Hanford Environmental Radiation Oversight Program

2023 Data Summary Report

January 2025

Washington State Department of HEALTH

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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 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.
- Section 3 presents environmental results.
- Section 4 provides a summary of results that are considered fair or poor.

- Appendix A provides tutorial information on radiation.
- Appendix B lists the laboratory lower limits of detection.
- 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 2023, the laboratory participated in three proficiency test and exercise programs. 1) The Department of Energy's Mixed Analyte Performance Evaluation Program (MAPEP), which tests the laboratory's ability to correctly analyze multiple radionuclides covering four matrices (soil, air filter, vegetation, and water); this is a National Institute of Standards and Technology traceable proficiency-testing program that involves two sets of samples in all matrices each year. 2) The BioRad2 exercise under the International Consortium of Laboratory Networks (ICLN); this was a rapid turnaround test of mixed biological/radiological hazards. The radiological component was isotopic uranium in three water samples by chemical separation

and alpha spectrometry. 3) An annual exercise under the Food and Drug Administration's Food Emergency Response Network (FDA/REFN); this test was mixed radionuclides in four samples of maple syrup by gamma spectroscopy.

These programs provide an independent check of laboratory proficiency for analyzing environmental samples. The laboratory quality assurance plan also includes analysis of quality control samples (QCs), blanks, duplicates and/or matrix spike duplicates. Quality Controls are either standard reference materials (SRM) or laboratory control samples (LCS) as part of analysis of a batch of samples. SRMs are environmental media containing certified quantities of radioactive material in a homogenous matrix. LCS are national metrology institute-traceable radionuclides that are spiked into the appropriate sample matrix.

Also, during 2023 the laboratory participated two method development projects. The first was a pilot project with the Centers for Disease Control and Prevention (CDC) to test methods for bioassay in emergency clinical specimens. The second was an interlaboratory test of a method for rapid radioactive strontium in food under the FERN program. All-together, these proficiency test, exercise and method development projects included 46 samples during 2023.

2.2 Interpretation of Results

Environmental radiation data are reported as the number of radiation decays per unit time per unit quantity of sample material. Most results are reported in units of picocuries.

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

2.2.1 Uncertainty in Radioactivity Measurements

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

The uncertainties reported in this report are primarily 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 detect 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 most 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 most of the samples, and there is no apparent systematic bias.

The results of scatter plot regression analysis (discussed in Section 2.2.4.2 below) and relative percent difference analysis (discussed in Section 2.2.4.3 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 enough 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.

2.2.4.3 Relative Percent Difference (RPD)

Relative Percent Difference analysis (RPD) is employed to indicate how well the split or collocated Health and Energy results agree. The RPD value is defined as the difference in Health's and Energy's concentration values divided by the average of their values. As an example, if Health reports 20 pCi/g and Energy reports 10 pCi/g, the RPD is 67%.

$$RPD\ (\%) = 100 * (H - E)/((H + E)/2)$$

H = Health's concentration value,

E = Energy's concentration value.

In addition to the RPD value, the uncertainty associated with each reported sample concentration is considered in the RPD analysis. Health considers the agreement between split or collocated results to be in good agreement if the uncertainties for that measurement (error bars) overlap, regardless of the RPD value (see Section 2.2.1 for discussion of error bars and uncertainty). When the error bars overlap, it is not possible to rule out that there is no significant difference between the two results.

Health defines an RPD of greater than 33% to be poor agreement for that sample result. If one-third of the sample results in a set of data have RPDs greater than 33%, then Health defines the agreement for that data set to be poor. If one-sixth of the sample results in a set of data have RPDs greater than 33%, then Health defines the agreement for that data set to be fair.

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 air concentrations are in fair agreement for gross alpha and H-3 (tritium) activity, and in poor agreement for gross beta activity.
- Health and Energy air concentrations are in good agreement for Sr-90, Am-241, and isotopes of uranium and plutonium. All concentrations are consistent with historical results, and any detectable results are only slightly above lower limits of detection.

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 a minimum of 10 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).

The text following the table discusses 1) cases in which the agreement between Health and Energy data is not good (i.e. is fair or poor), 2) cases in which some of the Health data are anomalous compared to historical results, or 3) other data topics of interest.

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	468	**fair**	0.0005 to 0.007	no
Gross Beta	biweekly	468	**poor**	0.003 to 0.06	no
H-3	monthly	26	**fair**	< 0.24 to 13	no
Am-241	semiannual	26	good	< 0.000004	no
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	semiannual	36	good	< 0.00001	no
Pu-239/240	semiannual	36	good	< 0.000006 to 0.00001	no
Pu-241	semiannual	8	good	< 0.0002	no
Sr-90	semiannual	34	good	< 0.00008 to 0.0001	no
U-234	semiannual	32	good	< 0.000005 to 0.00003	no
U-235	semiannual	32	good	< 0.000004	no
U-238	semiannual	32	good	< 0.000005 to 0.00003	no

Health and Energy collocated biweekly gross alpha concentrations are in fair agreement. The data from the different sample locations fall into two categories, one in which the data are either in good or fair agreement, and one in which the agreement is poor. Figures 3.1.2 and 3.1.3 show line and point charts for an example of good agreement at 100B Reactor, while Figures 3.1.4 and 3.1.5 show line and point charts for an example of poor agreement at Purex. The line charts emphasize the trend of concentrations over time and do not show the error bars.

A relative percent difference (RPD) analysis is employed to assess the agreement of the Health and Energy collocated data (see Section 2.2.4.3 for a description of the RPD analysis). The gross alpha results at 100B Reactor are in good agreement (Figures 3.1.2 and 3.1.3), as the Health and Energy error bars overlap for most of the data at this location, and only three of the twenty-six results have a relative percent difference of greater than 33%. The RPD analysis at most other locations indicate good or fair agreement. The only location with poor agreement is at Purex (Figures 3.1.4 and 3.1.5), where more than one-third of the data have an RPD greater than 33%. In addition, there is a systematic bias at Purex in which Health reports higher concentrations than Energy.

Considering the data from all sites as one set, the RPD analysis indicates fair agreement for gross alpha concentrations in air. The scatter plot in Figure 3.1.6 shows a bias in which Health often reports higher concentrations than Energy, as a significant percentage of the data fall to the right of the line corresponding to perfect agreement.

Health and Energy collocated biweekly gross beta concentrations are in poor agreement. The data from the different sample locations fall into two categories, one in which the data are either in good or fair agreement, and one in which the agreement is poor. Figures 3.1.7 and 3.1.8 show line and point charts for an example of good agreement at Battelle Complex, while Figures 3.1.9 and 3.1.10 show line and point charts for an example of poor agreement at 100B Reactor.

The gross beta results at Battelle Complex (Figures 3.1.7 and 3.1.8) are in good agreement, as the Health and Energy error bars overlap for most of the data at this location, and only three of the twenty-six results have and RPD greater than 33%. The results at 100B Reactor are in poor agreement (Figures 3.1.9 and 3.1.10), as more than one-third of the data have an RPD greater than 33%. In addition, there is a systematic bias at 100B Reactor in which Health reports lower concentrations than Energy. The RPD analysis at the other locations indicate agreements ranging from good to fair to poor.

Considering the data from all sites as one set, the RPD analysis indicates poor agreement for gross beta concentrations in air. The scatter plot in Figure 3.1.11 shows a bias in which Health often reports lower concentrations than Energy, as a significant percentage of the data fall to the left of the line corresponding to perfect agreement.

Health and Energy H-3 (tritium) concentrations in monthly atmospheric water vapor samples are in fair agreement, as shown in Figure 3.1.12. The Health and Energy detection limits are significantly different. Health's detection limit is approximately 1 pCi/m^3 or less, and Health detects concentrations in the range from the detection limit to 13 pCi/m^3. Energy's detection limit is much higher, ranging between 2 and 7 pCi/m^3, and most of their results are considered below their sample specific detection limit. Approximately one-fourth of the data have an RPD greater than 33%, indicating fair agreement for the collocated tritium results.

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/m^3. Health and Energy occasionally detect Cs-137 in air samples, but this was not the case in 2023.

Health and Energy collocated semiannual Sr-90 concentrations are in good agreement. Health's sample specific minimum detectable activity (MDA) ranges from 0.00002 to 0.00008 pCi/m^3. Twelve of Health's results are considered as detected with concentrations ranging from 0.00002 to 0.0001 pCi/m^3. Energy's MDA is 0.0005 pCi/m^3, which is too high to confirm any of Health's detected results. All Health and Energy results are below Energy's MDA.

Health and Energy collocated semiannual Pu-239/240 concentrations are in good agreement. Health's sample specific minimum detectable activity (MDA) ranges from 0.000002 to 0.000006 pCi/m^3. Three of Health's results are considered as detected with concentrations ranging from 0.000002 to 0.0001 pCi/m^3. Energy's MDA is 0.00004 pCi/m^3, which is too high to confirm any of Health's detected results. All Health and Energy results are below Energy's MDA.

Health and Energy collocated semiannual U-234 and U-238 concentrations are in good agreement. For both radionuclides, Health and Energy consider a few of the results to be detected at concentrations slightly above detection limits. Health's sample specific MDA is approximately 0.000005 pCi/m^3 for all samples, while Energy's sample specific MDA ranges from 0.00001 to 0.00007 pCi/m^3. Both Health and Energy's highest detectable concentration is 0.00003 pCi/m^3.

Health and Energy collocated semiannual Am-241, Pu-238, Pu-241, and U-235 concentrations are in good agreement, and all results are below detection limits.

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. Most of Health's results are within the range of background; however, Health's highest gross alpha results are slightly 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 2023	Energy's Data Range for Background Location (pCi/m^3)	Energy's Average for Background Location (pCi/m^3)
Gross alpha	0.0005 to 0.007	-0.00012 to 0.0042	0.00083
Gross beta	0.003 to 0.06	0.0043 to 0.095	0.018
Sr-90	< 0.00008 to 0.0001	-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.

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 3.1.13 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

