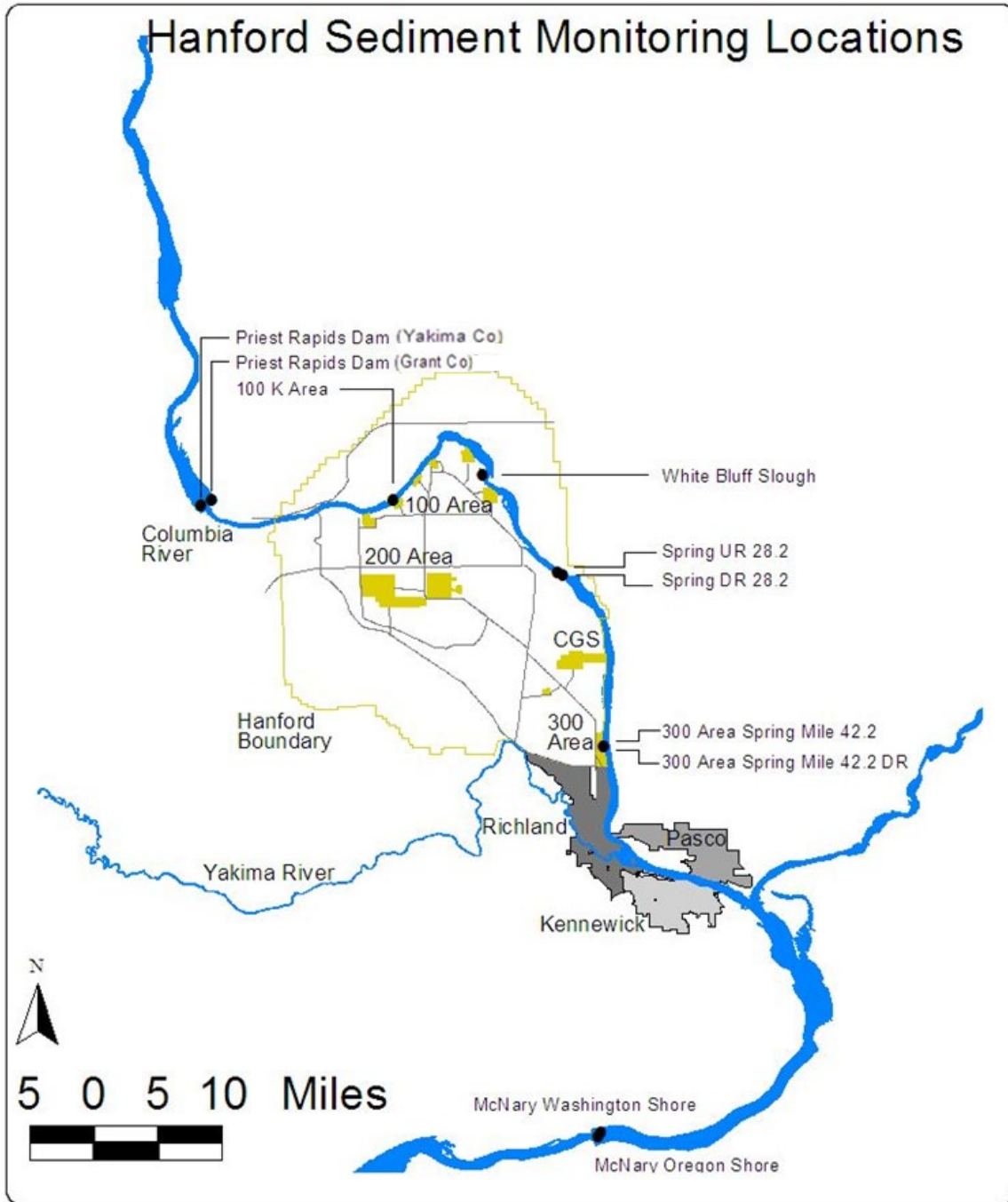


Figure 3.4.2 – Co-60 Concentrations in Sediment and Soil

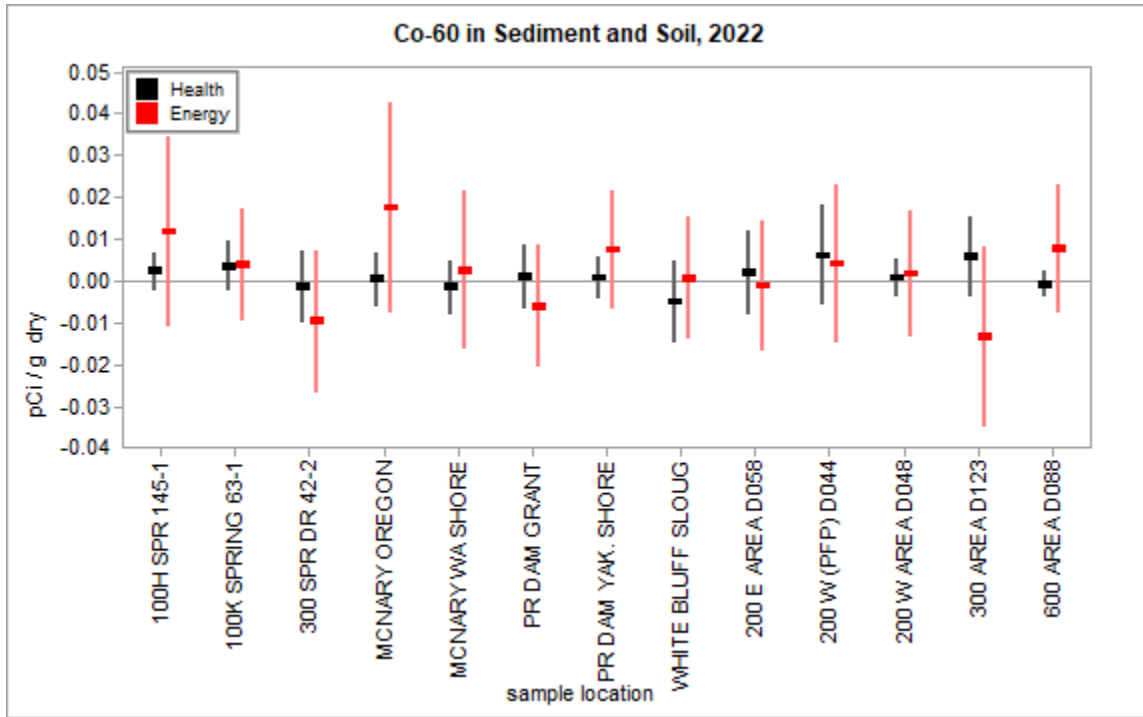


Figure 3.4.3 – Pu-238 Concentrations in Sediment and Soil

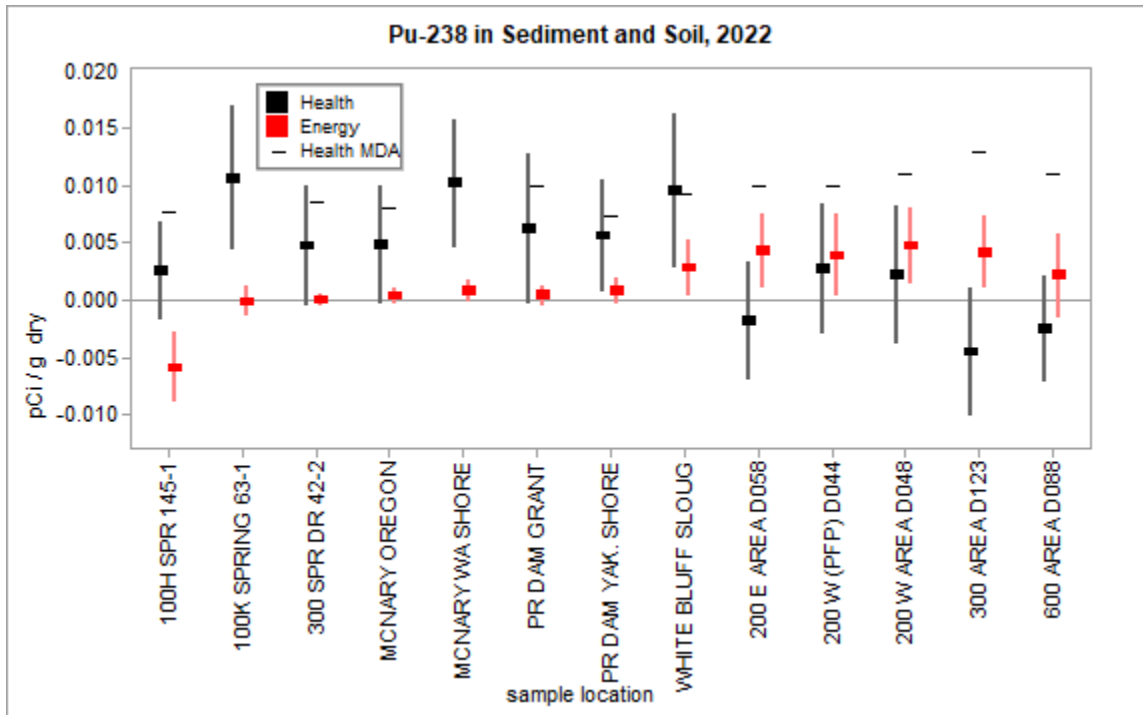


Figure 3.4.4 – Pu-239/240 Concentrations in Sediment and Soil

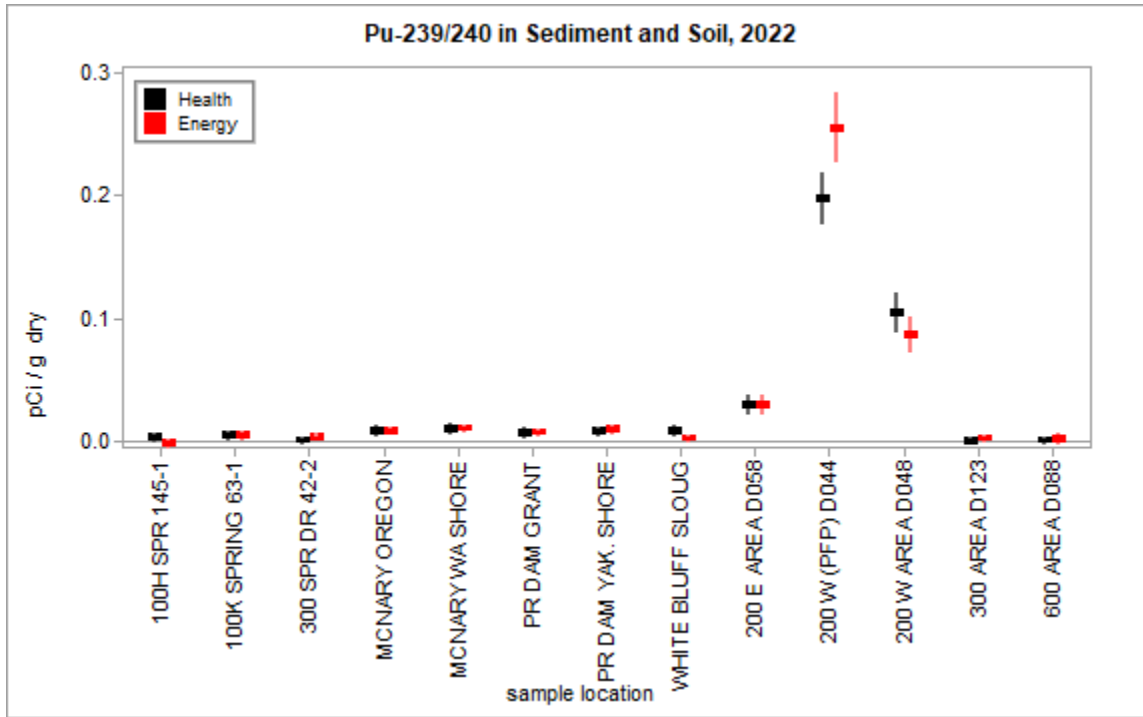


Figure 3.4.5 – U-234 Concentrations in Sediment and Soil

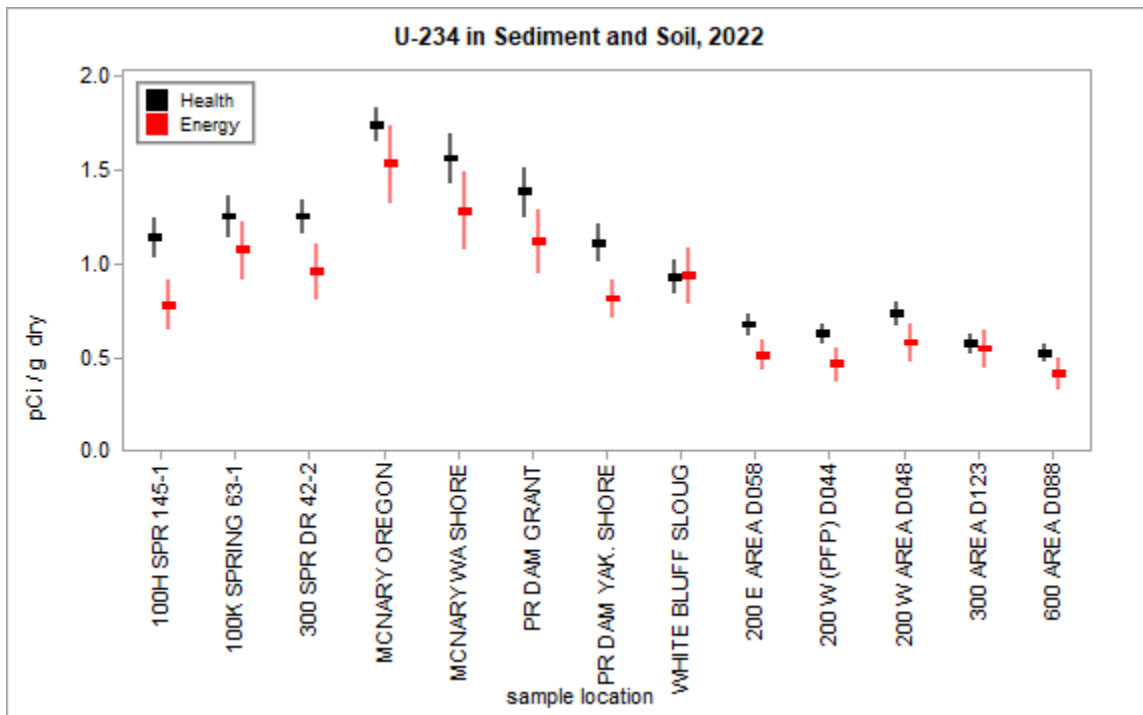
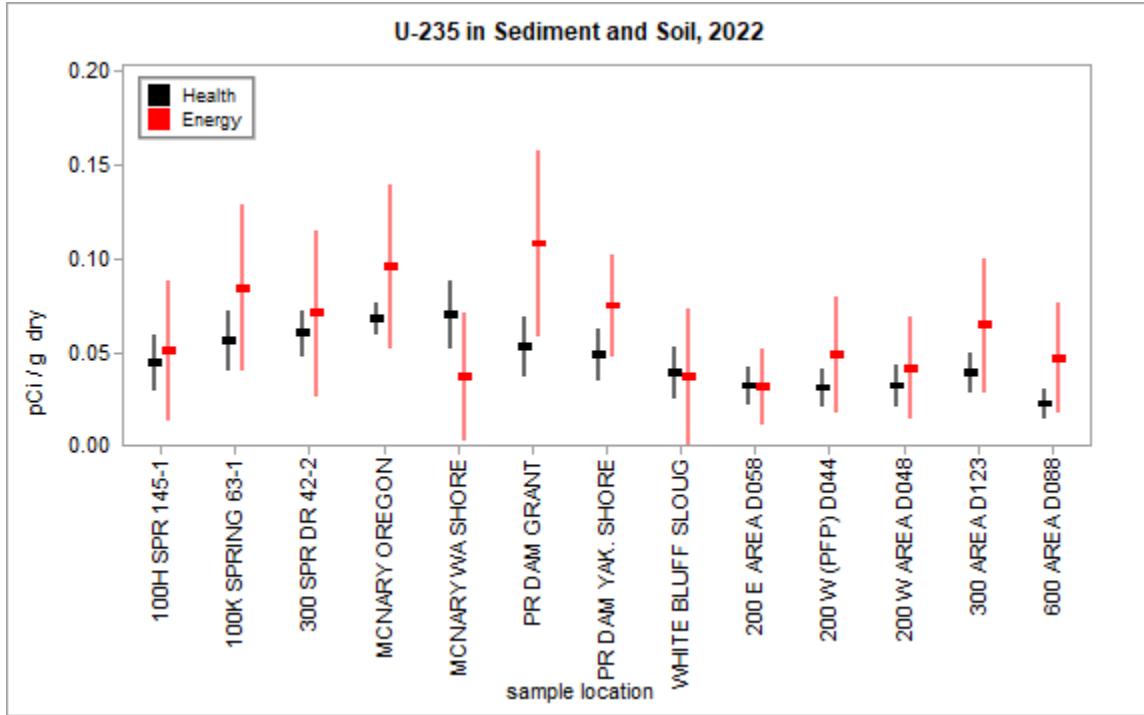


Figure 3.4.6 – U-235 Concentrations in Sediment and Soil



3.5 Biota Monitoring

Major Findings:

- All Health and Energy radionuclide concentrations are in good agreement.
- Most Health radionuclide concentrations are below detection limits. C-14, Cs-137, H-3, and isotopes of uranium and plutonium were detected in a few biota samples, with most concentrations consistent with historical results.

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 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 include 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 also 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 