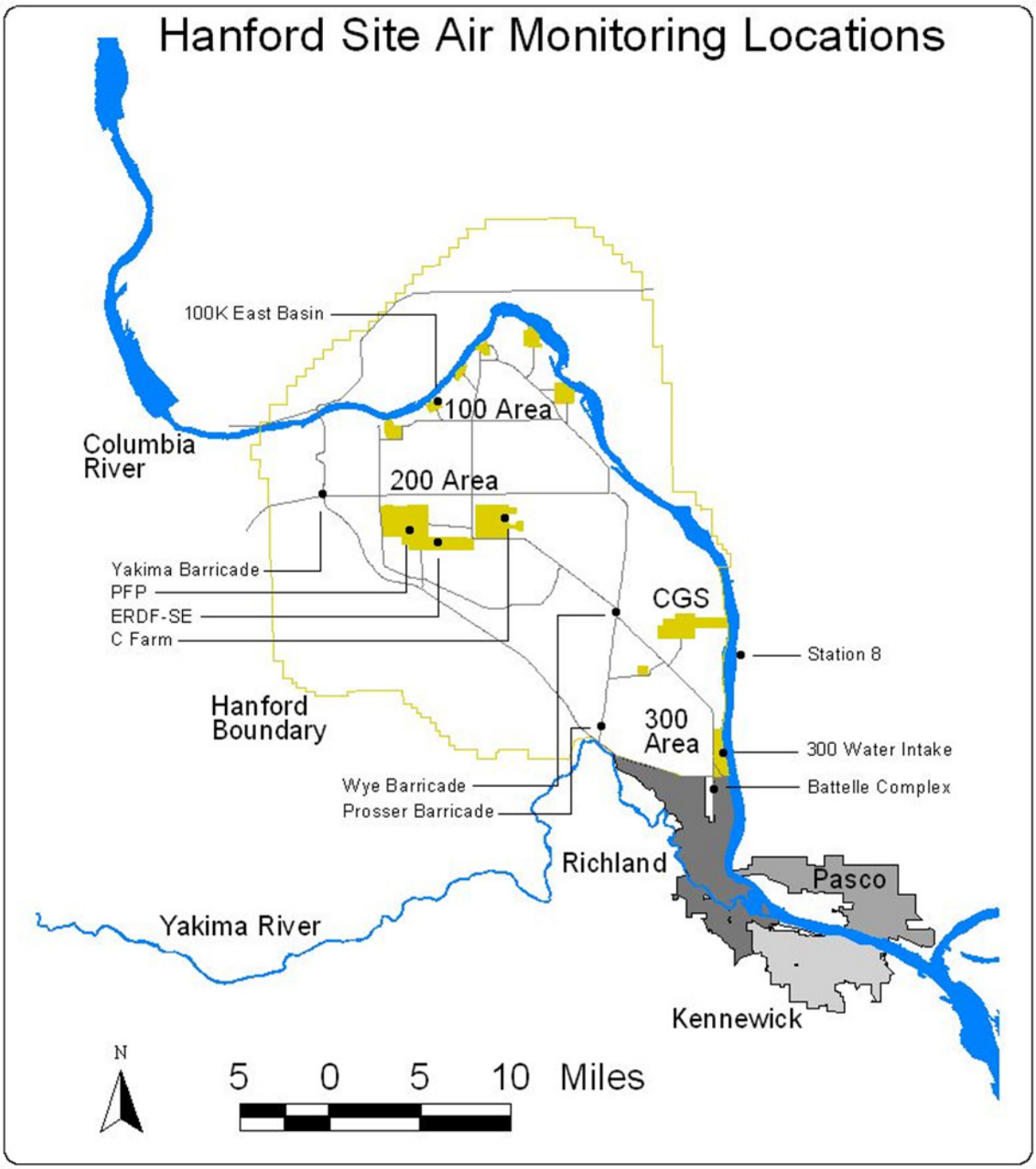


Figure 3.1.2 Gross Alpha Concentrations in Air at 100B Reactor

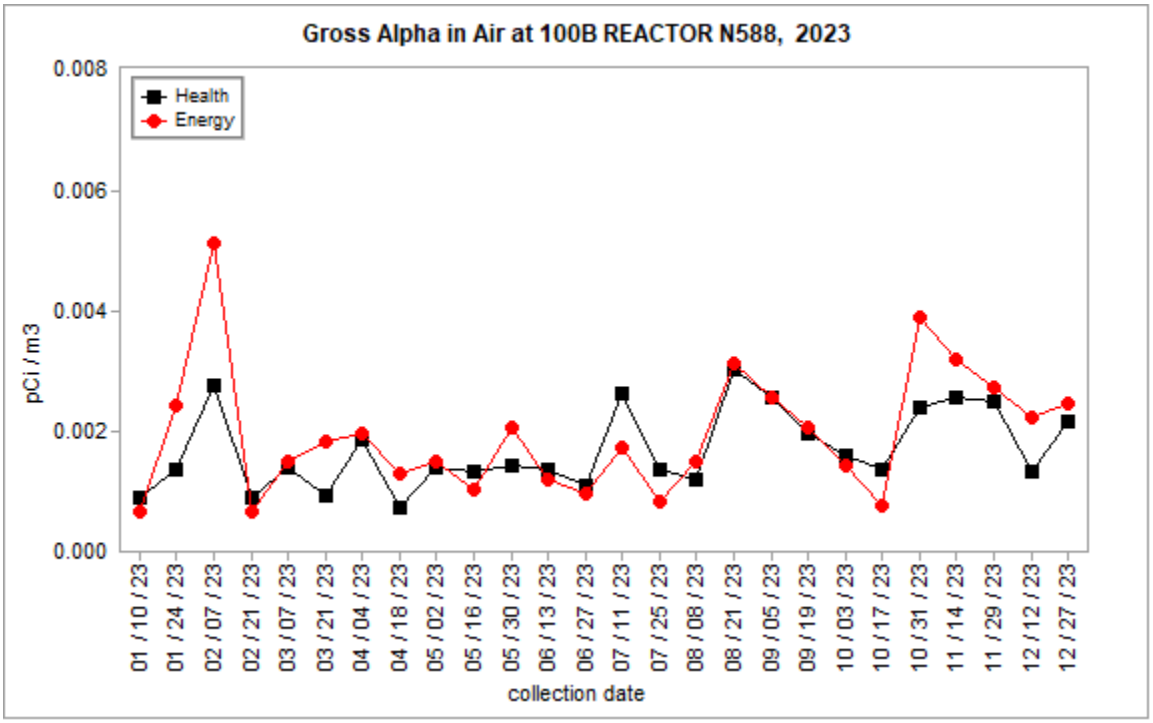


Figure 3.1.3 Gross Alpha Concentrations in Air at 100B Reactor

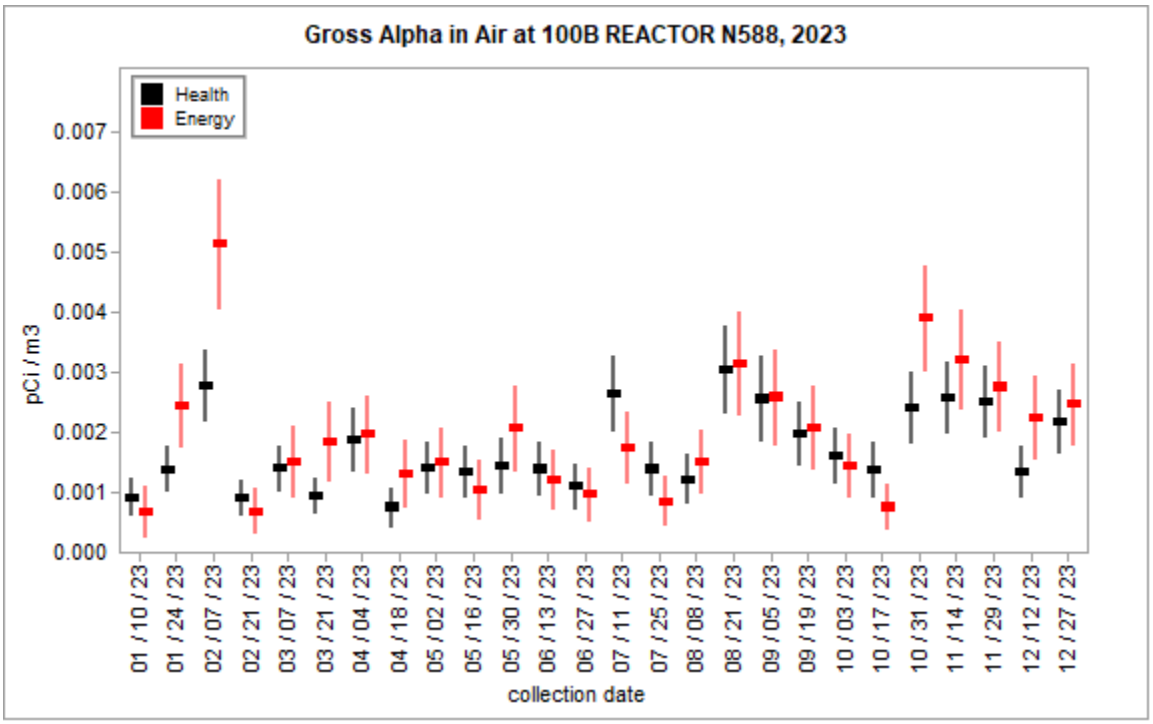


Figure 3.1.4 Gross Alpha Concentrations in Air at Purex N985

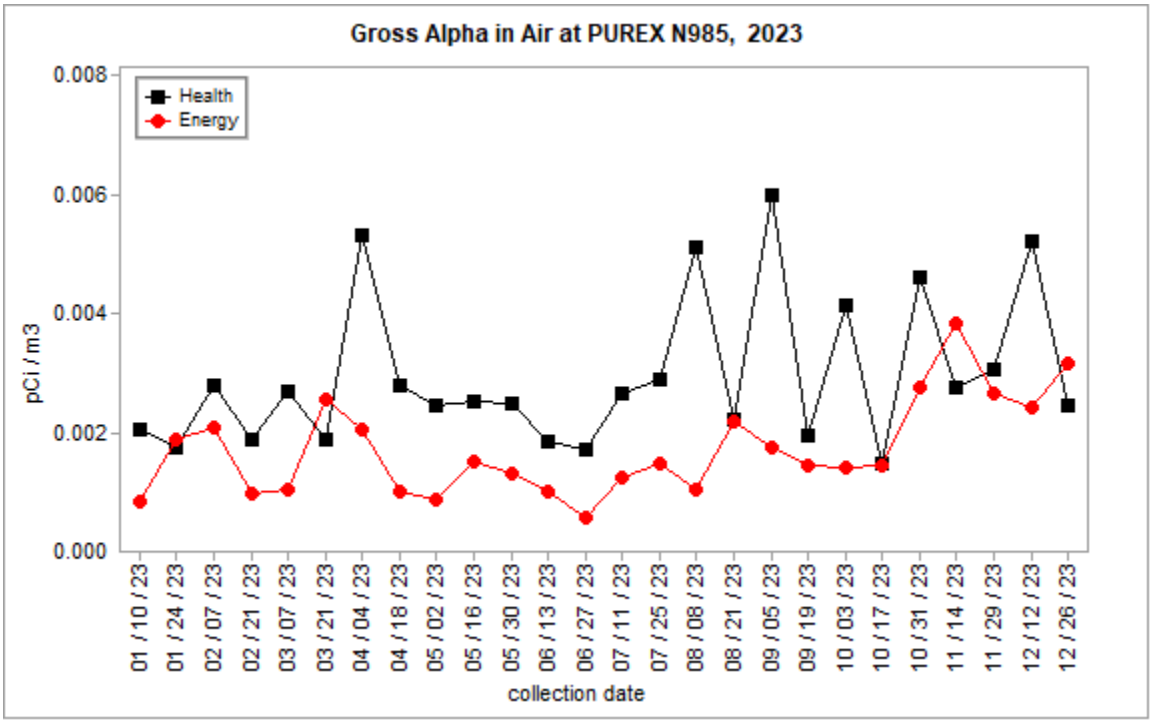


Figure 3.1.5 Gross Alpha Concentrations in Air at Purex N985

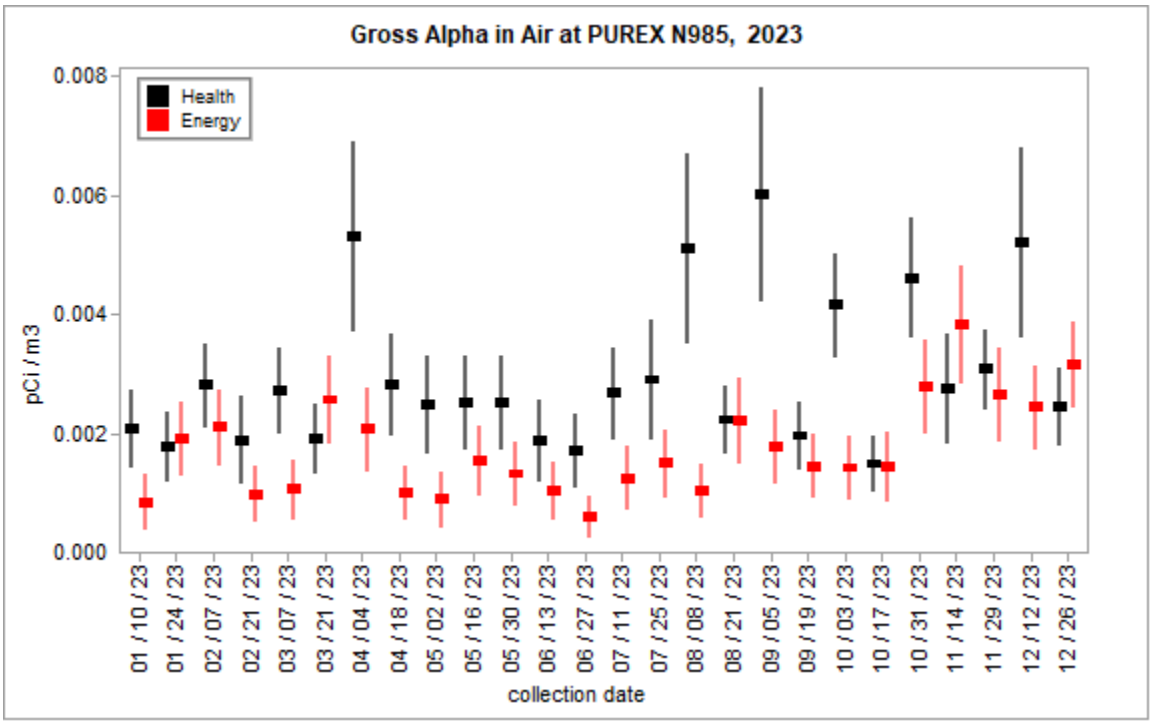


Figure 3.1.6 Scatter Plot for Gross Alpha in Air

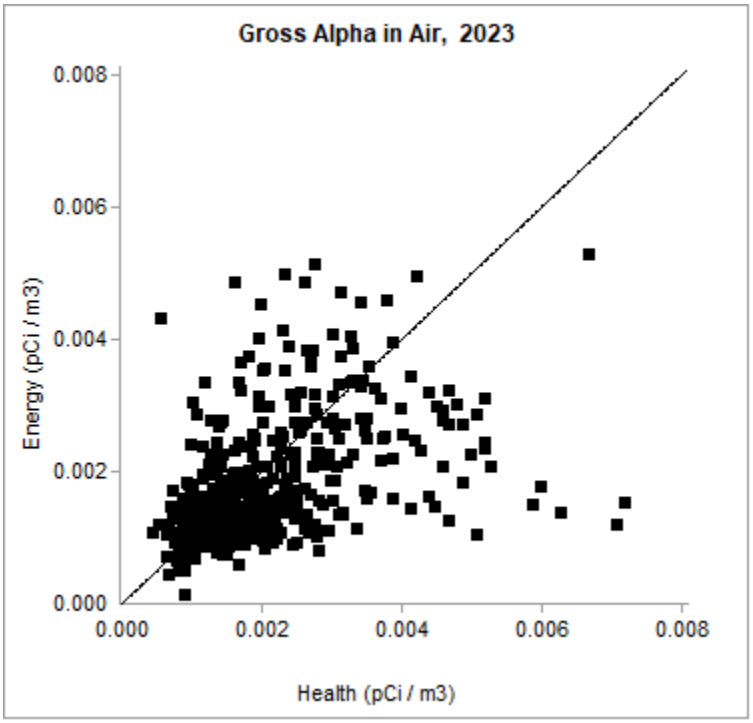


Figure 3.1.7 Gross Beta Concentrations in Air at Battelle Complex

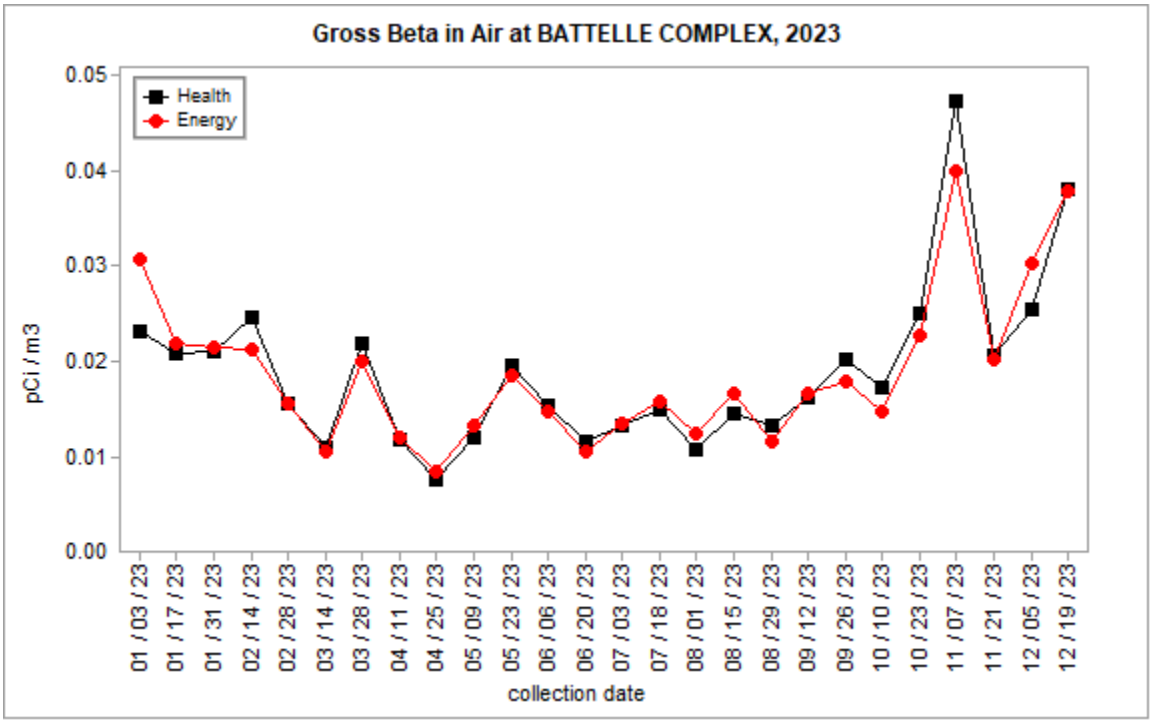


Figure 3.1.8 Gross Beta Concentrations in Air at Battelle Complex

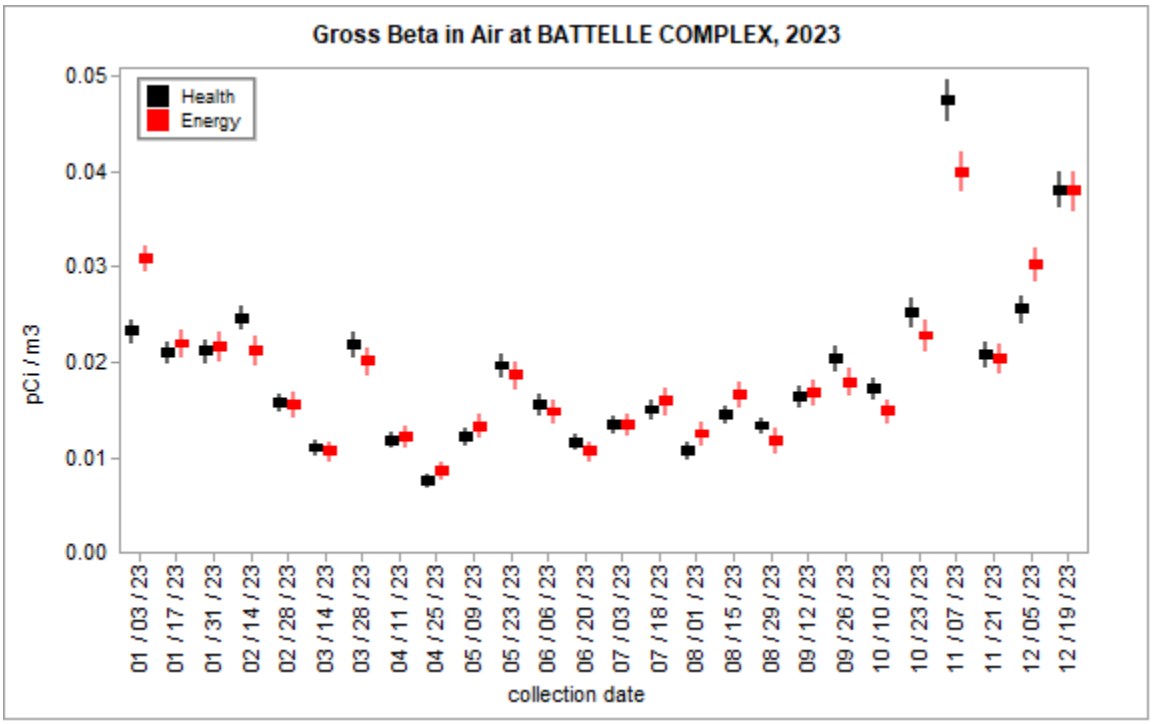


Figure 3.1.9 Gross Beta Concentrations in Air at 100B Reactor

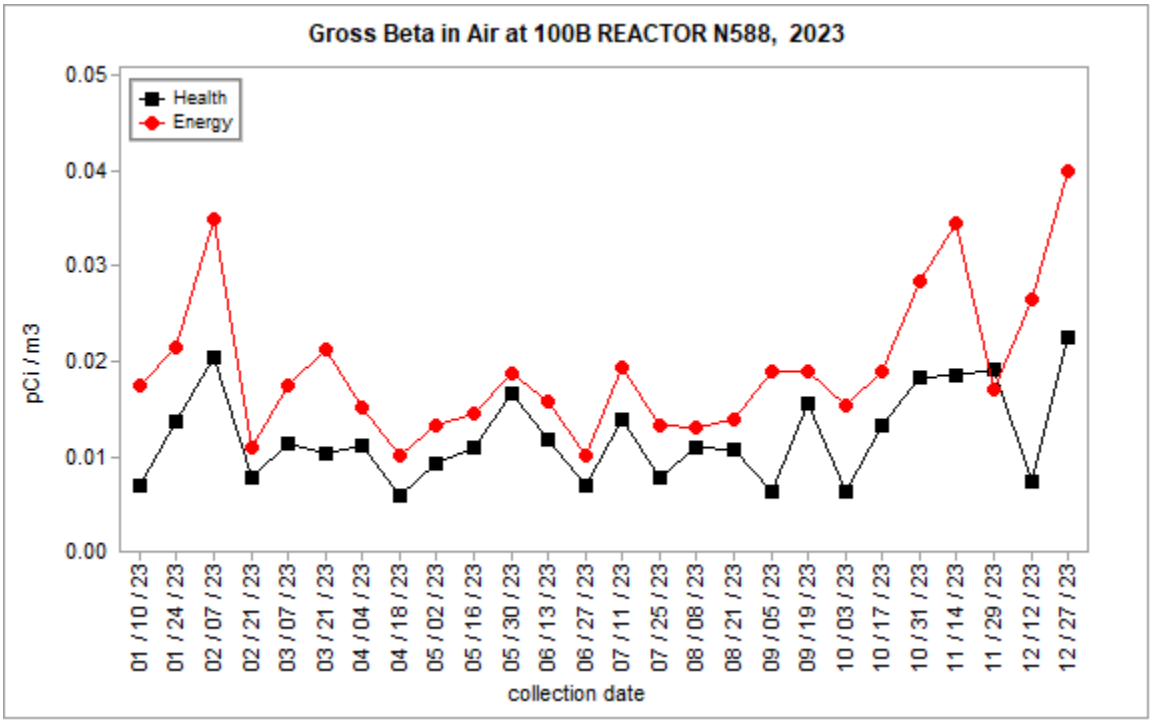


Figure 3.1.10 Gross Beta Concentrations in Air at 100B Reactor

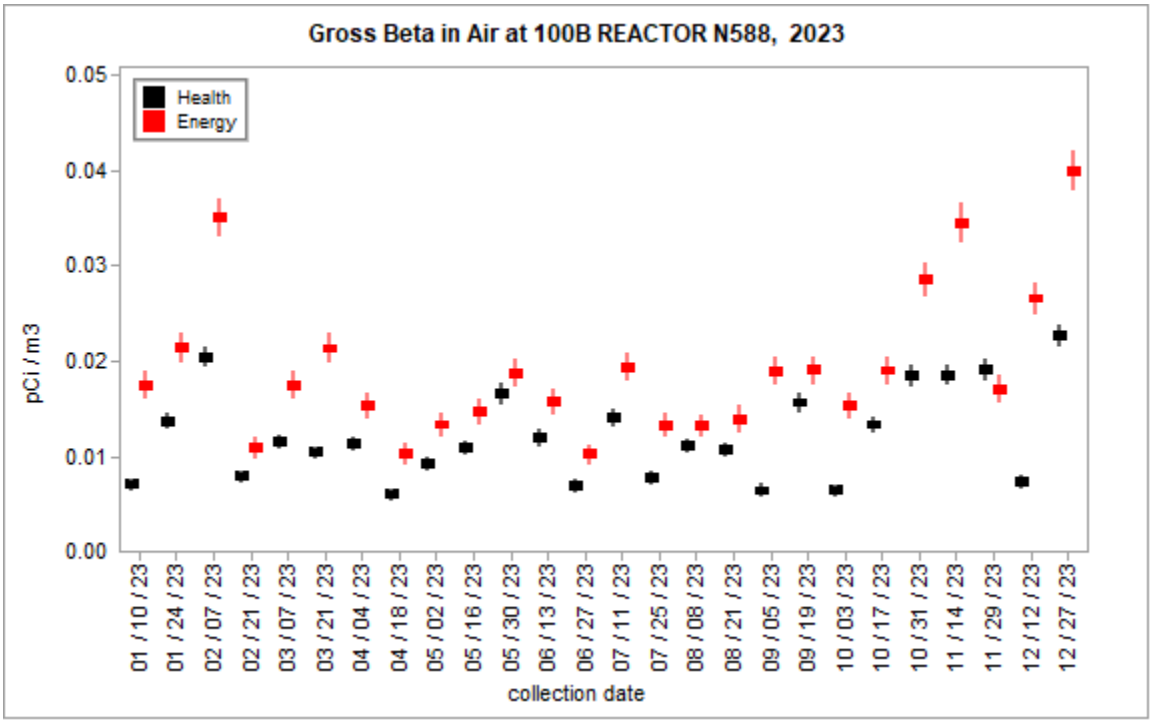


Figure 3.1.11 Scatter Plot for Gross Beta in Air

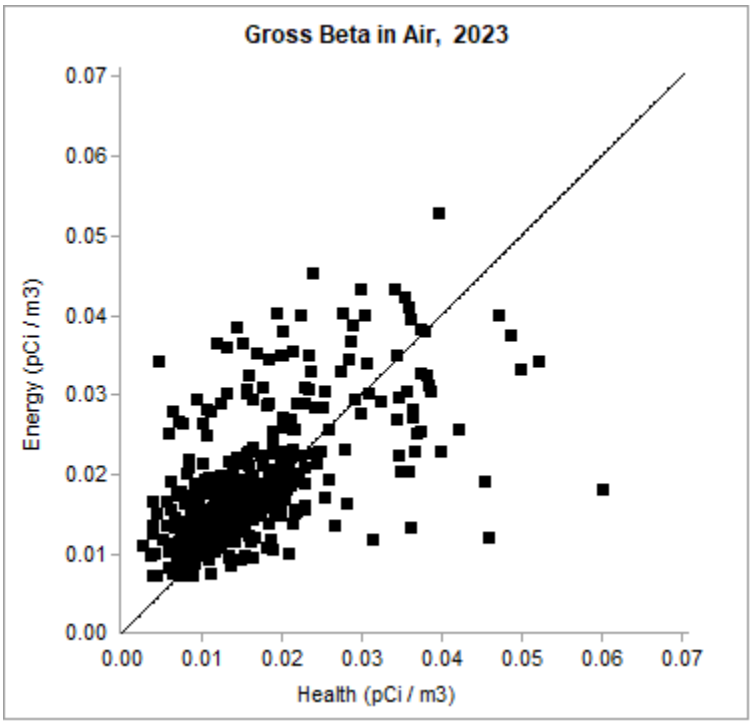


Figure 3.1.12 Health and Energy H-3 Concentrations in Air

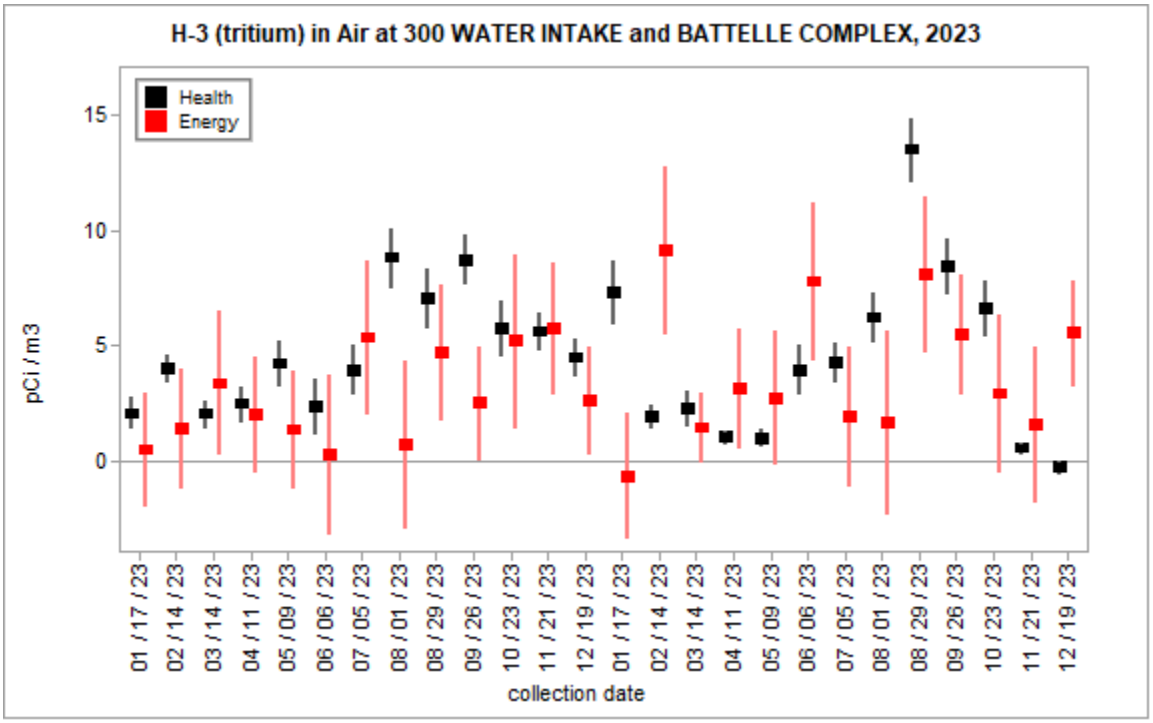
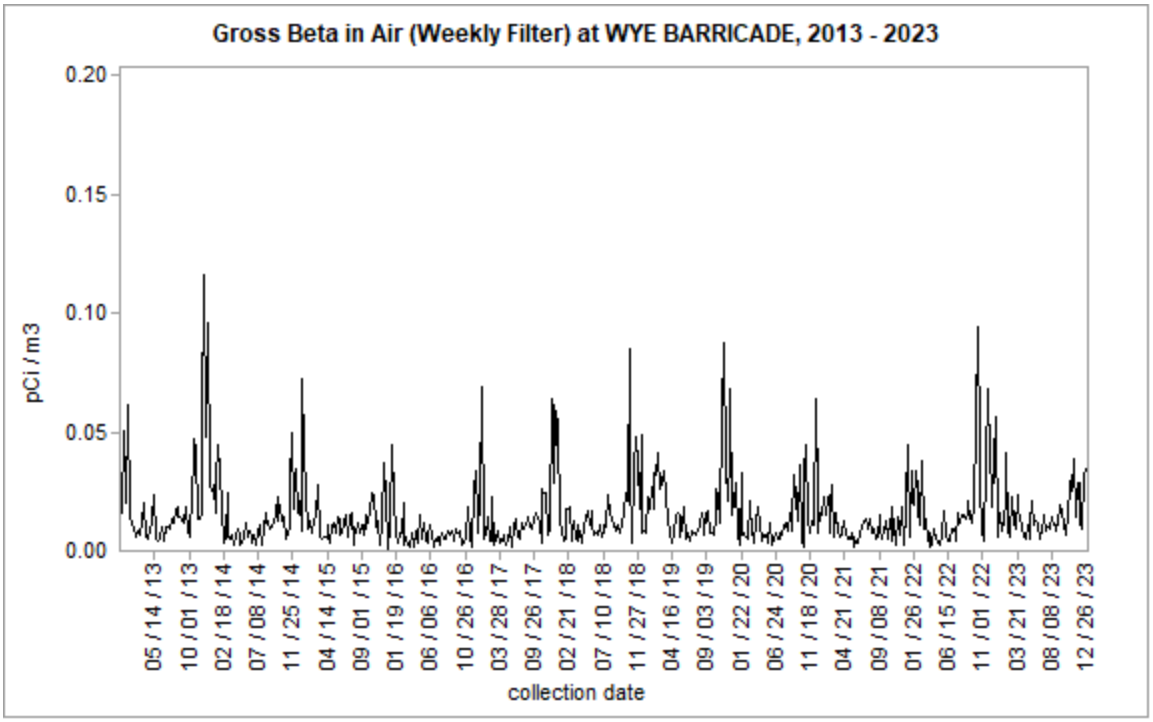


Figure 3.1.13 – Gross Beta in Air at Wye Barricade 2013 – 2023



3.2 Water Monitoring

Major Findings:

- Health and Energy split water concentrations are in poor agreement for C-14, gross beta, and I-129; fair agreement for gross alpha, Pu-238, 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-238, 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 state and 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 15 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, five split samples came from 100 Area wells, six from the 200 Area, two from the 300 Area, and two from the 600 Area.

The 100 Area consists of nine retired reactors and support facilities located along the Columbia River. Tritium (H-3), C-14, and Sr-90 are contaminants commonly found in groundwater beneath the reactor facilities. A primary objective of the groundwater collection in the 100 Area is to monitor contaminants that may enter the Columbia River. At the 100K Area, groundwater is sampled to evaluate potential changes in radioactivity as spent nuclear fuel, shield water, and sludge are removed from the 100K East Fuel Storage Basin.

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

The 300 Area consists of retired reactor fuel fabrication facilities located adjacent to the Columbia River. Groundwater contains 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 along the Hanford Site boundary (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 (Pacific Northwest National Laboratory, 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).

The text following the table discusses 1) cases in which the agreement between Health and Energy data is not good (i.e. is fair or poor), 2) cases in which some of the Health data are anomalous compared to historical results, or 3) other data topics of interest.

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	**poor**	195 to 21,200	no
Co-60	annual	12	good	< 1 to 1.7	no
Cs-134	annual	12	good	< 1.6	no
Cs-137	annual	12	good	< 1.8 to 570	no
Eu-152	annual	12	good	< 5	no
Eu-154	annual	12	good	< 5	no
Eu-155	annual	12	good	< 9	no
Gross Alpha	annual	22	**fair**	<3 to 25,500	no
Gross Beta	annual	22	**poor**	0.8 to 42,000	no
H-3	annual	32	good	< 80 to 171,000	no
I-129	annual	5	**poor**	< 0.5 to 7.7	no
Pu-238	annual	5	**fair**	< 0.07 to 2.0	**yes**
Pu-239/240	annual	5	**fair**	< 0.04 to 475	**yes**
Sr-90	annual	22	good	< 0.8 to 820	no
Tc-99	annual	14	good	< 1.6 to 37,000	no
U-234	annual	18	good	0.12 to 13,300	no
U-235	annual	18	good	< 0.14 to 720	no
U-236	annual	4	good	< 0.1 to 0.48	no
U-238	annual	18	good	0.15 to 13,400	No

Health and Energy C-14 concentrations in water samples are in poor agreement. Figure 3.2.2 shows the C-14 split data for concentrations less than 1,100 pCi/L. The result from groundwater well 199-K-106A is omitted from the chart because the higher concentrations at this site would obscure the lower concentration data. Figure 3.2.3 shows historical data for groundwater well 199-K-106A. For both the 2023 data and the historical data at 199-K-106A, at least one-third of the sample results have a relative percent difference (RPD, see Section 2.2.4.3) of greater than 33%, resulting in poor agreement of the split results.

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. In addition to the high RPD values, Energy typically reports greater C-14 concentrations than Health, as can be seen in the scatter plot for historical split results at this well, Figure 3.2.4.

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 examples, Figures 3.2.6 and 3.2.7 show the historical Co-60 and Cs-137 concentrations at groundwater well 299-E28-24 from Hanford's 200 East Area.

Health and Energy gross alpha concentrations in water samples are in fair agreement. Figure 3.2.8 shows data at low concentrations, and these data are in good agreement.

Figures 3.2.9 and 3.2.10 show historical gross alpha results at groundwater well 299-E33-344 in the 200 East Area, where concentrations are much higher. The scatter plot indicates that Health systematically reports higher concentrations than Energy when the concentrations are high. One-quarter of these higher concentration data have an RPD greater than 33%. Combining analysis of the higher and lower concentration data leads to an assessment of fair agreement for the split gross alpha data.

Health and Energy gross beta concentrations in water samples are in poor agreement. Similar to the gross alpha data, the gross beta results are in good agreement for lower concentration data below 500 pCi/L (Figure 3.2.11). Figure 3.2.12 shows historical gross beta results at groundwater well 299-E33-344, where concentrations are much higher. At these higher concentrations, Health systematically reports greater concentrations than Energy, and most of the data have RPD values greater than 33%, leading to an assessment of poor agreement for the split gross beta data.

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 3.2.13 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 are in poor agreement. Greater than one-third of the 2023 results have an RPD value greater than 33% (Figure 3.2.14). Health routinely detects I-129 in groundwater from well 699-36-70A, at concentrations ranging from 5 to 15 pCi/L, and about half of these historical results have an RPD value greater than 33% (Figure 3.2.15), leading to an assessment of poor agreement for the split I-129 data.

Health and Energy Pu-238 concentrations in water samples are in fair agreement. Figure 3.2.16 shows that the agreement is good for the four results with concentrations below or near the

detection limit of 0.07 pCi/L. However, the RPD is greater than 33% for the result at 299-E28-23 where both Health and Energy detect Pu-238. Figure 3.2.17 shows historical results at this well, where all the data prior to 2023 are below or near the detection limit. Both Health and Energy detect an anomalously high concentration in 2023 (Health's result of 2.0 pCi/L is approximately ten times the prior highest measured concentration); however, the RPD exceeds the criterion for good agreement with Energy.

Health and Energy Pu-239/240 concentrations in water samples are in fair agreement. Figure 3.2.18 shows that the agreement is good for the four results with concentrations below or near the detection limit of 0.04 pCi/L. However, the RPD is greater than 33% for the result at 299-E28-23 where both Health and Energy detect Pu-239/240. Figure 3.2.19 shows historical results at this well, where all the data prior to 2023 range between 9 and 43 pCi/L. Both Health and Energy detect an anomalously high concentration in 2023 (Health's result of 475 pCi/L is approximately ten times the prior highest measured concentration); however, the RPD exceeds the criterion for good agreement with Energy.

Health and Energy Sr-90 concentrations in water samples are in good agreement for concentrations spanning several orders of magnitude. Figure 3.2.20 shows all the 2023 data, while Figure 3.2.21 shows the lower concentration data. 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 did not split a groundwater sample from the 100N Area in 2023.

Health and Energy Tc-99 concentrations in water samples are in good agreement for concentrations spanning several orders of magnitude. Groundwater well 299-E33-344 is targeted for sampling due to its historically high concentrations of Tc-99 (Figure 3.2.22). 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 for concentrations spanning several orders of magnitude. Figure 3.2.23 shows the data for U-234 concentrations less than 1 pCi/L, while Figure 3.2.24 shows the data for concentrations of U-234 less than 50 pCi/L. Higher U-234 concentrations, seen at groundwater well 299-E-33-344 in the 200 East Area, are shown for historical data in Figure 3.2.25. As can be seen in the figures, the agreement is good spanning several orders of magnitude. The agreement is similar for U-235 and U-238. Uranium is typically detected in 200 Area groundwater wells and in Columbia River seep or river water near the 300 Area.

Health and Energy U-236 concentrations in water samples are in good agreement. In 2023, all four U-236 split samples came from Columbia River surface water or riverbank seep water samples. The concentration at the 300 Area riverbank seeps is 0.48 pCi/L, while the 300 Area Columbia River surface water samples are below the detection limit of 0.1 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 2023, Health independently analyzed six groundwater samples for U-236 (four in the 200 Area and two in the 300 Area), with results ranging from below the detection limit of 0.1 pCi/L to 291 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 3,600 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