one peach sample; two samples each of corn, leafy vegetable, melon, and potato; and eight 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 three fish from the Columbia River, one bass and one carp from the 300 Area, and one carp from the 100 Area. Game birds include two quail, one from the 100 Area and one from the 300 Area.

Eight rabbit brush vegetation samples were collected on the Hanford Site, three samples from the 200 Area, one from the 300 Area, one from the 600 Area, and three from offsite background locations. The onsite 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 Hanford Mission Integrated Solutions, HMIS) 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, made from grapes grown on vineyards near the Hanford Site, is analyzed for gamma emitting radionuclides, tritium (H-3), and C-14. Concentration units are pCi/L.

Fish and Wildlife

For fish sampling, the Energy contractor (currently HMIS) 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 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 HMIS) 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).

For some radionuclides, Health has not completed analysis for all of the scheduled samples, or Energy has not provided results for all of the scheduled samples, and in these cases the value in the “Number of Results” column represents the number of scheduled results followed by the number of actual results in parentheses.

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?
Am-241	annual	1	good	< 0.002	no
C-14	annual	6	good	< 0.9	no
Co-60	annual	22	good	< 0.04	no
Cs-134	annual	22	good	< 0.04	no
Cs-137	annual	22	good	< 0.04 to 0.07	no
Eu-152	annual	11	good	< 0.09	no
Eu-154	annual	11	good	< 0.1	no
Eu-155	annual	11	good	< 0.1	no
H-3	annual	3	good	< 0.8	no
Pu-238	annual	11	good	< 0.003 to 0.002	no
Pu-239/240	annual	11	good	< 0.0018 to 0.0031	no
Sr-90 ^(a)	annual	14 (0)			
U-234	annual	11	good	0.0008 to 0.015	no
U-235	annual	11	good	< 0.002	no
U-238	annual	11	good	< 0.0008 to 0.017	no

(a) Health has not completed analyte specific analysis for some or all of the scheduled samples. The value in the “Number of Results” column represents the number of scheduled results followed by the number of actual results in parentheses.