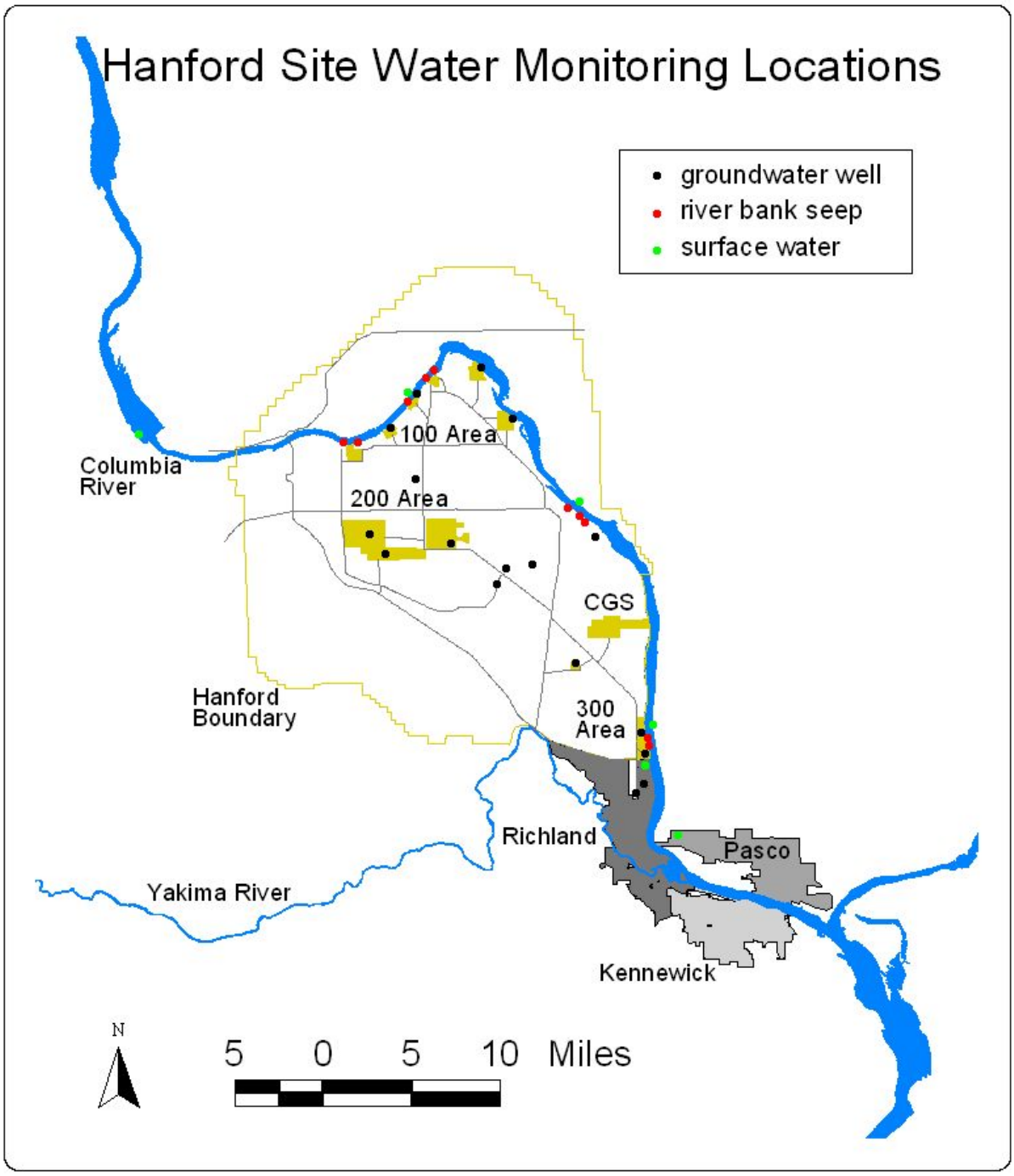


Figure 3.2.2 C-14 Concentrations in Water, Low-Range Data

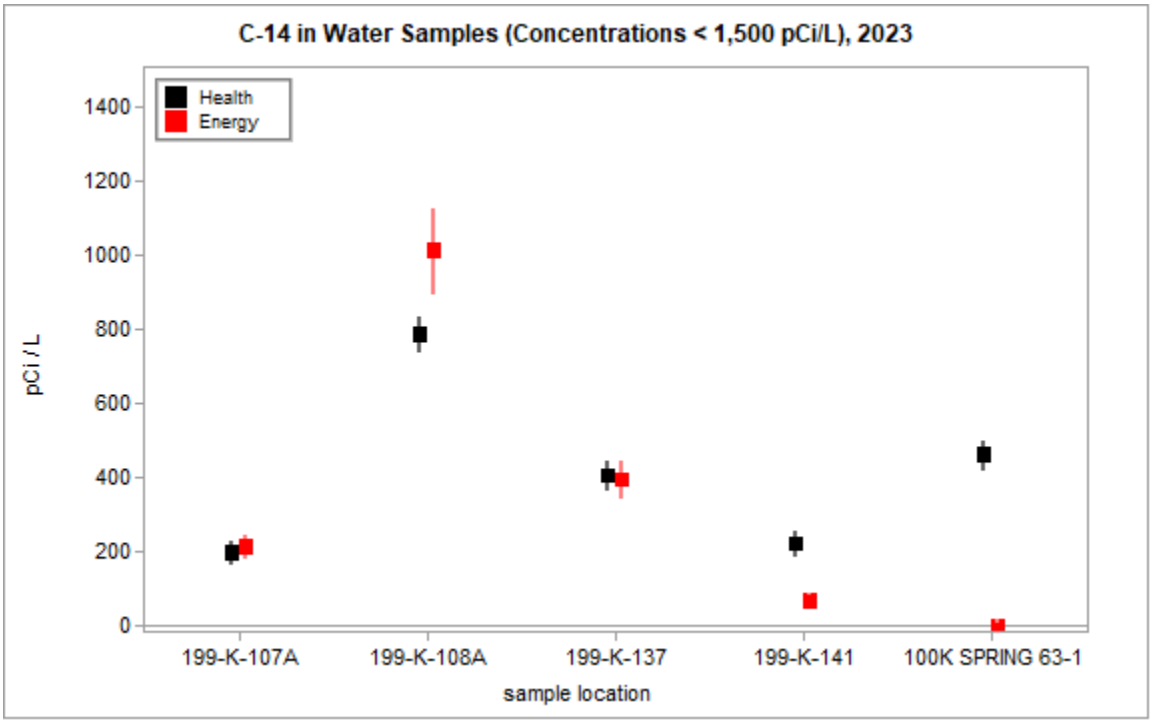


Figure 3.2.3 C-14 Concentrations in Groundwater at 199-K-106A

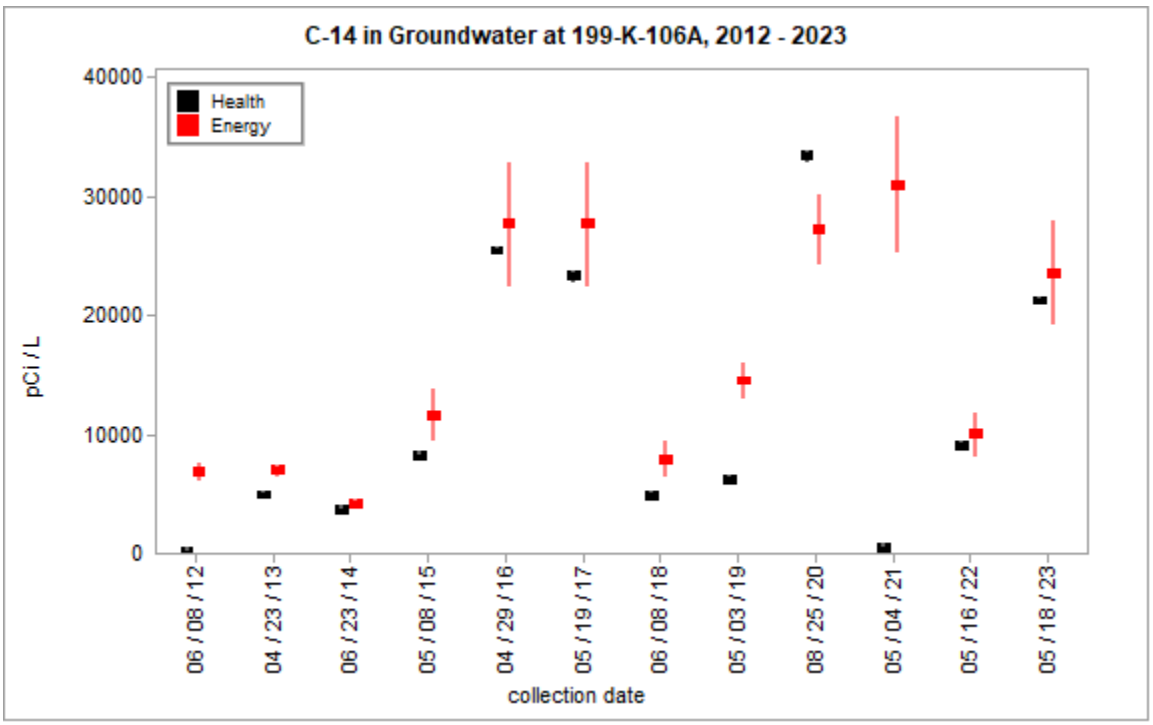


Figure 3.2.4 C-14 Concentrations in Groundwater at 199-K-106A

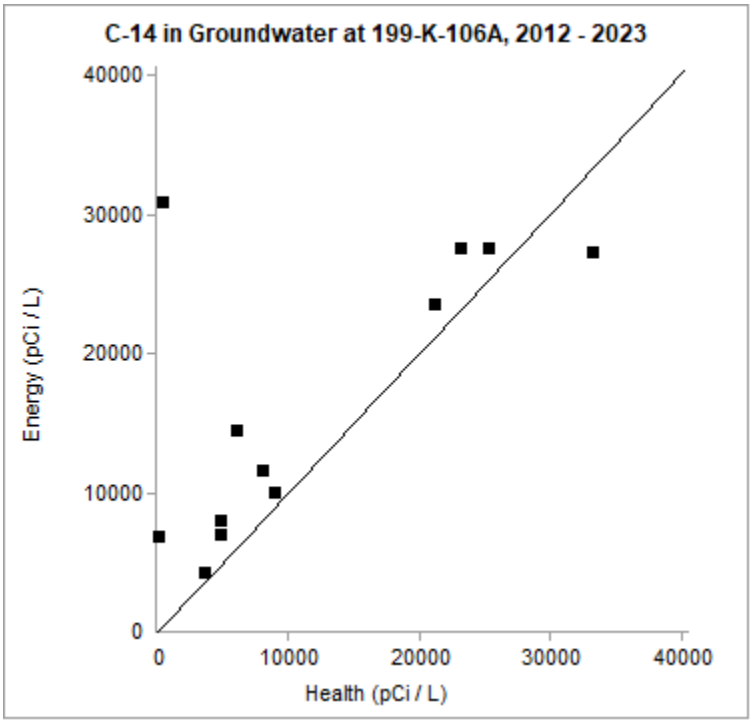


Figure 3.2.5 Co-60 Concentrations in Water

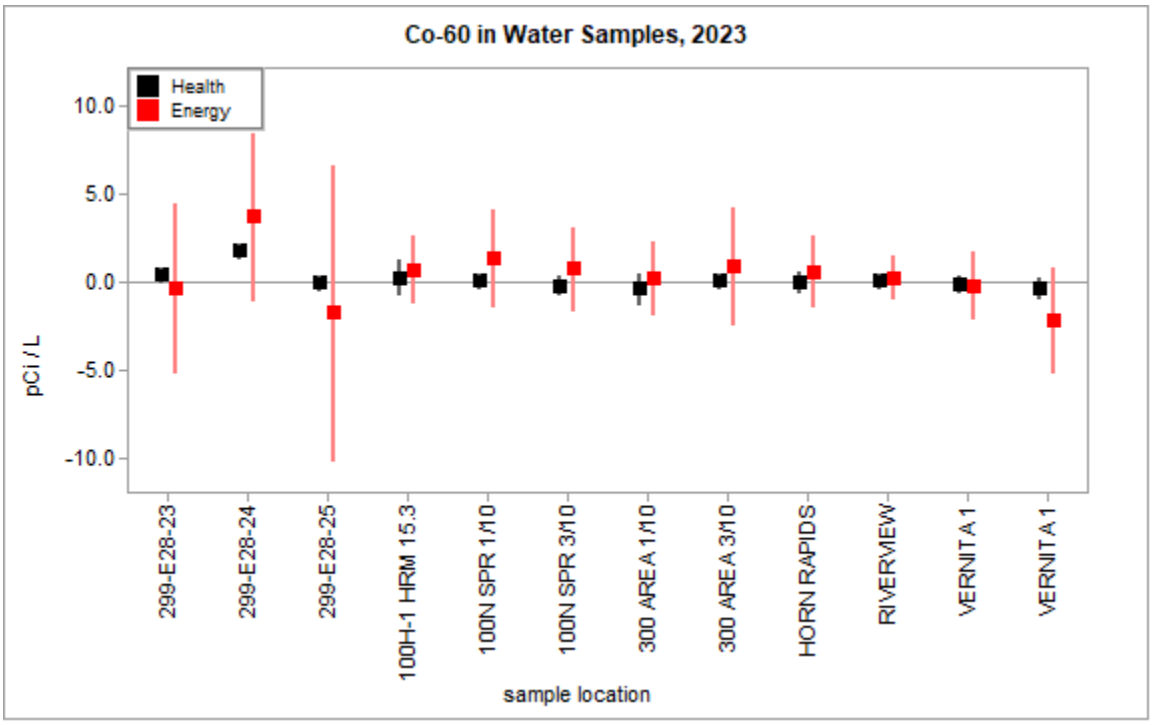


Figure 3.2.6 Co-60 Concentrations in Groundwater at 299-E28-24

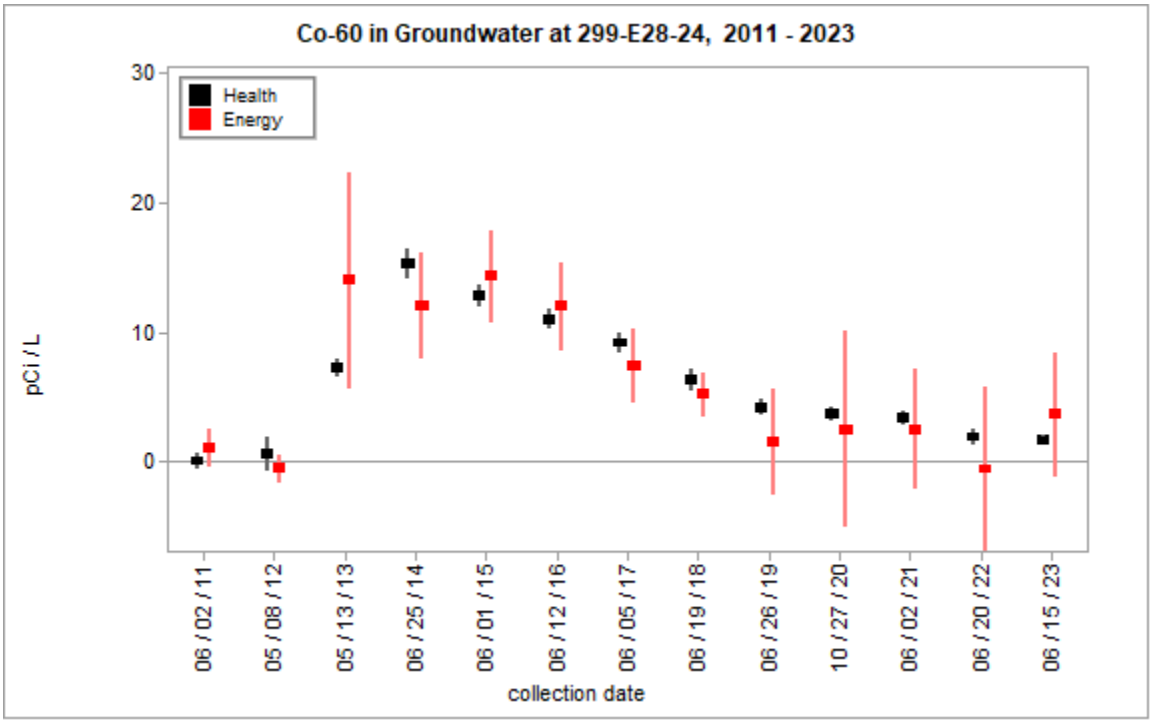


Figure 3.2.7 Cs-137 Concentrations in Groundwater at 299-E28-24

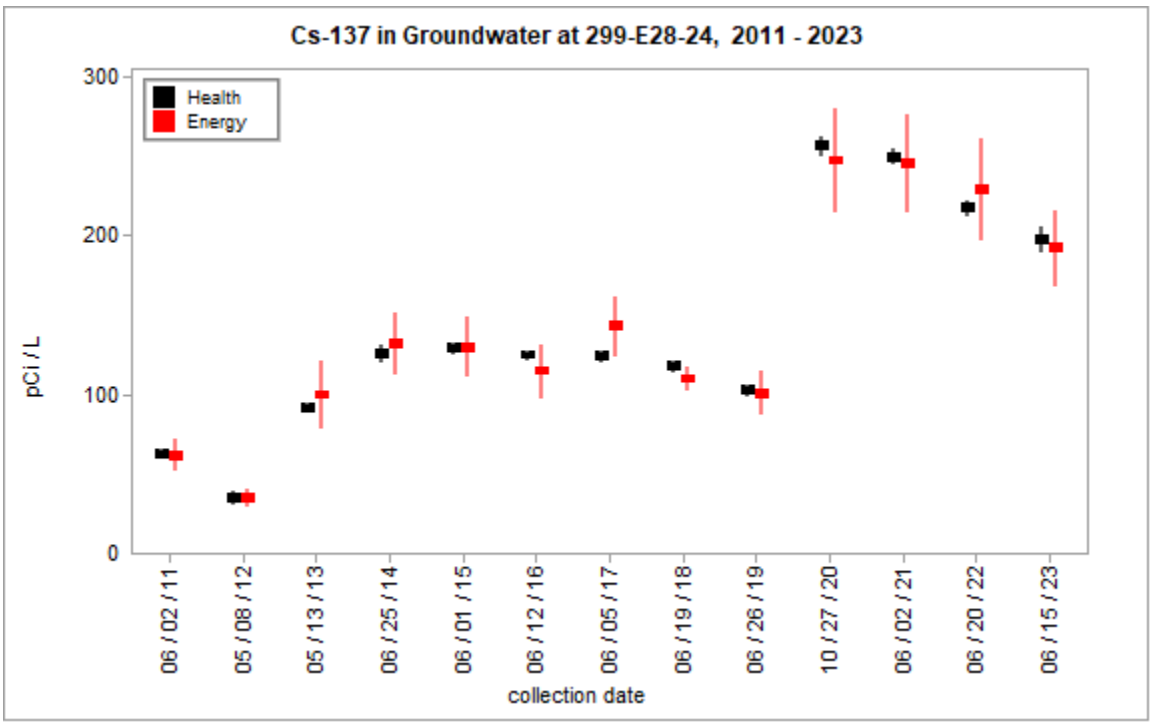


Figure 3.2.8 Gross Alpha Concentrations in Water, Low-Range Data

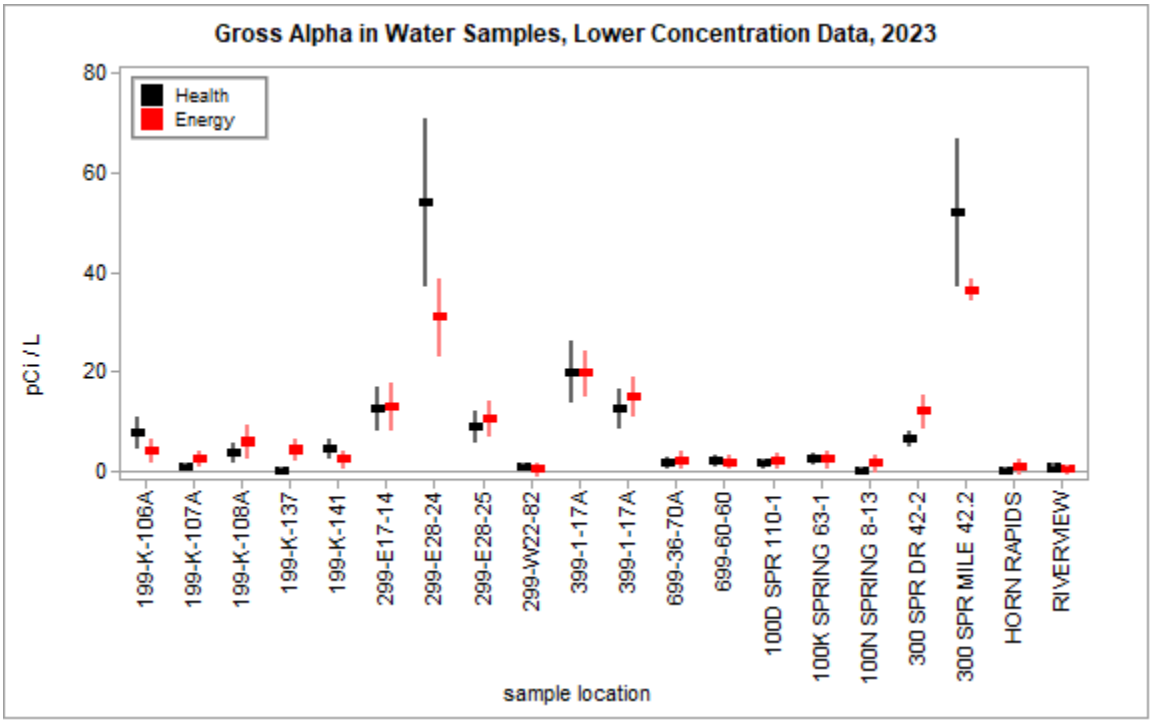


Figure 3.2.9 Gross Alpha Concentrations in GW at 299-E33-344

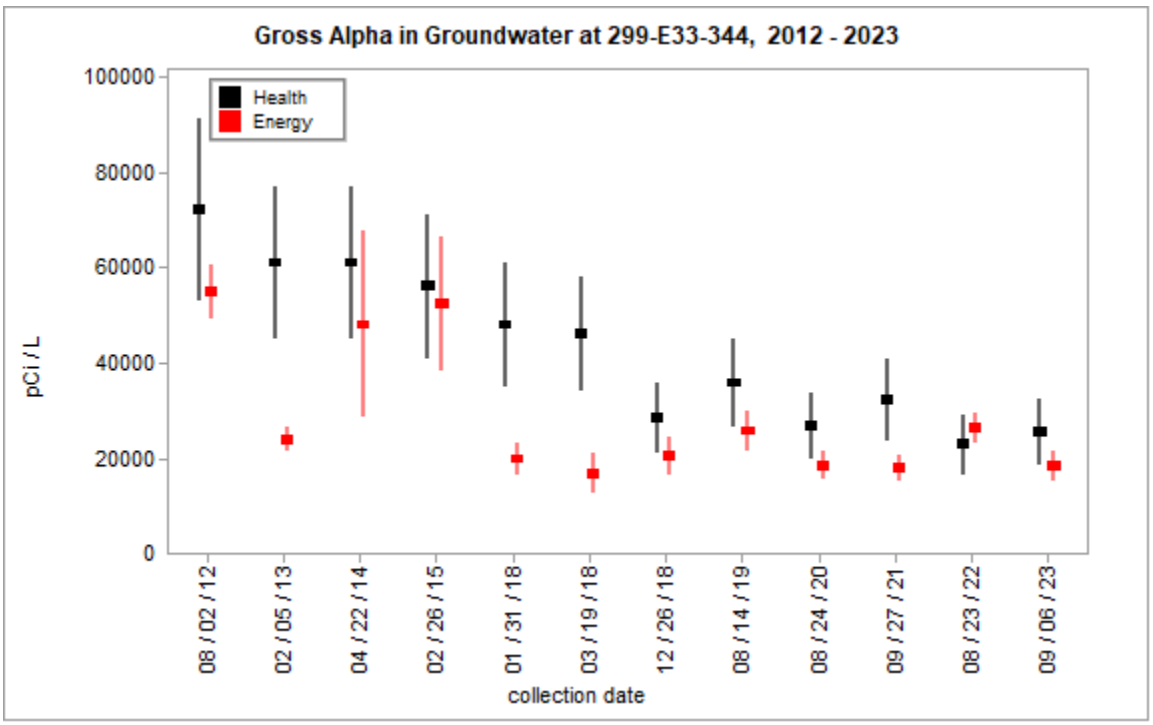


Figure 3.2.10 Gross Alpha Concentrations in GW at 299-E33-344

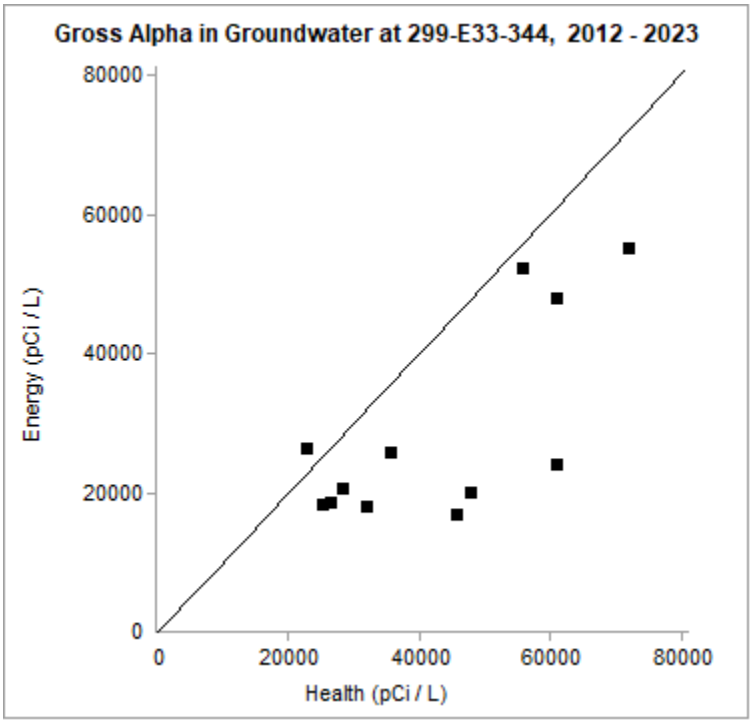


Figure 3.2.11 Gross Beta Concentrations in Water, Low-Range Data

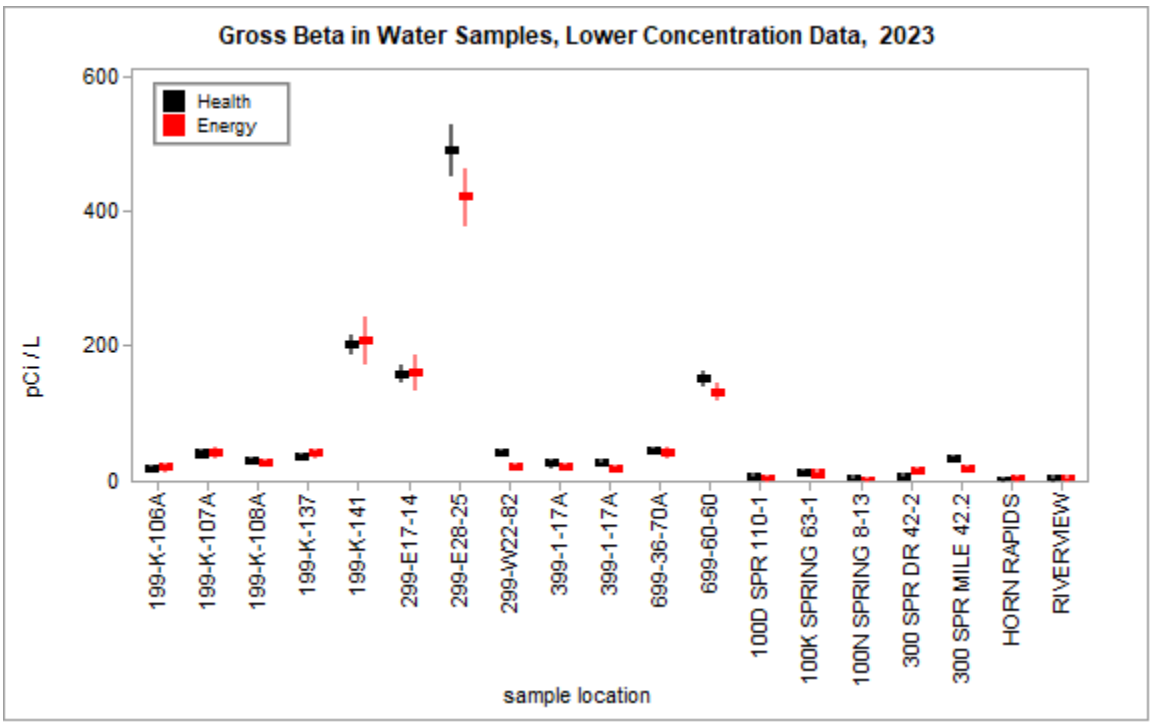


Figure 3.2.12 Gross Beta Concentrations in GW at 299-E33-344

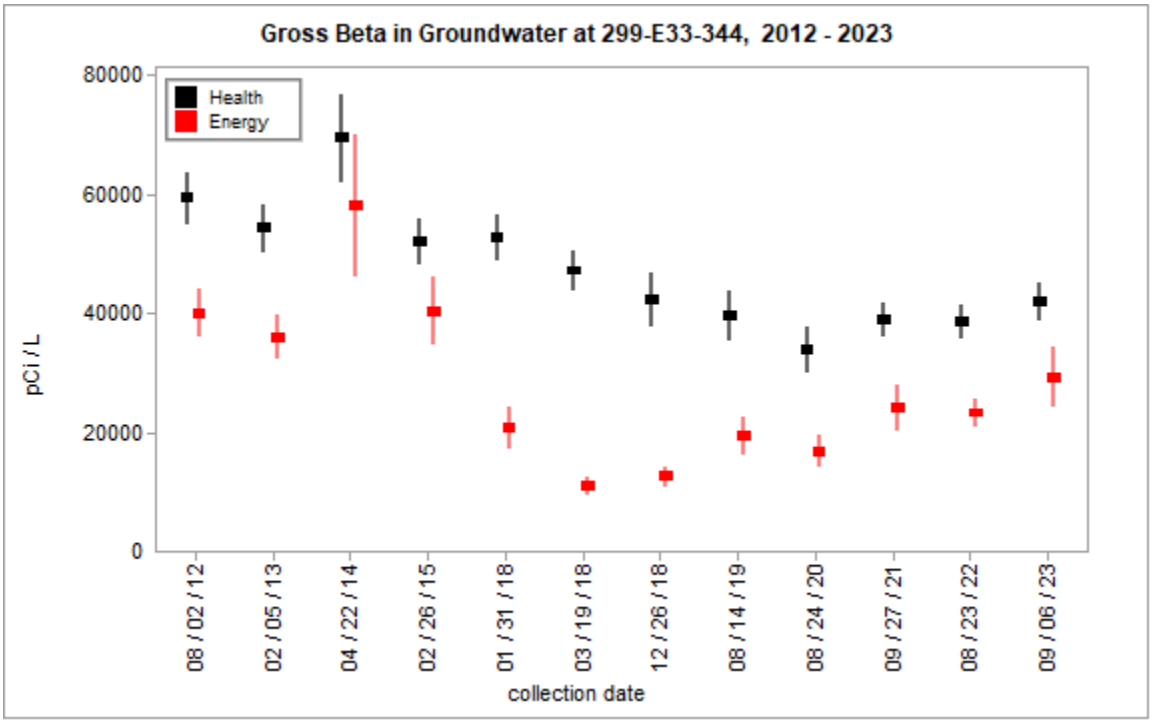


Figure 3.2.13 H-3 Concentrations in Groundwater at 299-E17-14