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?
C-14	annual	8	good	< 60 to 660	no
Co-60	annual	8	good	< 10	no
Cs-134	annual	8	good	< 10	no
Cs-137	annual	8	good	< 10	no
Eu-152	annual	8	good	< 30	no
Eu-154	annual	8	good	< 30	no
Eu-155	annual	8	good	< 30	no
H-3	annual	8	good	< 80 to 940	no

All Health and Energy concentrations in split biota samples (Table 3.5.1) are in good agreement. Most results are below detection limits, while a few samples have concentrations of Cs-137, Pu-238, Pu-239/240, U-234, or U-238 slightly above detection limits but also consistent with historical results. Analytes with detected values are shown in Figures 3.5.1 through 3.5.4 (U-238 data is similar to the U-234 data shown in the Figure).

All the Health and Energy concentrations in split wine samples (Table 3.5.2) are in good agreement. Most results are below detection limits, while a few samples have concentrations of C-14 (Figure 3.5.5) or H-3 (Figure 3.5.6) above detection limits. The detected H-3 data are consistent with historic results. Health recently started to analyze wine samples for C-14 in 2021, and the concentrations for that year were either less than detection limits or up to 130 pCi/L. For this reporting period, 2022, C-14 concentrations were either less than detection limits or up to 660 pCi/L. Energy’s C-14 sample-specific minimum detectable activity ranges from 400 to 1,800 pCi/L, so it is not possible for Energy to confirm Health’s positive detections.

3.5.5 Other Discussion

Health occasionally detects small concentrations of Cs-137, Sr-90, and isotopes of uranium and plutonium in biota samples, and tritium (H-3) in wine samples. Health does not typically detect gamma emitting radionuclides in biota or wine samples.

It is of interest to determine if detected concentrations of any radionuclide are due to a Hanford contaminant, as opposed to natural or fallout-related radioactivity. In the case of biota samples, this can be a difficult assessment, as detected concentrations are often only slightly

above limits of detection, or only slightly above background values (which include natural background and fallout).

Health has historical data for Pu-239/240 concentrations in vegetation collected from background locations, which include the cities of George, Othello, and Wanapum, and these data are shown in Figure 3.5.7. Figure 3.5.8 shows results for Hanford Site vegetation samples with detected values of Pu-239/240. Also in Figure 3.5.8 are the statistics for the background data in Figure 3.5.7. Specifically, the dark blue line indicates the average background concentration, the light blue band represents the standard deviation about the average, and the pink lines represent the minimum and maximum measured background concentrations. While Health has not designed a robust program to measure Pu-239/240 background, this limited set of data indicates the Hanford Site vegetation samples may contain Hanford related contaminants.

Figure 3.5.1 – Cs-137 Concentrations in Fish and Vegetation

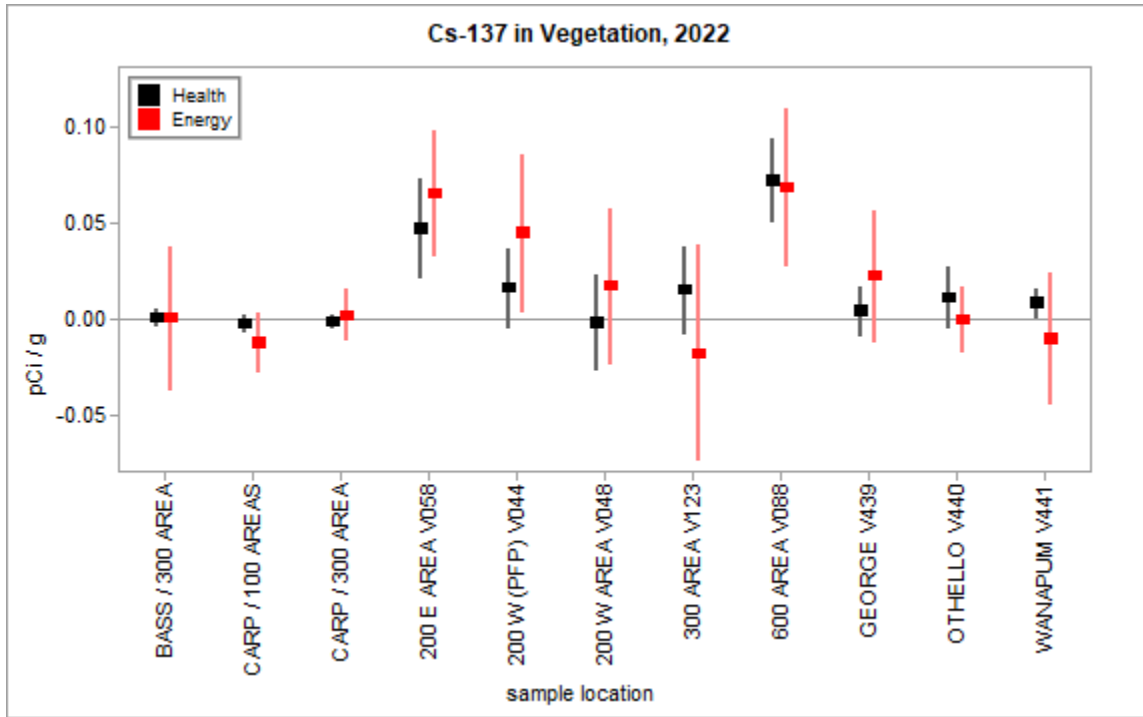


Figure 3.5.2 – Pu-238 Concentrations in Fish and Vegetation

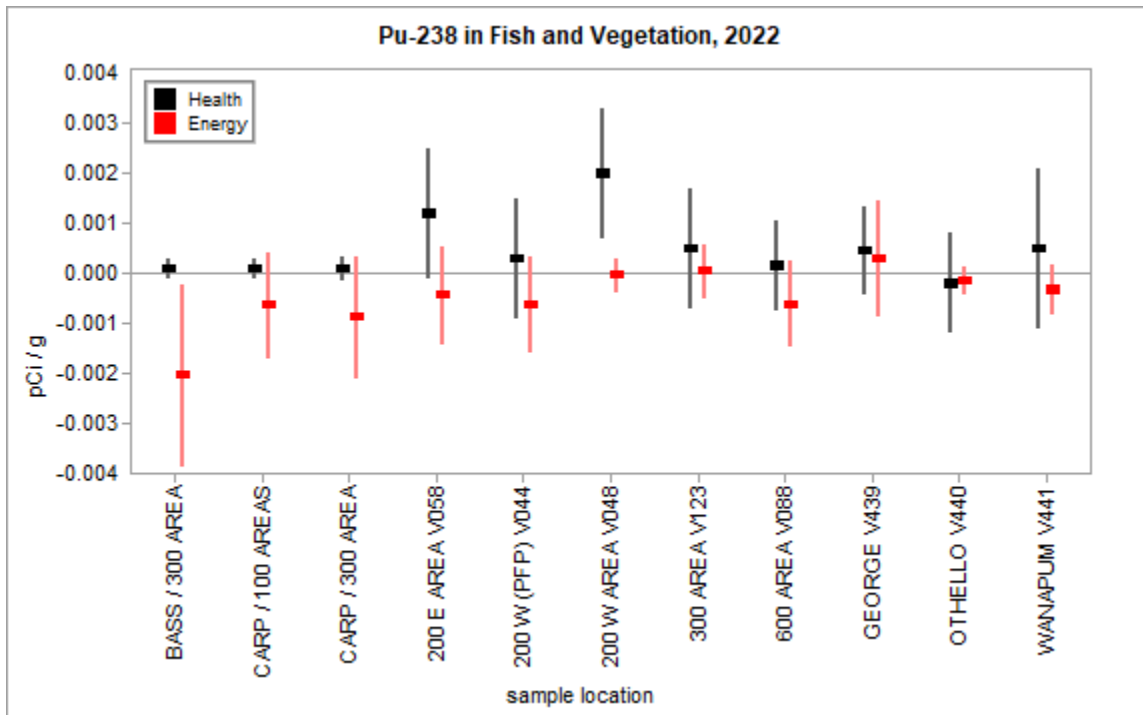


Figure 3.5.3 – Pu-239/240 Concentrations in Fish and Vegetation

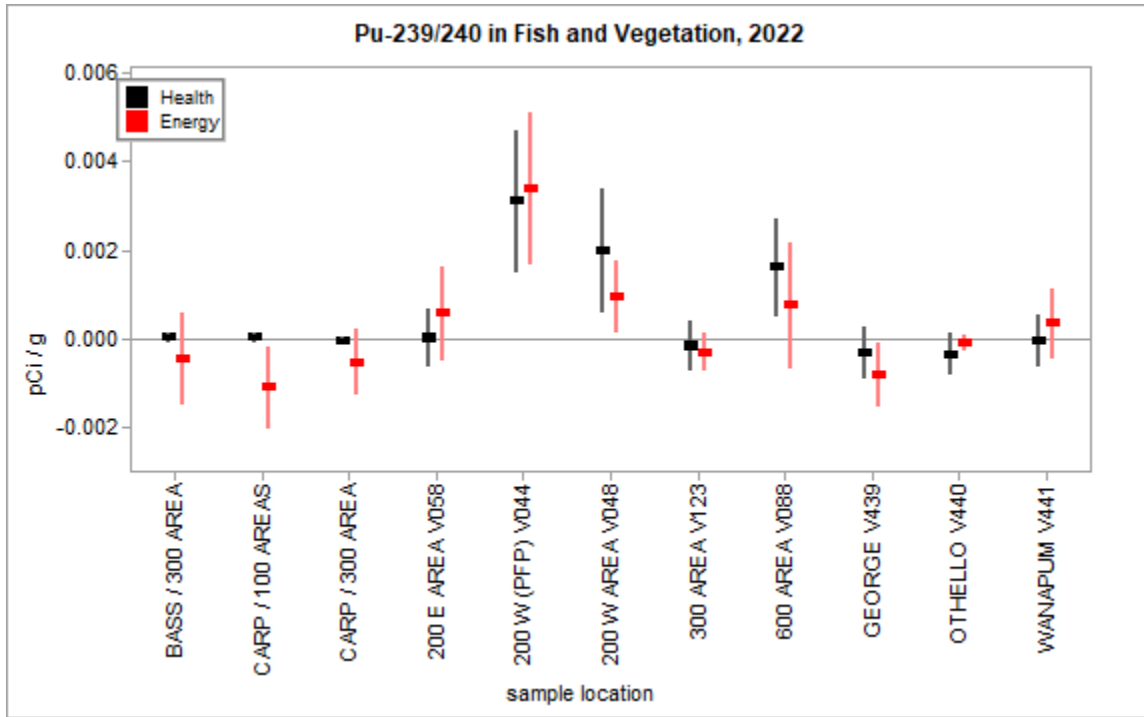


Figure 3.5.4 – U-234 Concentrations in Fish and Vegetation

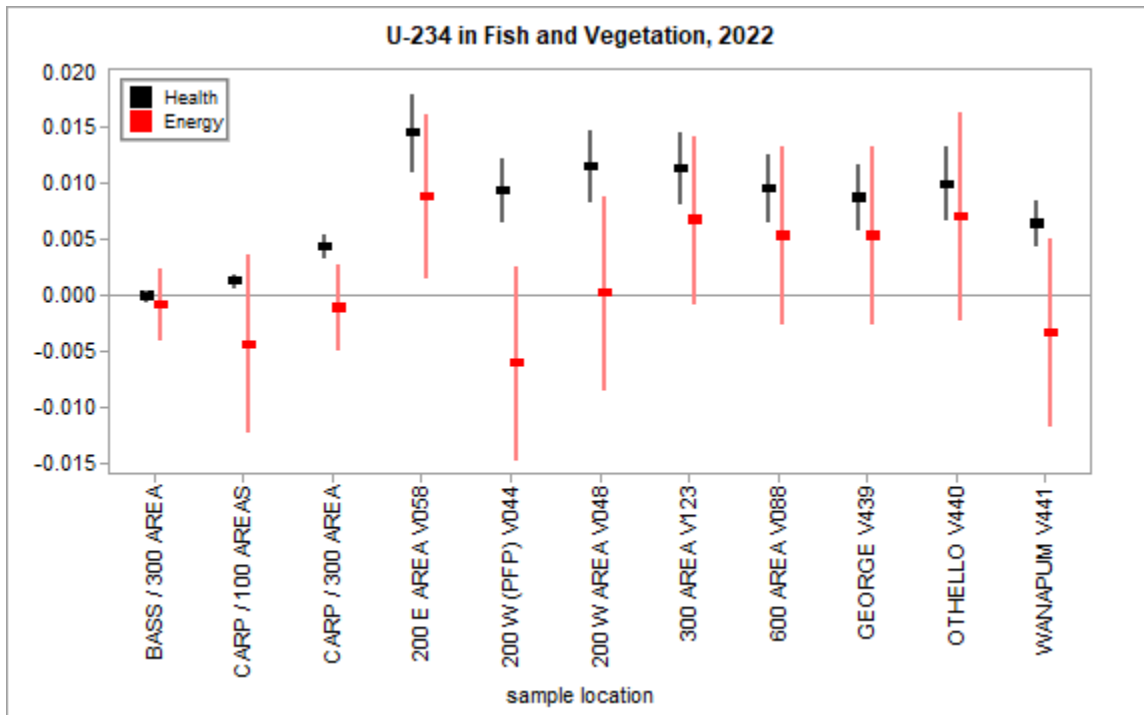


Figure 3.5.5 – C-14 Concentrations in Wine

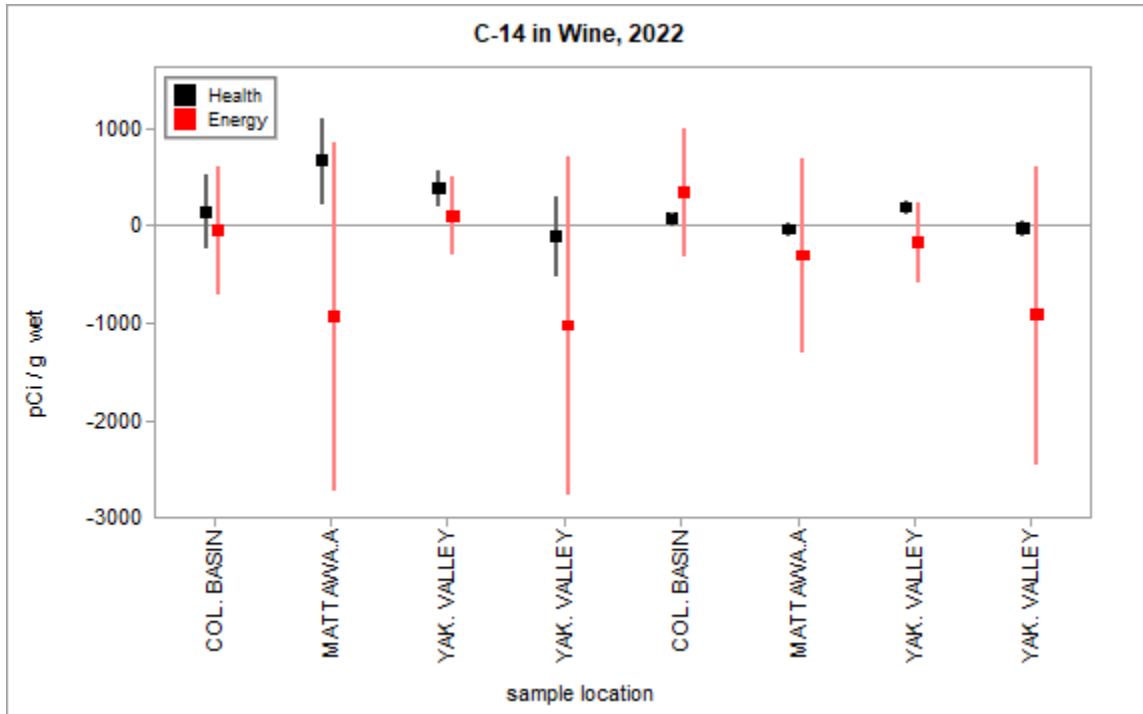


Figure 3.5.6 – H-3 Concentrations in Wine

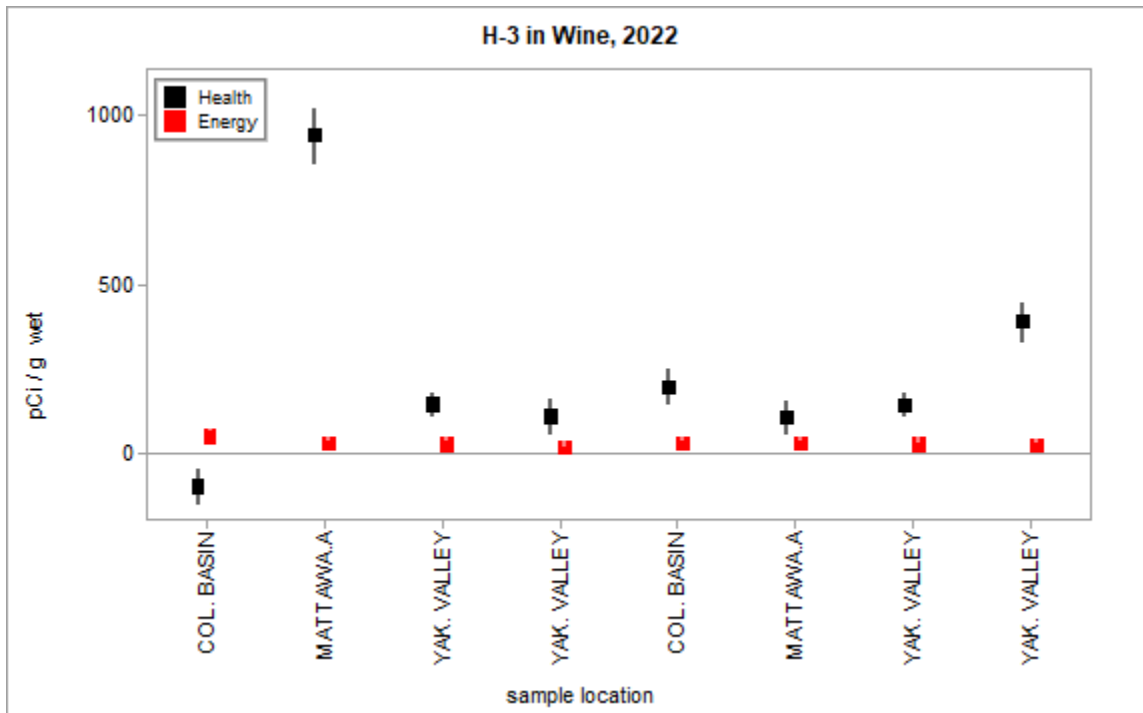


Figure 3.5.7 – Pu-239/240 Background Concentrations in Vegetation

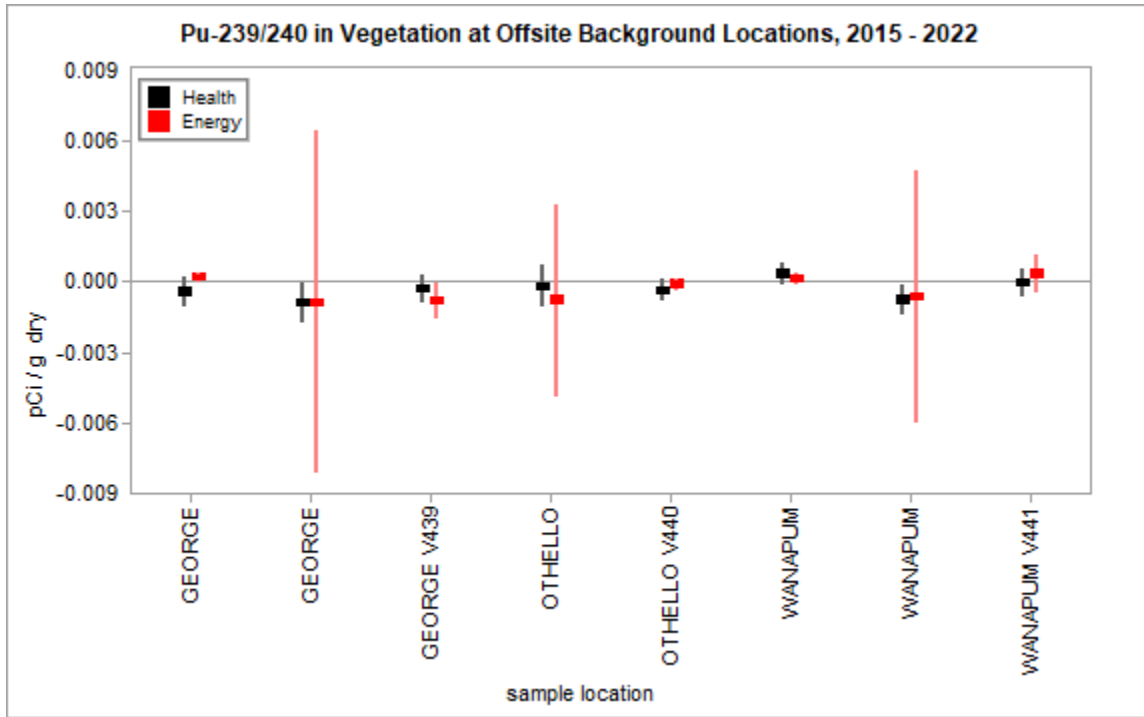
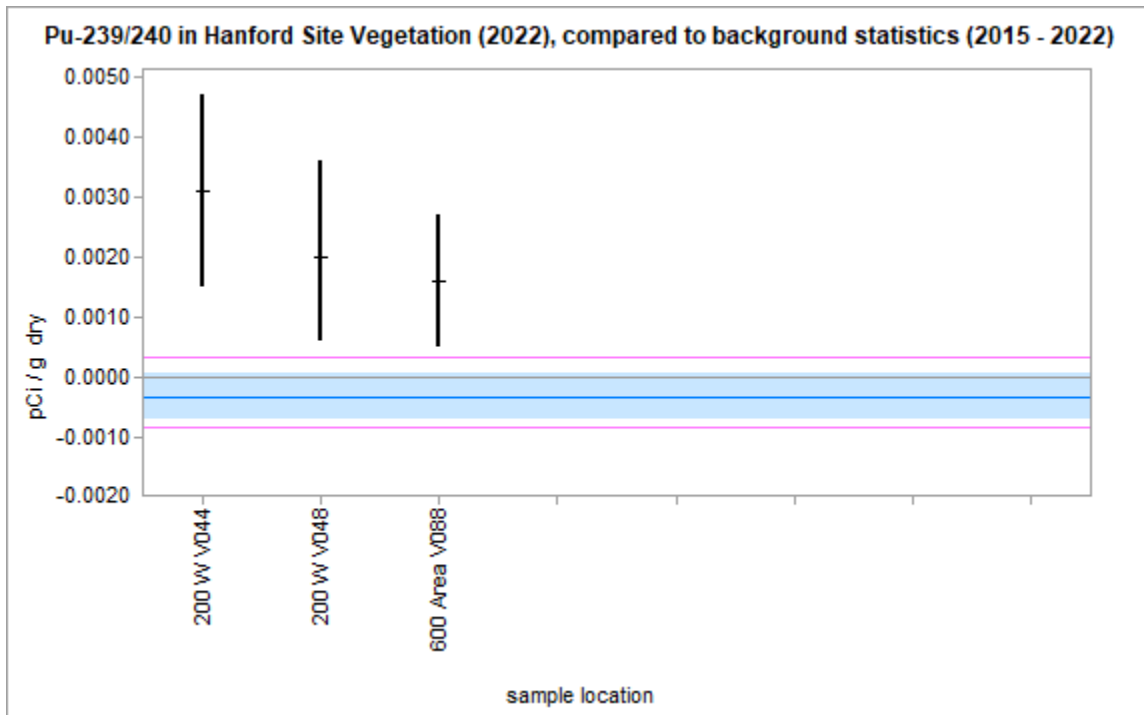


Figure 3.5.8 – Pu-239/240 in Vegetation Compared to Background



4. Summary of Health and Energy Results

This report describes the agreement between Health and Energy contractor results qualitatively, with the categories of *good*, *fair*, and *poor*. This section also describes actions taken to address changes in procedures because of findings from previous reports.