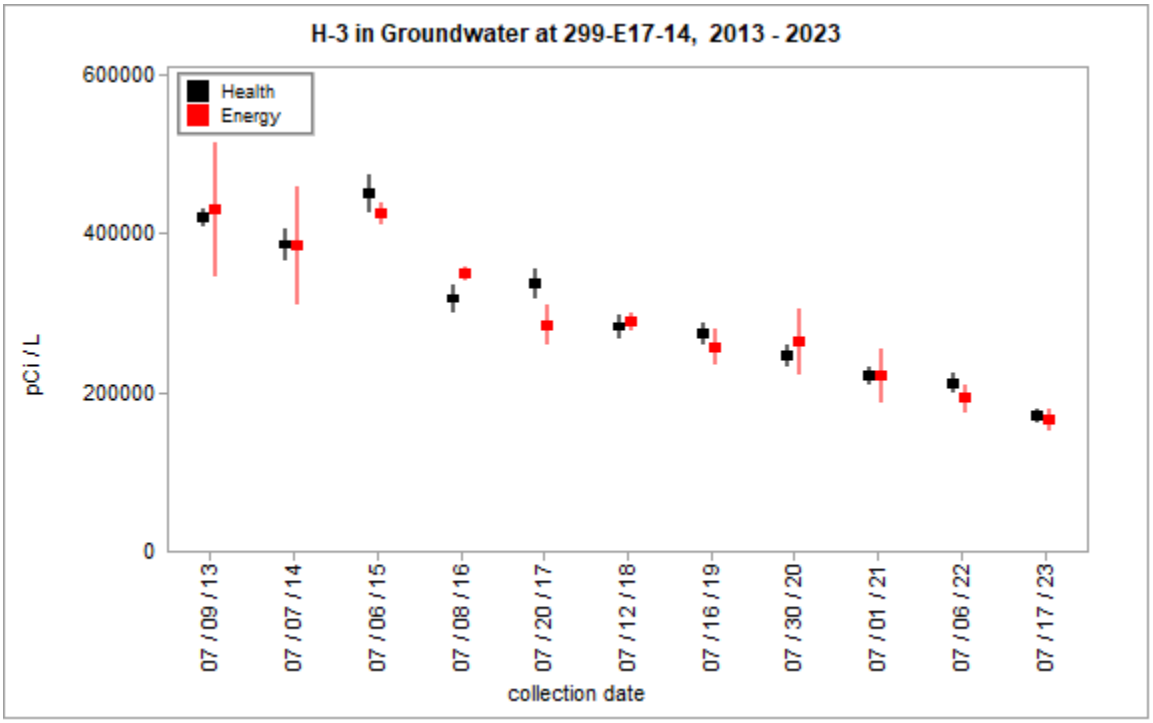


Figure 3.2.14 I-129 Concentrations in Water

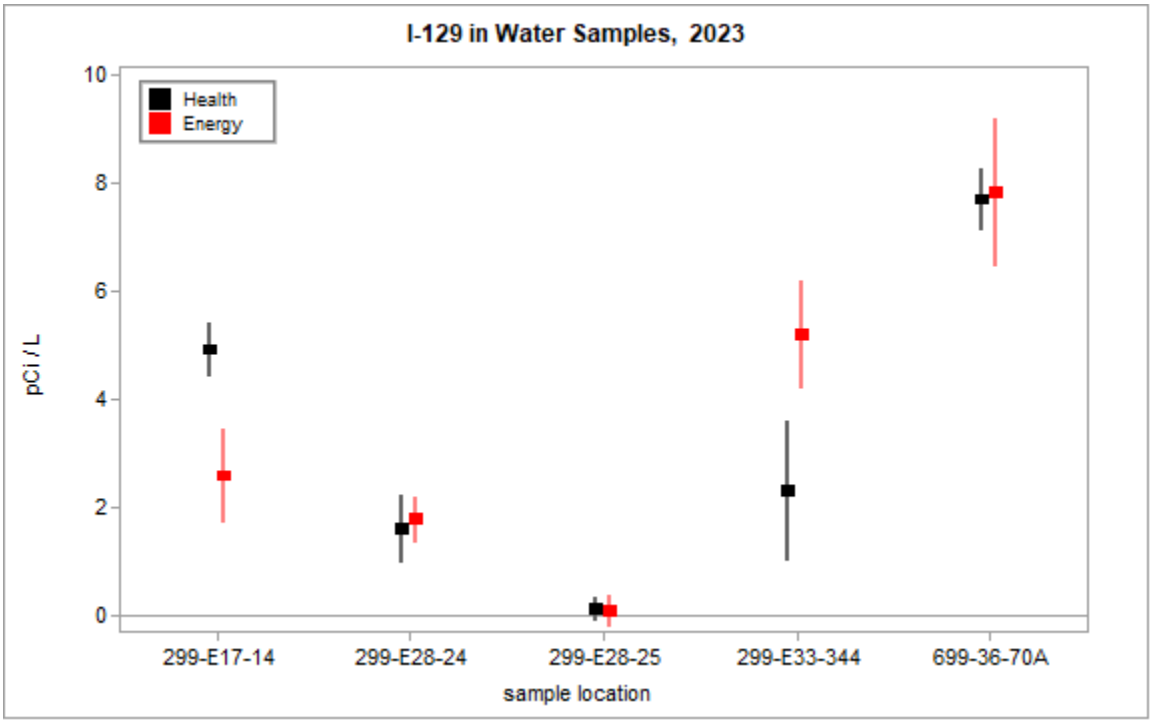


Figure 3.2.15 I-129 Concentrations in Groundwater at 699-36-70A

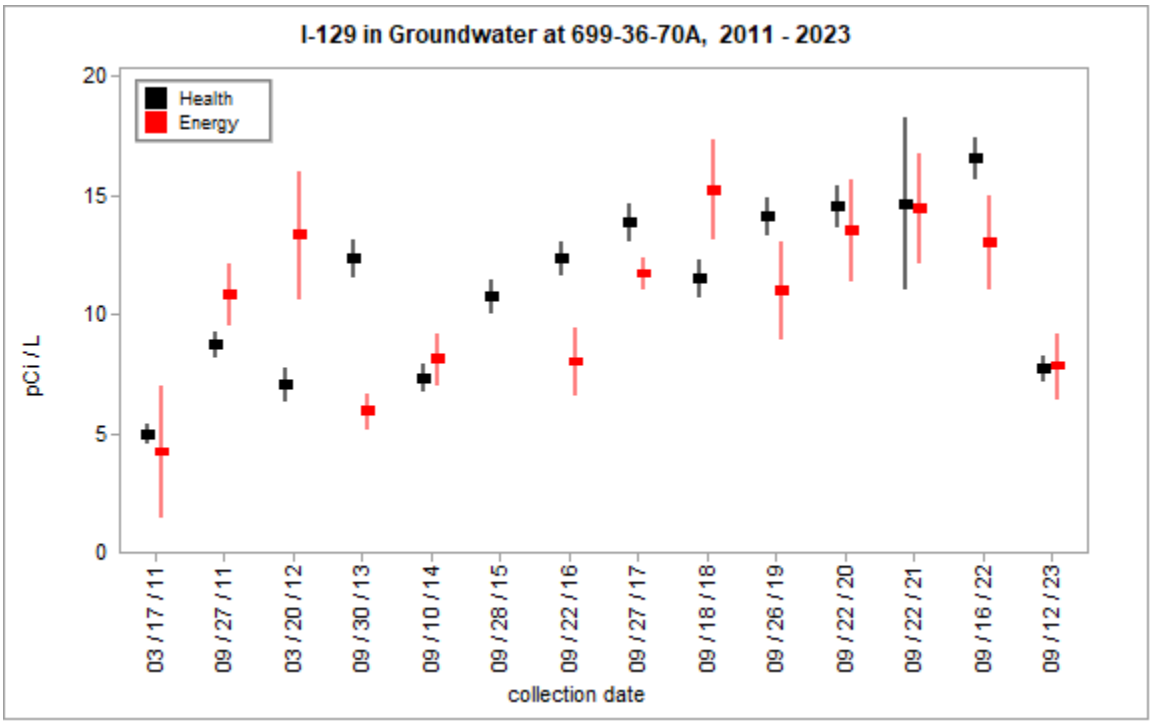


Figure 3.2.16 Pu-238 Concentrations in Water

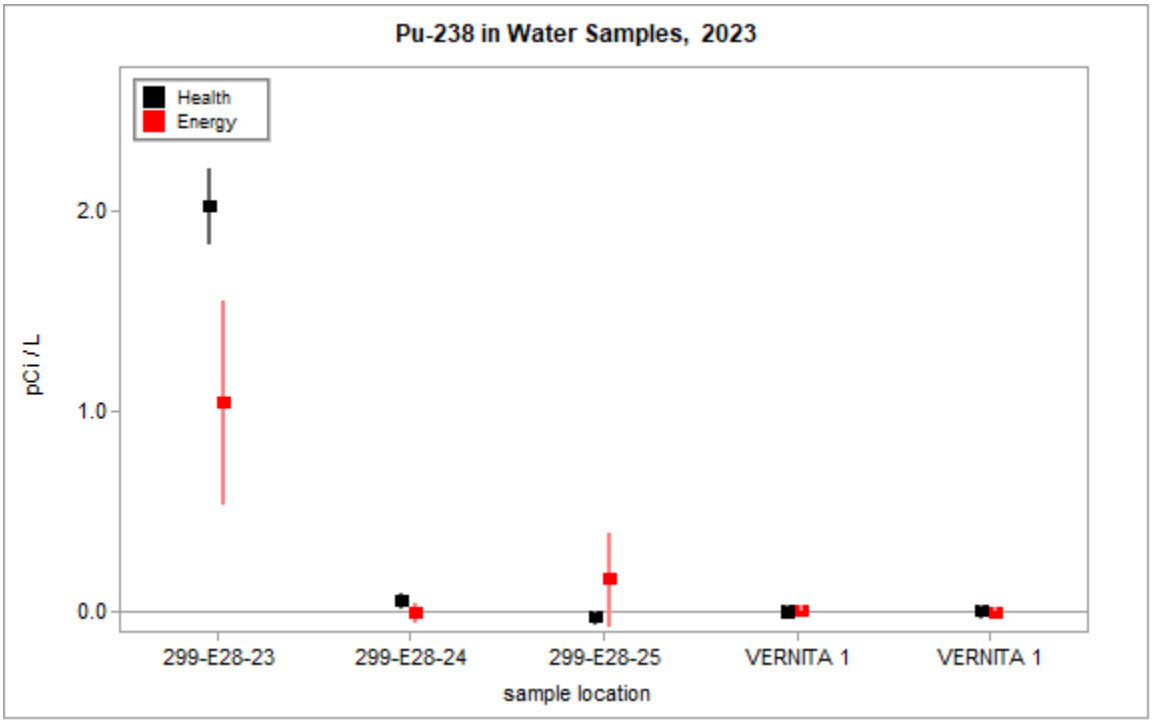


Figure 3.2.17 Pu-238 Concentrations in Groundwater at 299-E28-23

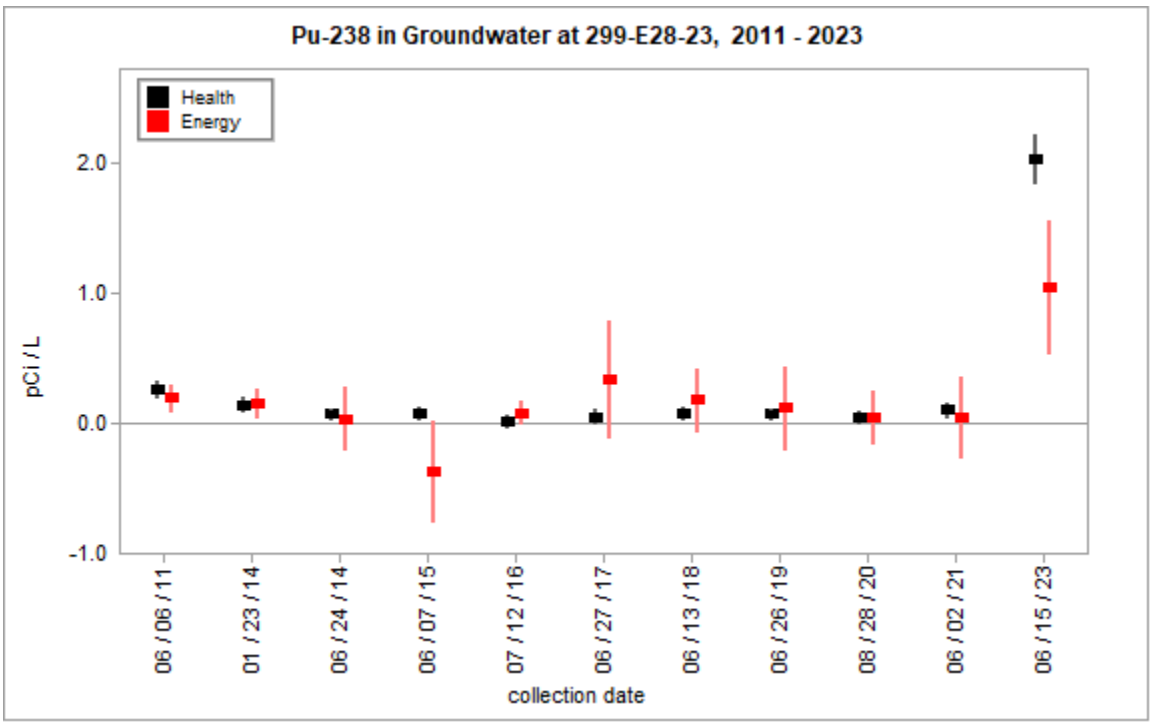


Figure 3.2.18 Pu-239/240 Concentrations in Water

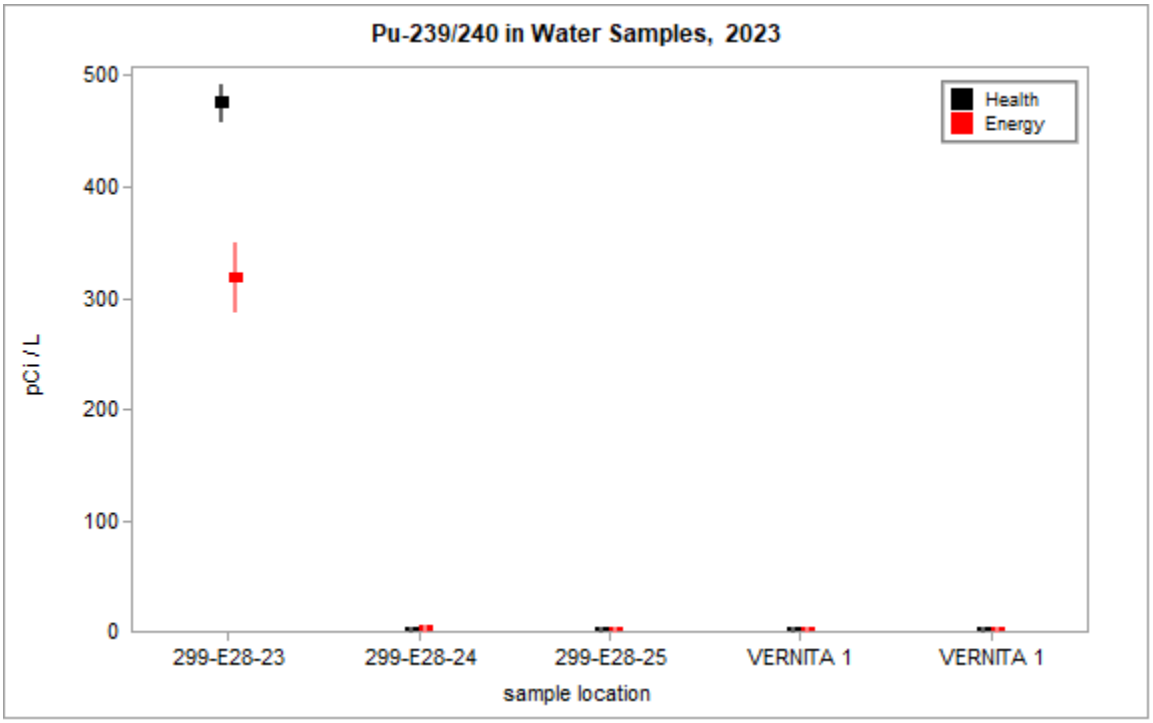


Figure 3.2.19 Pu-239/240 Concentrations in in GW at 299-E28-23

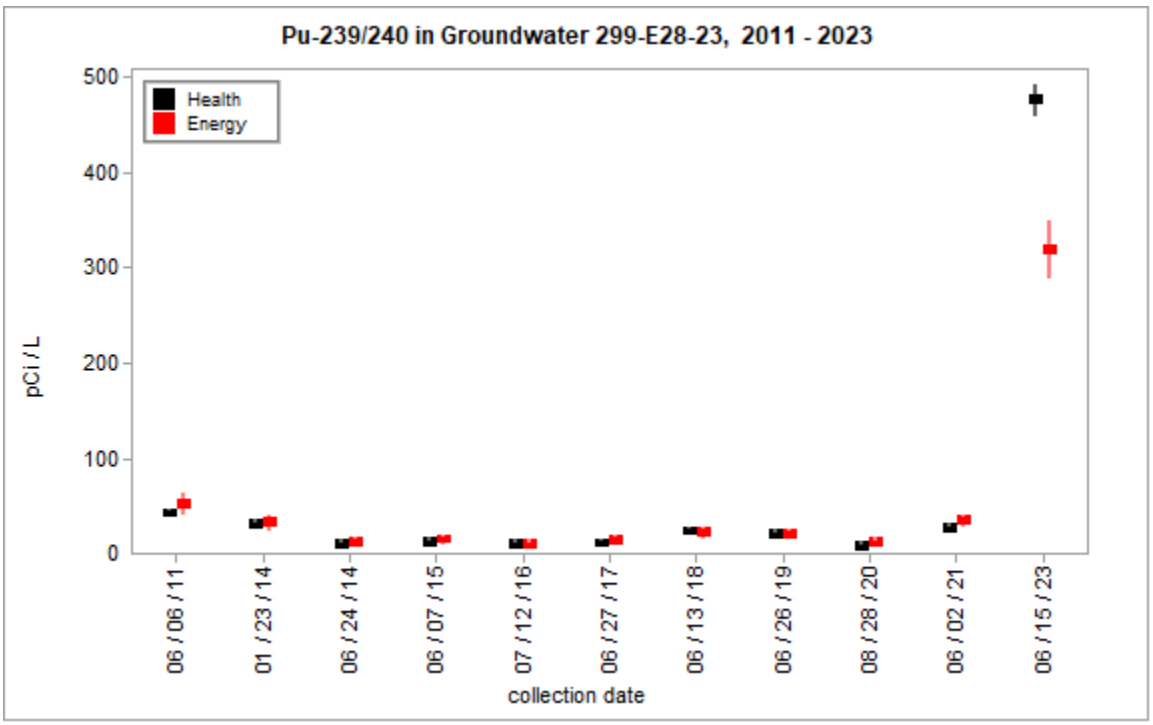


Figure 3.2.20 Sr-90 Concentrations in Water

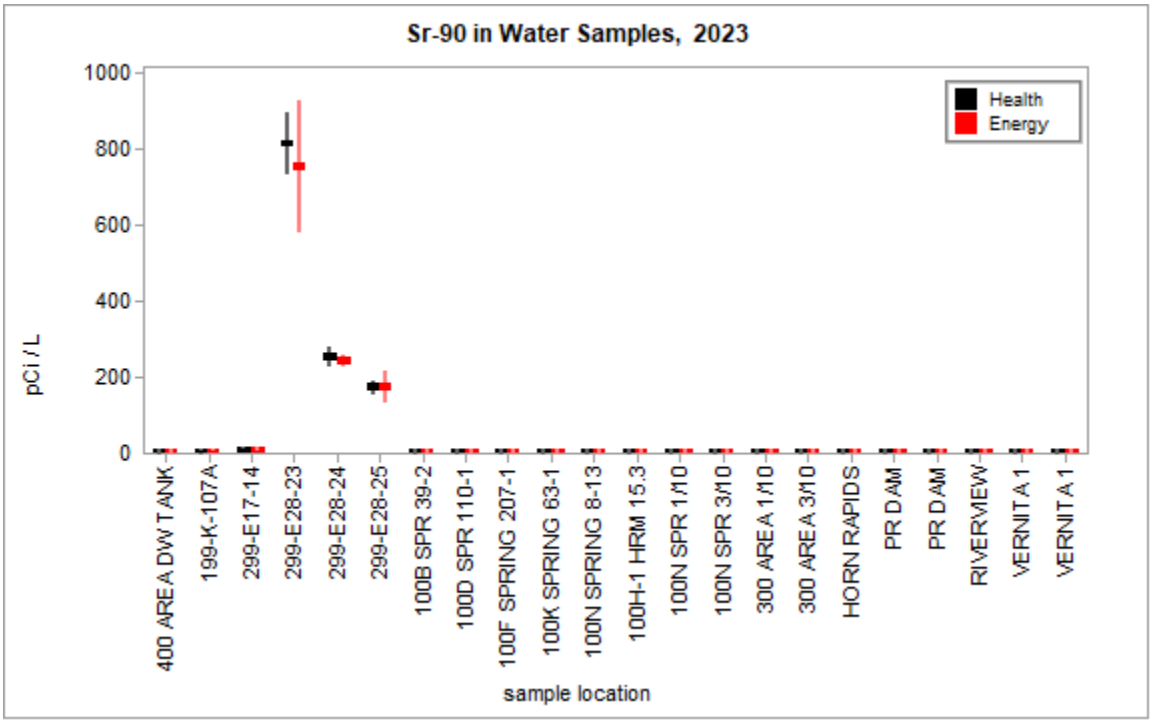


Figure 3.2.21 Sr-90 Concentrations in Water, Low Range Data

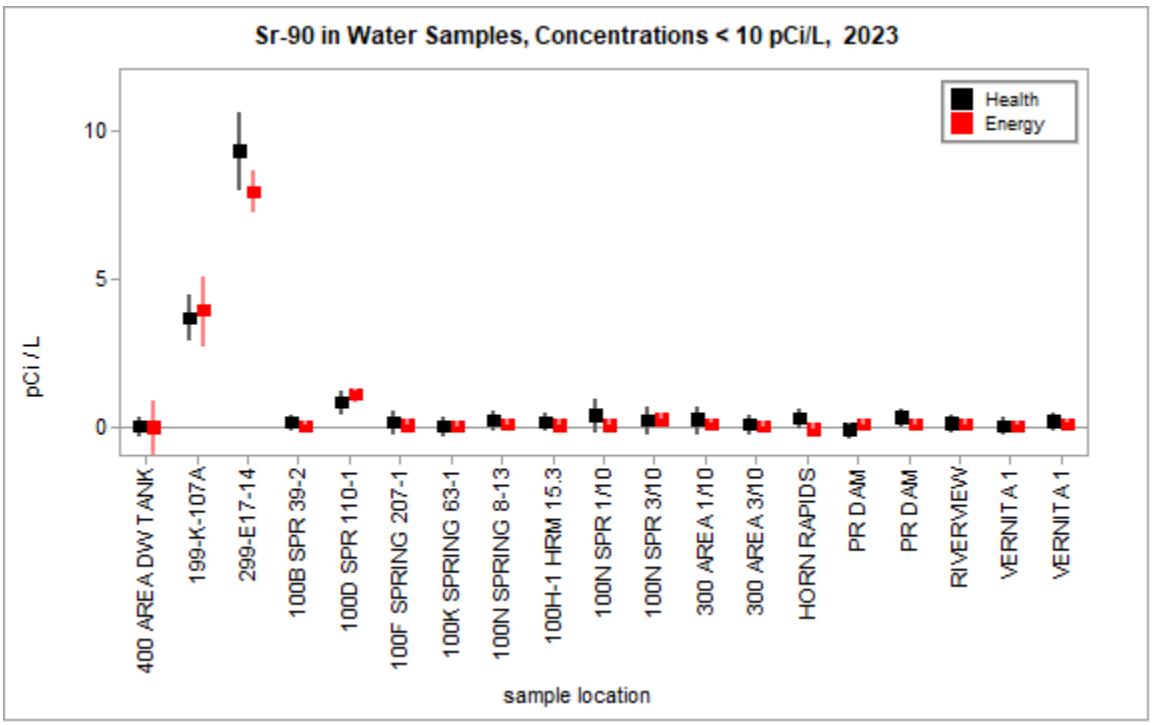


Figure 3.2.22 Tc-99 Concentrations in Groundwater at 299-E33-344

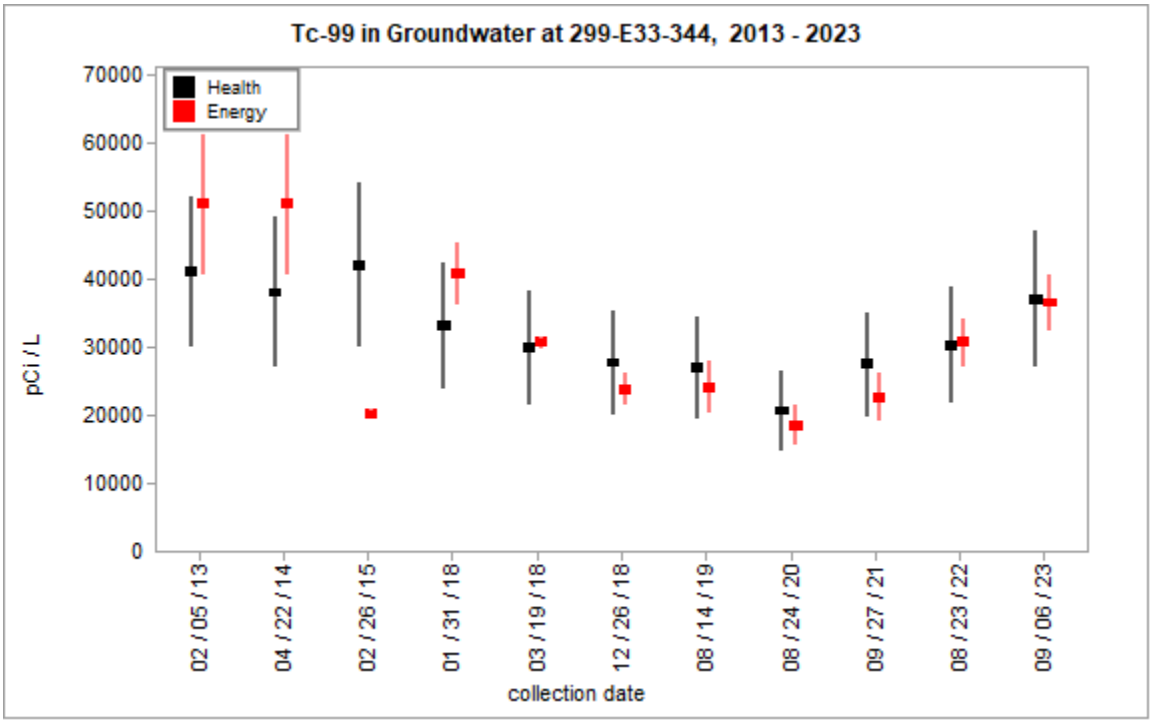


Figure 3.2.23 U-234 Concentrations in Water, Low Range Data

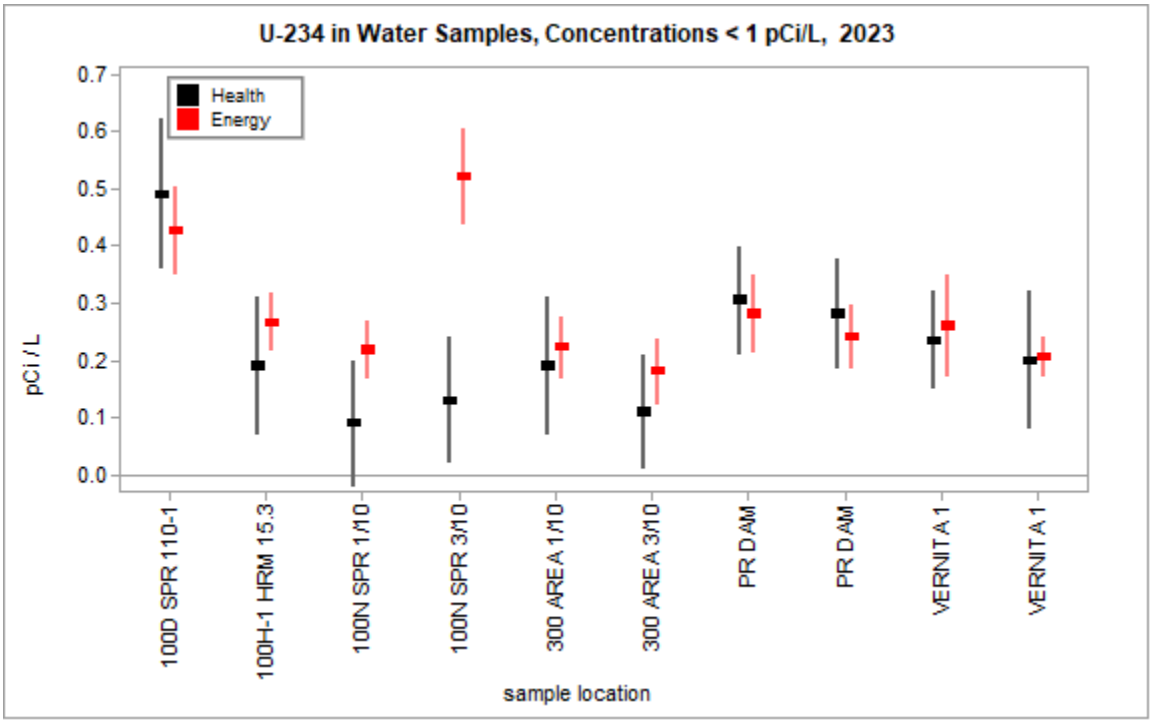


Figure 3.2.24 U-234 Concentrations in Water, Mid Range Data

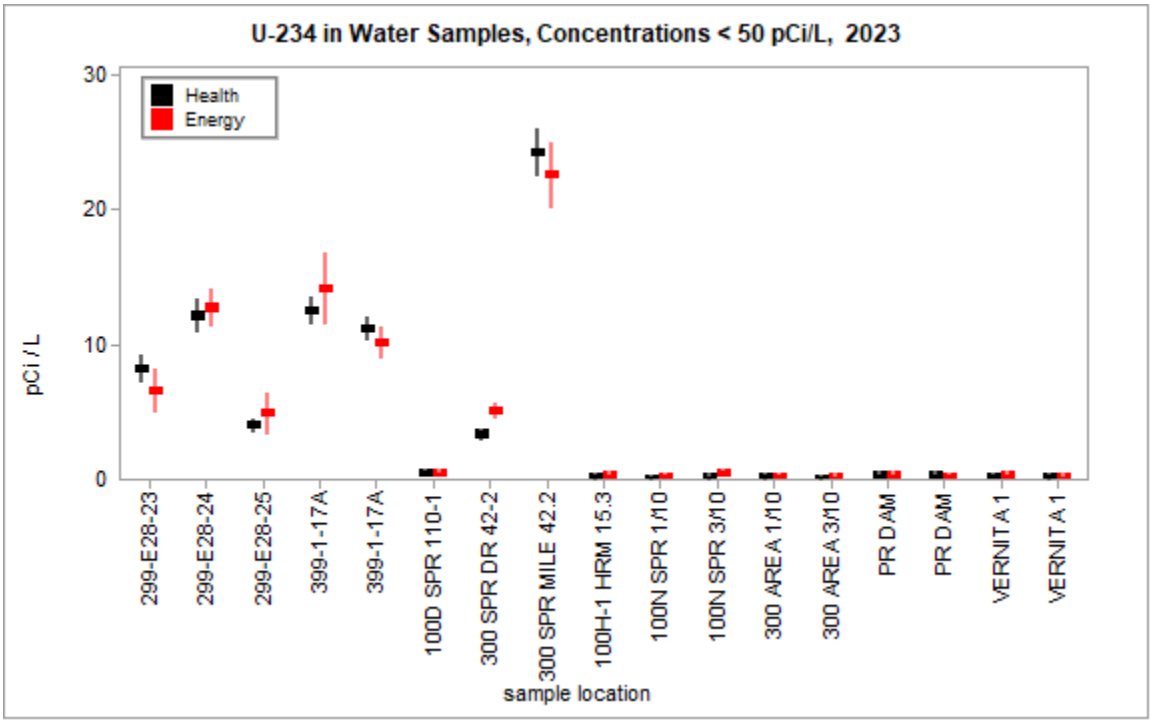
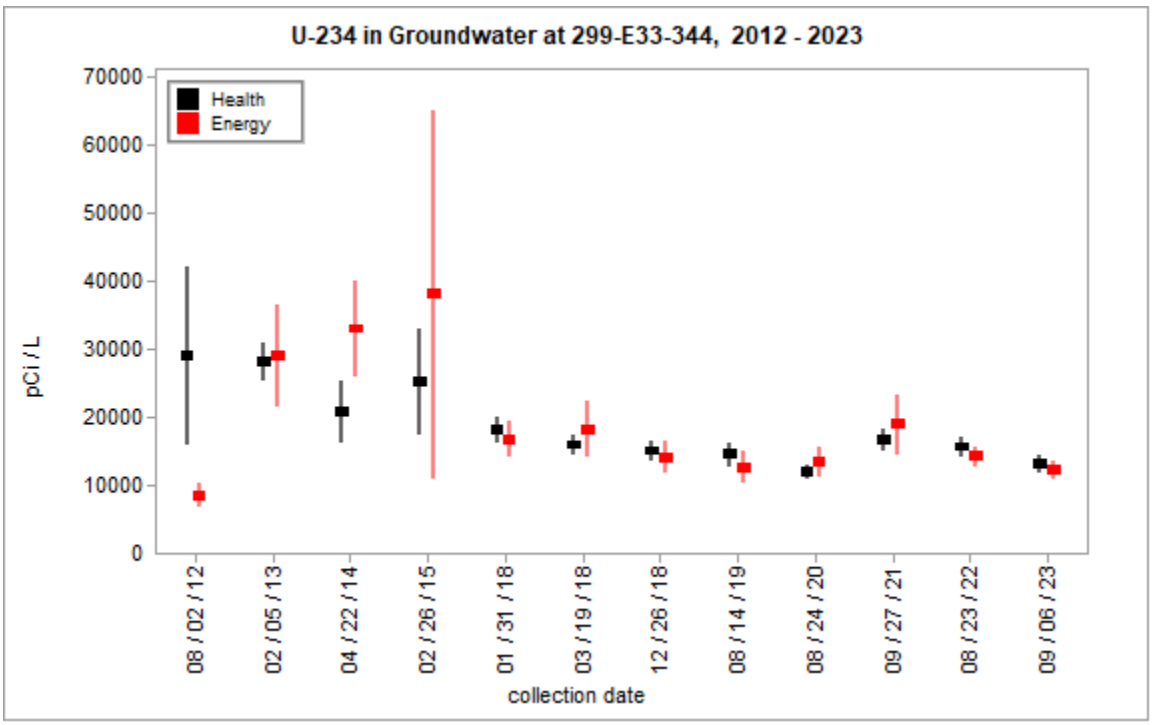


Figure 3.2.25 U-234 Concentrations in Groundwater at 299-E33-344



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 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 49 external radiation monitoring locations that are relevant to the Hanford Site; 48 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 40 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. Ten 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 far away from radiation sources. Twenty-four sites are along the Columbia River shoreline from the Vernita Bridge to downstream of Bateman Island at the mouth of the Yakima River. Nine sites are located around the Hanford Site perimeter. The remaining three sites (Othello, Yakima Airport, and Benton County Shops) are significantly distant from the Hanford Site. Many of these dosimeter sites are collocated with the air monitoring sites discussed in Section 3.1.

3.3.3 Monitoring Procedures

Most collocated dosimeters are deployed on a quarterly basis at each monitoring location, with the dosimeters retrieved at the end of each calendar quarter. Columbia River dosimeters, 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**	0.16 to 3.5	no

Health and Energy collocated 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 2023), 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).