Categories of fair and poor do not necessarily indicate a problem with either laboratory's analyses but may demonstrate the influence of differences in sampling protocol as well as the unquantified contribution of sampling error to the combined measurement uncertainty. In cases where samples are split (i.e., water, soil, sediment), effort is made to completely homogenize a sample before dividing to increase the likelihood that each laboratory receives a representative sample. However, it is possible that one of the split samples may contain a radioactive particle while the other sample does not, resulting in sample error.

For collocated air samples, there is no way to ensure that any present contamination is captured equally 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 example, demolition of the PFP, reported in the 2018 summary report, 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 biweekly gross alpha results for air are in poor agreement because of the many instances where Health reports elevated gross alpha in air and Energy does not. Gross alpha is a screening tool, and the results are highly dependent on assumptions such as the radionuclides chosen for the instrument's calibration, and the radiation absorption properties of the particulates in the sample. Differences in the selections for these parameters between laboratories can have a sizable impact on the reported results, though the data should have the same trends over location and time.

Health and Energy biweekly air samples are in fair to good agreement for gross beta activity. 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.

As with gross alpha, gross beta measurements are subject to parameters related to the efficiency calibration and absorption coefficient curves.

Health and Energy tritium (H-3) concentrations in monthly air samples are in good agreement, as they were for several years. Historically however, significant differences between the Health

and Energy concentrations occurred, where Energy often reported concentrations higher than those reported by Health. For H-3 in air samples, the detection limit between Health and Energy are significantly different. Most of the results for Energy were below their detection limit of 5pCi/m³, while Health's detection limit, normally in the range of 1pCi/m³, can measure lower concentrations.