The Relative Percent Difference (see Section 2.2.4.3) values for the collocated data are all negative, indicating that Energy systematically reports higher radiation rates than Health. In addition, most of the RPD values are less than the poor agreement criterion of 33%. For these reasons, Health considers the overall agreement of the dosimeter data to be fair.

Figure 3.3.5 shows the collocated historical (2018 - 2023) 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 consistently reports radiation rates greater than those reported by Energy (Figure 3.3.5).

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 49 external radiation monitoring locations, 48 of which are environmental monitoring locations, and one location is inside the 100B Reactor building. Table 3.3.2 summarizes data from the 48 environmental monitoring locations.

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	135	0.15 to 0.33	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

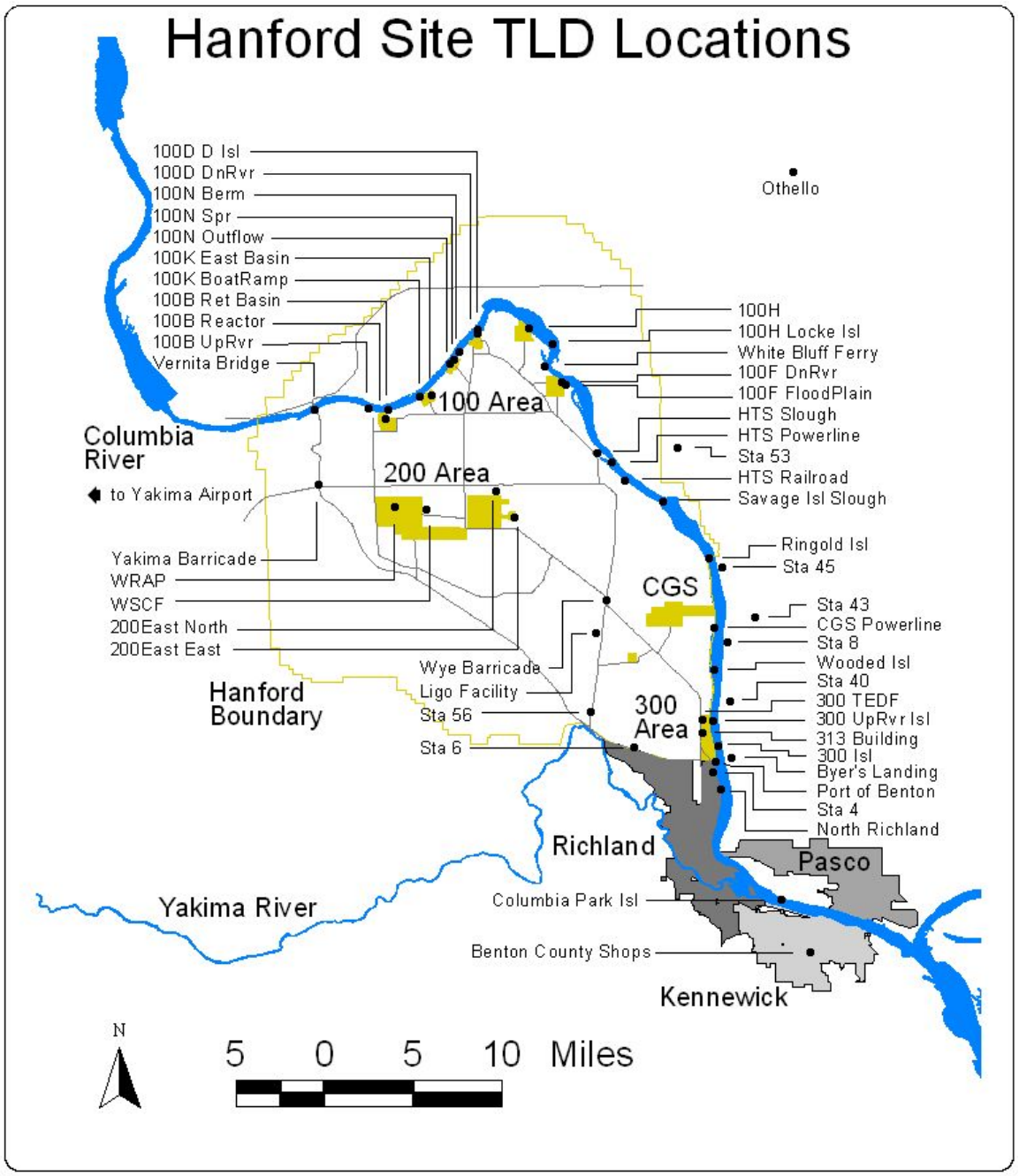


Figure 3.3.2 – Quarterly Ambient Radiation Rates

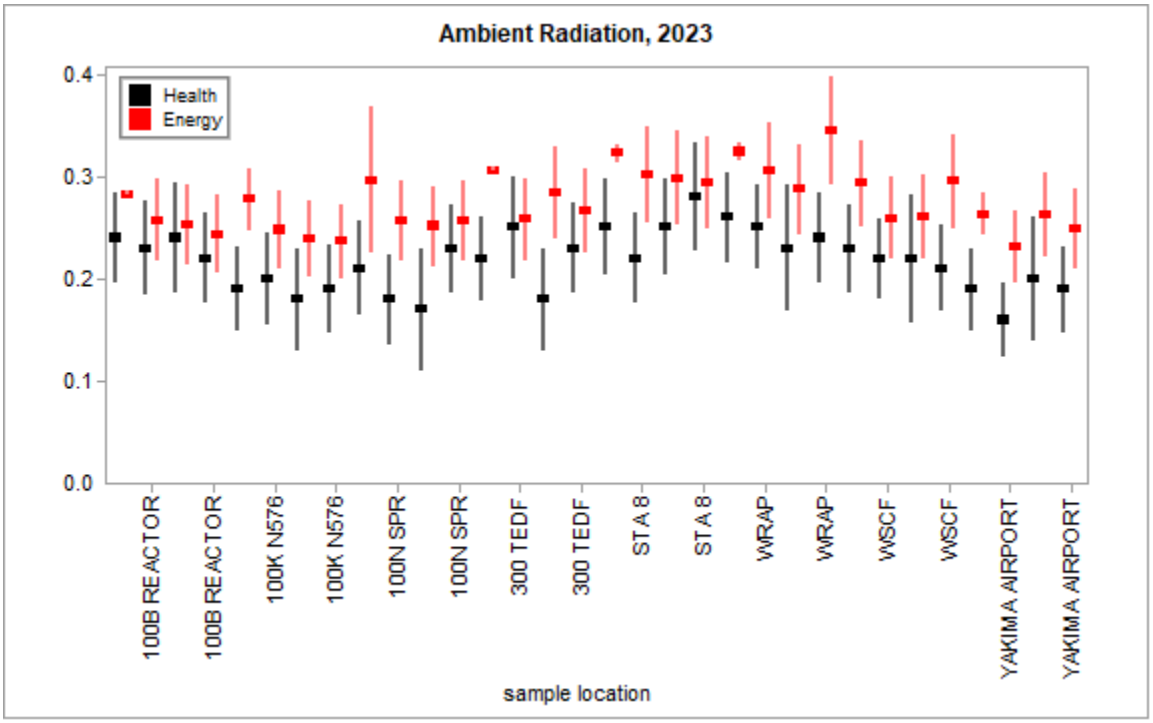


Figure 3.3.3 – Quarterly Ambient Radiation Rates

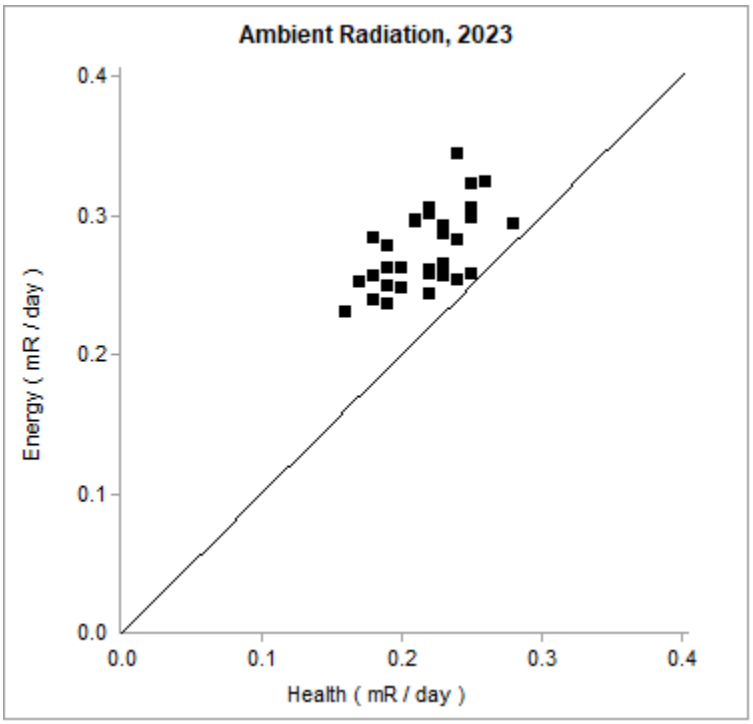


Figure 3.3.4 – Quarterly Ambient Radiation Rates (2019)

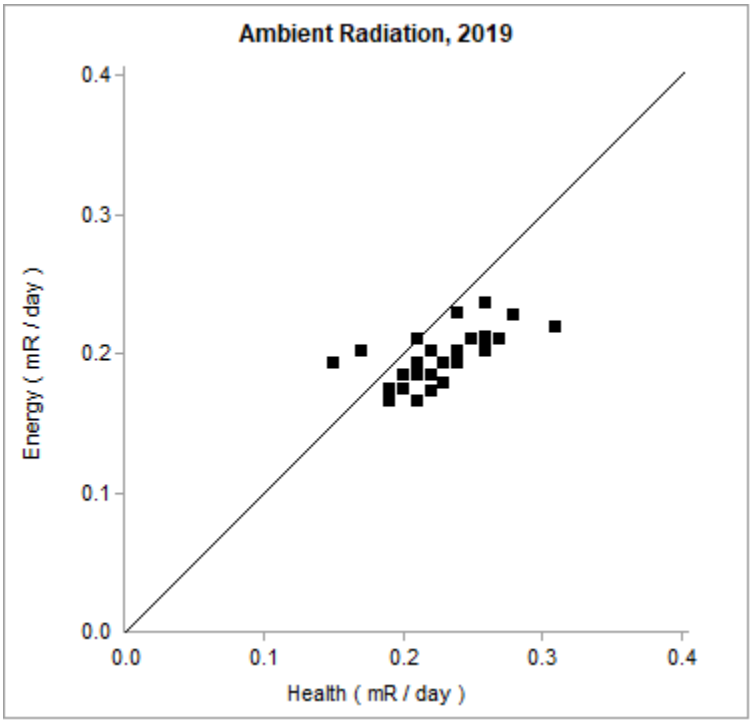


Figure 3.3.5 – Quarterly Ambient Radiation Rates Inside 100B Reactor

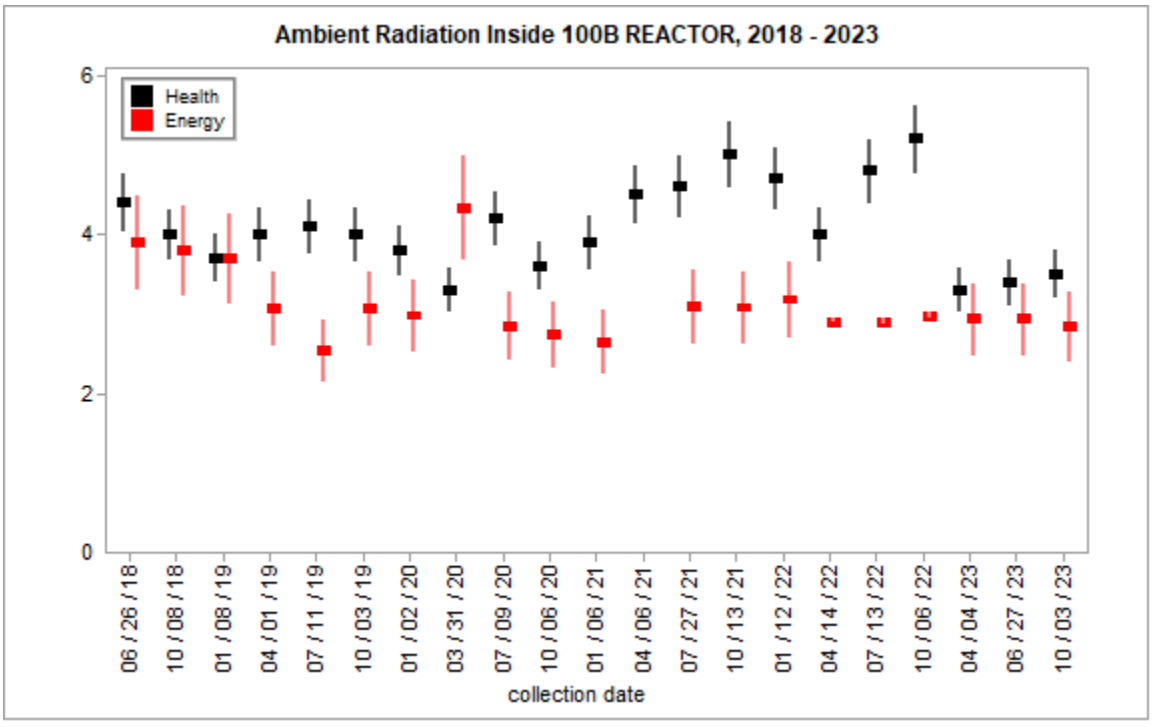
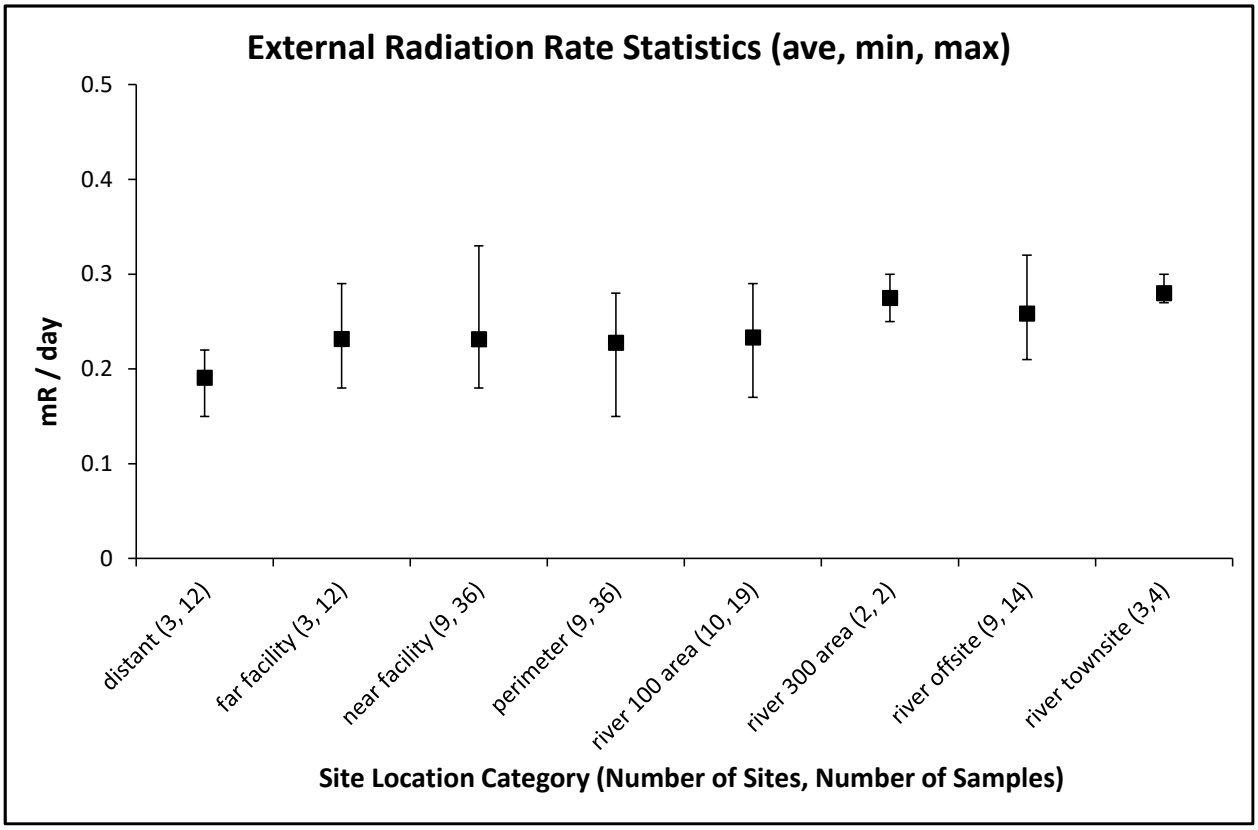


Figure 3.3.6 – External Radiation Rates by Location Category



3.4 Sediment and Soil Monitoring

Major Findings:

- Health and Energy sediment and soil concentrations are in fair agreement for Sr-90, and 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: Hanford Mission Integrated Solutions, HMIS) 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).

The text following the table discusses 1) cases in which the agreement between Health and Energy data is not good (i.e. is fair or poor), 2) cases in which some of the Health data are anomalous compared to historical results, or 3) other data topics of interest.

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	0.017 to 0.021	no
C-14	annual	1	good+	2.9	no
Co-60	annual	13	good	< 0.02	no
Cs-134	annual	13	good	< 0.06	no
Cs-137	annual	13	good+	< 0.02 to 2.5	no
Eu-152	annual	13	good	< 0.04 to 0.043	no
Eu-154	annual	13	good	< 0.06	no
Eu-155	annual	13	good	< 0.05	no
Pu-238	annual	13	good	< 0.012	no
Pu-239/240	annual	13	good+	< 0.012 to 0.11	no
Sr-90	annual	13	**fair**	< 0.002 to 0.29	no
U-234	annual	13	good	0.58 to 2.3	no
U-235	annual	13	good	0.018 to 0.11	no
U-236	annual	1	good	0.043	no
U-238	annual	13	good	0.57 to 2.2	no

+ see discussion in text below

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

Operations in the 200 West Area have resulted in possible transuranic contamination in soils. Health analyzes split soil samples from 200 West for transuranic isotopes, including Am-241. Figure 3.4.2 shows historical Am-241 concentrations in 200 West soil samples. The Health and Energy split Am-241 concentrations are in good agreement, and the concentrations from the 2023 samples are consistent with historical results.

Carbon-14 found in 100K Area groundwater can transfer to Columbia River sediment through riverbank seeps or groundwater upwelling at the groundwater/river interface. The Health and

Energy split C-14 sediment concentrations are in good agreement for the single sample from the 100K Area collected in 2023.

However, the agreement for historical C-14 sediment data ranges from good to fair to poor for any given year. Figure 3.4.3 shows historical C-14 data for 100K Area sediment. For the two cases when Health detected concentrations greater than 5 pCi/g, Energy did not detect C-14, resulting in poor agreement for these samples. In addition, the absolute value of the Relative Percent Difference (RPD, see Section 2.2.4.3) for the three cases where the error bars do not overlap range from 103% to 223%, far greater than the 33% criterion to consider the agreement as poor. Historically, the Health and Energy split C-14 results in sediment are in poor agreement.

The Health and Energy split concentrations for the gamma emitting isotopes Co-60, Cs-134, Eu-152, Eu-154, and Eu-155 are in good agreement and most results are below the detection limits. As an example, Figure 3.4.4 shows the split Co-60 concentrations.

Historically, Eu-152 is not typically detected in Columbia River sediments; however, Health has detected this isotope in sediments at White Bluffs Slough since 2011 with an average concentration of 0.06 pCi/g (Figure 3.4.5).

The Health and Energy split Cs-137 concentrations are in good agreement for all but one sample at 200 West D045, where Energy reports a concentration approximately four times Health's result (Figure 3.4.6). Figure 3.4.7 shows the results for low concentrations less than 1 pCi/g, and here the agreement is good for all results. Figure 3.4.8 shows historical results (2017 - 2023) for higher concentrations greater than 1 pCi/g, where most of the results are in good agreement. The disagreement of the 2023 Cs-137 result at D045 appears to be anomalous.