As a result of the historically 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 the tritium captured in the collection process is measured. Between 2014 and 2016, Health undertook a project to validate the H-3 collection as well as the measurement method. This included contracting with a vendor to provide samples with certified concentrations of tritium for a qualitative validation of the analysis protocol. The project showed Health's method yields results that are accurate within the range of its measurement uncertainty. Since 2018 split H-3 data in air are in much better agreement than historical data and is categorized for this reporting period as good.

While Health's airborne tritium collection and measurement validation study confirmed effective collection and measurement techniques, it was noted that Health's collection process is designed to capture only tritiated water vapor. In 2005, Health noted that in some locations Energy uses sampling systems that split the air stream to capture both tritiated water vapor and organically bound tritium.

Health has not completed analysis for Sr-90 or the alpha emitting radionuclides Pu-238, Pu-239/240, Pu-241, U-234, U-235, or U-238 in 2022 air samples. The results will be discussed in next year's report.

Health and Energy split concentrations in water samples are in fair agreement for C-14, gross beta, I-129 and Pu-239/240 and in good agreement for all other radionuclides. Concentrations of C-14 in three of the six samples are in good agreement, but for the remaining three samples there is a significant discrepancy. Historically, the agreement has been fair to poor.

Health's laboratory is reviewing published methods to quantify C-14 in water samples. The method Health has historically used is direct addition to liquid scintillation cocktail followed by scintillation counting with energy window discrimination. This method does not have a low detection limit and is subject to interference from other radioactive materials. Each of the alternative methods that Health has investigated thus far present problems with chemical yield determination that are undesirable. Health's laboratory is continuing to investigate a method to improve C-14 measurements in water; a future report will discuss this effort.

Health and Energy gross beta concentrations in water samples are in fair agreement. For gross beta samples where activity is <200pCi/L, results are in good agreement. For samples where gross beta activity is >200pCi/L, agreement is fair. In these cases, Health often reports higher

concentrations than Energy. This trend is consistent with historic gross beta concentrations. The same issues described about the measurement of gross beta in air filters apply to water samples. Health's laboratory bases its gross beta on Sr-90 in equilibrium with its daughter Y-90. These calibrants were selected because they were considered representative of the radioactive materials of health interest around the Hanford reservation.

Health and Energy I-129 and Pu-239 results are in fair agreement. In both cases, the comparison is based on a small sample size with only one or two samples having detectable concentration of I-129 or Pu-239.

Health and Energy external radiation exposure rates are in fair agreement. Health reports radiation rates that range from 10% less to 40% greater than those reported by Energy. These exposure rates are consistent with historical results.

Uranium 234, 238 results in sediment and soil samples are in fair agreement. The results follow the same trend but there is a systematic bias in which Energy reports lower concentrations than those reported by Health. Historically, Energy's U-234 and U-238 concentrations can differ by as much as one-half of the value reported by Health.

Health results for Sr-90 are incomplete for sediment and soil. For the sediment results reported, Sr-90 results are in fair agreement. Soil and sediment Sr-90 will be evaluated in the next report, once all the analyses are complete.

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 sieverts. Since radiation doses are often small, units of millirem (mrem) or millisievert (mSv) are commonly used. A mrem is one-thousandth of a rem. Table A.1 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

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%

(National Council on Radiation Protection and Measurements Report No. 93, *Ionizing Radiation Exposure of the Population of the United States, 1987*)

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

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

Most exposures to radiation workers and the general public, however, involve low doses; i.e., lifetime doses of less than approximately 20,000 mrem above natural background. The Health effects of exposure to low doses of radiation are too small to unambiguously measure. In the

absence of direct evidence of the harmful effects of radiation at low doses, estimates of health effects are made by extrapolation from observations at high doses. There is much controversy and disagreement about the procedure for such an extrapolation. The conventional procedure traditionally has hypothesized a linear extrapolation of the high dose health effects data to a point of zero dose, zero risk.

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

Appendix B - Laboratory a priori Lower Limits of Detection

Air Cartridge (pCi/m³)

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

Air Filter (pCi/m³)

	Nuclide	Volume (m ³)	Method	Standard LLD (100 min.)
Alpha	Gross	450	αβ Cntr	5.00E-03
Beta	Gross	450	αβ Cntr	1.00E-03

Quarterly Composite Air Filter (pCi/m³)

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

Semi-Annual Composite Air Filter (pCi/m³)

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

Semi-Annual Composite Air Filter (pCi/m³)

	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	αβ Cntr	6.00E-04

Milk (pCi/l)

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

Milk (pCi/l)

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

Meat (pCi/g)

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

Shellfish (pCi/g)

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

Soil/Sediment (pCi/g)

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

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	αβ Cntr		2.00E-01
	Pu-238	0.5	Alpha Spec	8.00E-02	
	Pu-239	0.5	Alpha Spec	6.10E-02	
	Th-230	0.5	Alpha Spec	1.00E-01	
	Th 232	0.5	Alpha Spec	1.00E-01	
	Am-241	0.5	Alpha Spec	8.00E-02	
Standard LLD (1000 min.)					
Gamma	Am-241	3	INGe	1.00E+01	
	Ba-140	3	INGe	9.00E+00	
	Ce-144	3	INGe	1.30E+01	
	Co-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/ $\alpha\beta$ Cntr		7.00E-01
	Tc-99	0.5	3M/LS		4.00E+00
Gross	Alpha	0.1	$\alpha\beta$ Cntr		4.00E+00
	Beta	0.5	$\alpha\beta$ 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

$\alpha\beta$ Cntr = Alpha, Beta Counter

Alpha Spec = Alpha Spectrometry

LS = Liquid Scintillation

LEP = Low Energy Photon Detector

Appendix C - Formulas

A. Random Uncertainty

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

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

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

C. Lower Limit of Detection (LLD)

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

D. Definitions

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

T ₁	=	sample count time
T ₂	=	background count time
T _{1/2}	=	half-life of radionuclide counted
U	=	uncertainty (standard error) of the sample mean
V	=	volume in liters (or mass in grams) of sample
Y	=	fractional radiochemical yield (when applicable)

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,

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

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

A priori (detection limit)	This term indicates the calculation of a detection limit is based on customary sample and analysis variables (sample size, counting time, etc.) Information specific to a sample is not used.
A posteriori (detection limit)	This term indicates the calculation of a detection limit includes specific information regarding a sample and its analysis (sample size, counting time, etc.)
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.
Collocated	One of two or more independent samples collected so that each is equally representative for a given analyte at the same location and time.

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 / beta 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 <i>a posteriori</i> 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-40
NO ₂ +NO ₃	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