Plutonium-238 is occasionally detected in Columbia River sediments; however, all the Pu-238 concentrations are below the detection limit for 2023 samples. Figure 3.4.9 shows the data, including Health's minimum detectable activity for each sample (horizontal tick marks).

The Health and Energy split Pu-239/240 results are in good agreement for all but one sample at 200 West D045, where Energy reports a concentration approximately three times Health's result (Figure 3.4.10). Figure 3.4.11 shows the results for low concentrations less than 0.02 p/Ci/g, and here the agreement is good for all results.

Historical Pu-239/240 results (2017 - 2023) for higher concentrations greater than 0.03 pCi/g are shown in Figure 3.4.12. The absolute value of the Relative Percent Difference (see Section 2.2.4.3) for the six samples where the error bars do not overlap ranges from 25% to 91%, with four of the six RPD values greater than the 33% criterion to consider the agreement as poor. In addition, five of the six RPDs are negative, indicating that Energy reports higher concentrations than Health. Historically, the Health and Energy split Pu-239/240 results in 200 Area soil samples are in poor agreement.

The Health and Energy split Sr-90 results are in fair agreement. The agreement is good when results are below or near the detection limit of 0.002 pCi/g (see Figure 3.4.13). However, for higher concentrations above 0.05 pCi/g, the individual sample agreement is often poor. The RPD analysis indicates fair agreement for the set of data collected in 2023.

Figure 3.4.14 shows historical higher concentration Sr-90 data (2017 - 2023, note that one of the results where Health and Energy report 0.116 and 1.87 pCi/g, respectively, is not shown on the graph as it would obscure the details of the remaining data). Six of these results have a Relative Percent Difference of greater than the 33%, resulting in poor agreement for this historical higher concentration data.

The Health and Energy U-234, U-235, and U-238 concentrations are in good agreement. Figure 3.4.15 shows the U-238 data. Historically, there can be a systematic bias, in which Energy reports lower concentrations than those reported by Health, but this bias was not seen in 2023.

Health and Energy analyze one split Columbia River sediment sample, from the 300 Area, for U-236. Historical data from 2017 - 2023 are shown in Figure 3.4.16, where the agreement is generally good.

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, Sr-90, and U-236. 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 also 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 from the 300 Area, Health independently analyzed two soil samples from the 200 West Area for U-236, with both results below the detection limit of 0.004 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, Figures 3.4.17 and 3.4.18 show the last ten years of data for

Sr-90 and U-238, respectively, where sediment concentrations at the upstream and downstream locations are similar.

Figure 3.4.1 – Typical Sediment Monitoring Locations

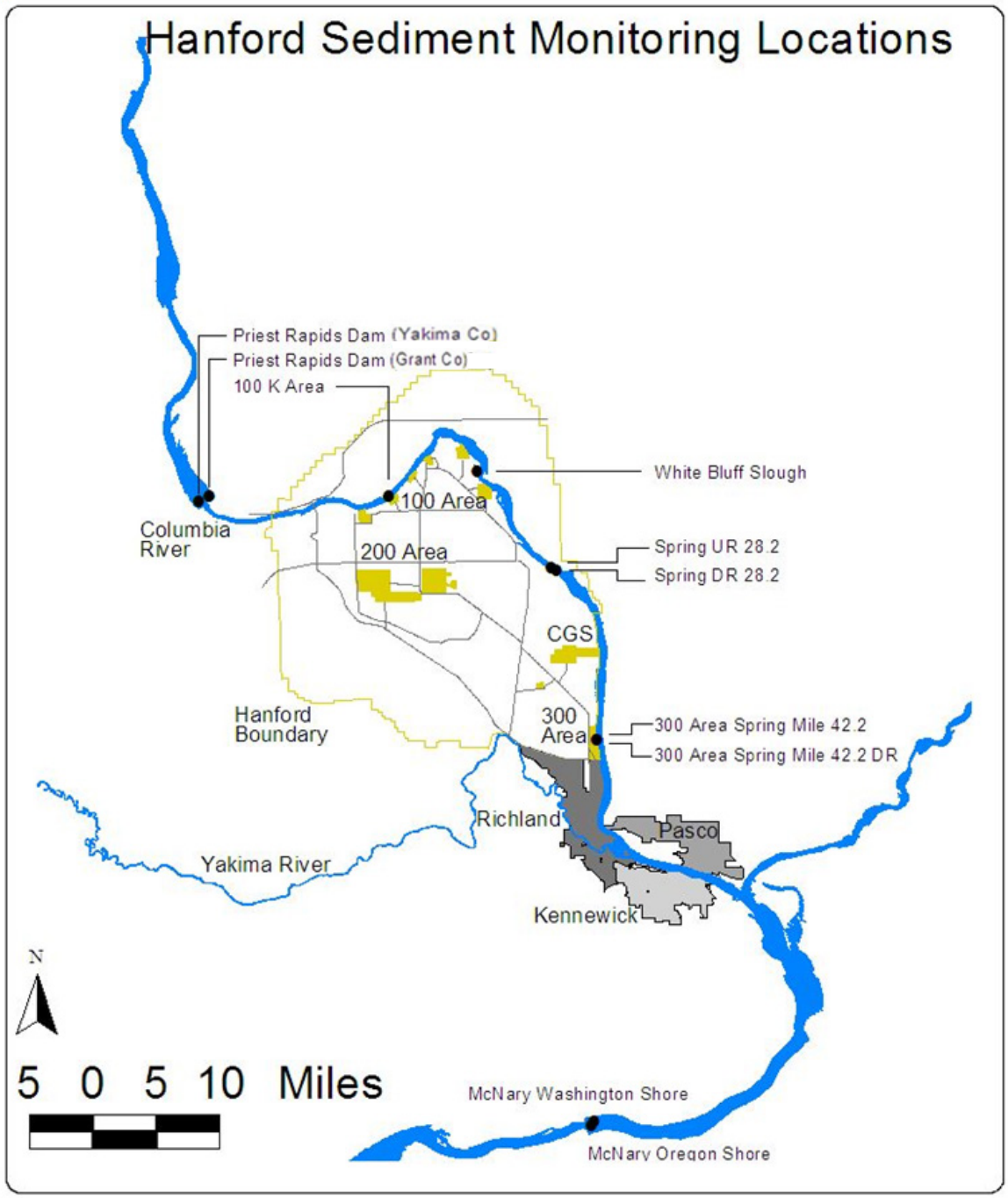


Figure 3.4.2 Am-241 Concentrations in Soil

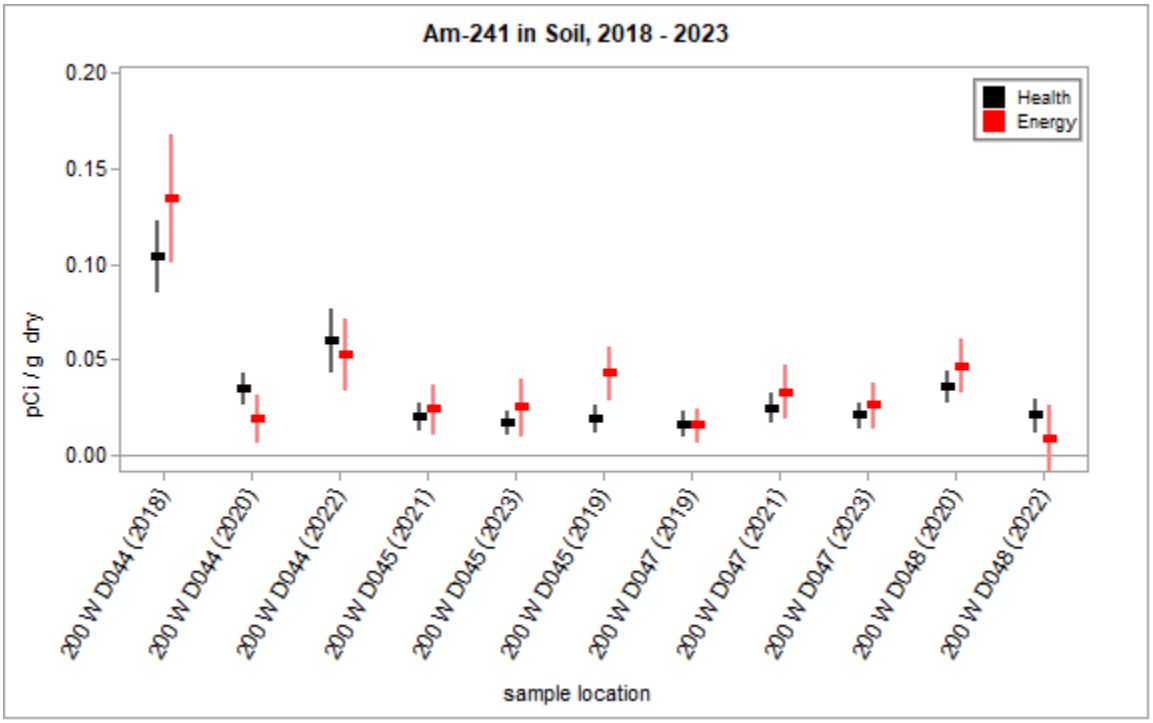


Figure 3.4.3 C-14 Concentrations in Sediment at 100K SPRING 63-1

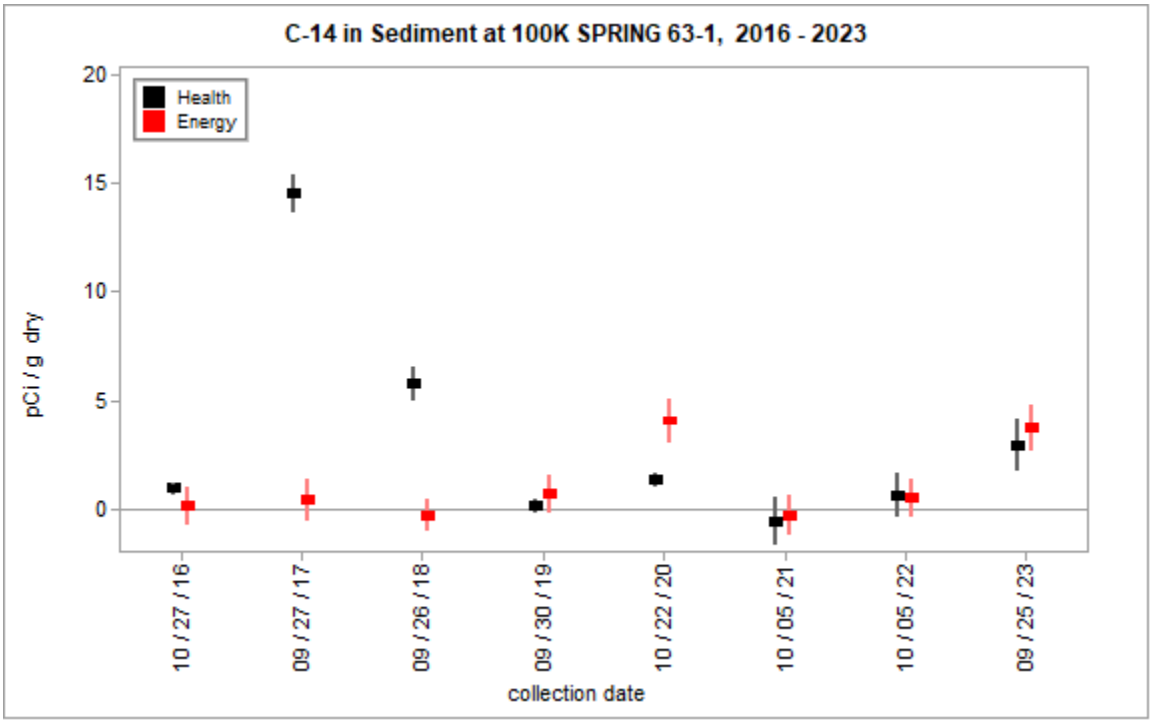


Figure 3.4.4 Co-60 Concentrations in Soil and Sediment

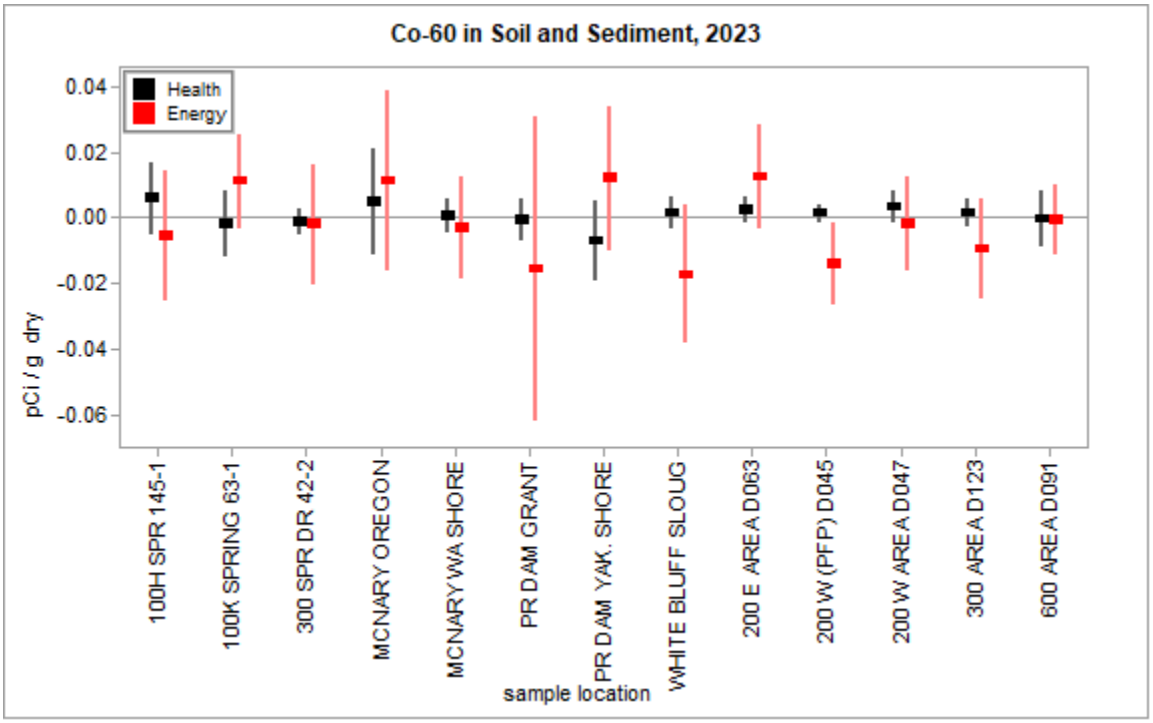


Figure 3.4.5 Eu-152 Concentrations in Sediment at White Bluff Slough

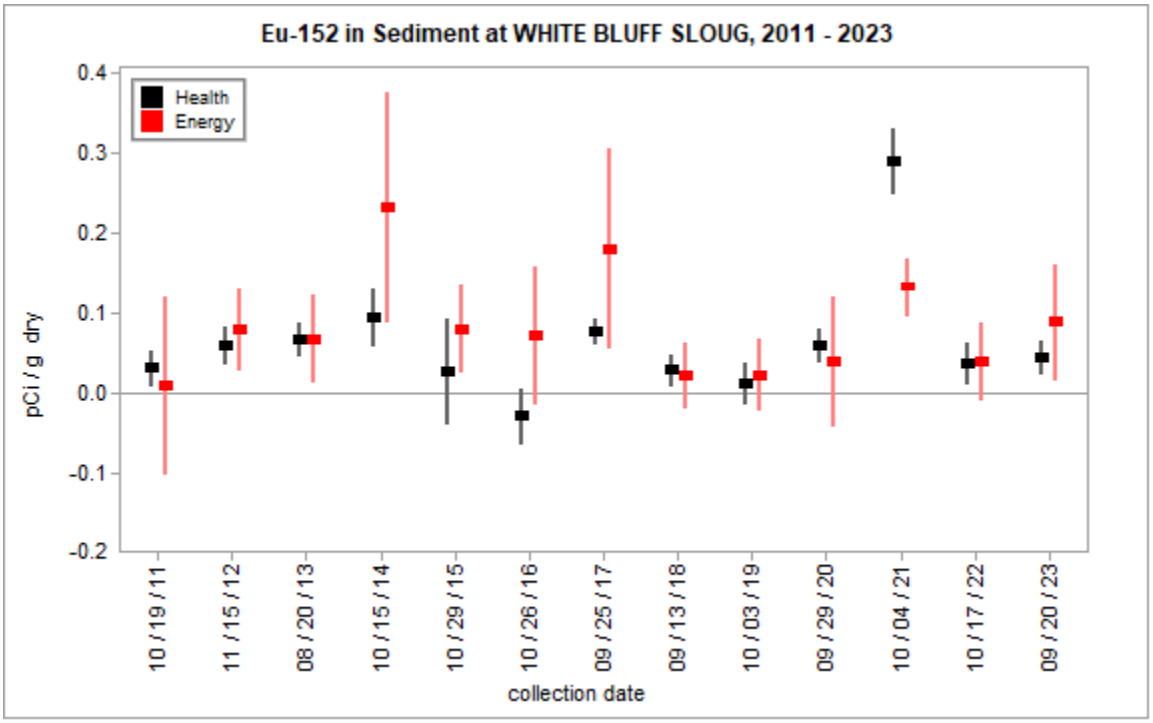


Figure 3.4.6 Cs-137 Concentrations in Soil and Sediment

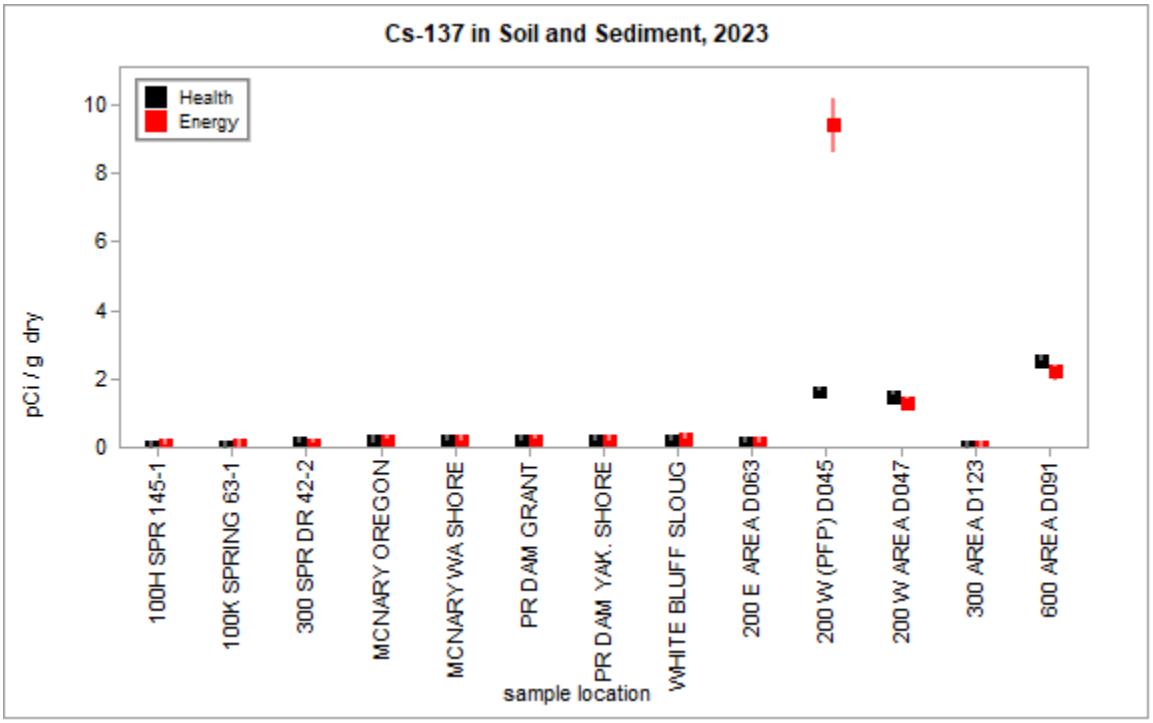


Figure 3.4.7 Cs-137 Low Concentrations in Soil and Sediment

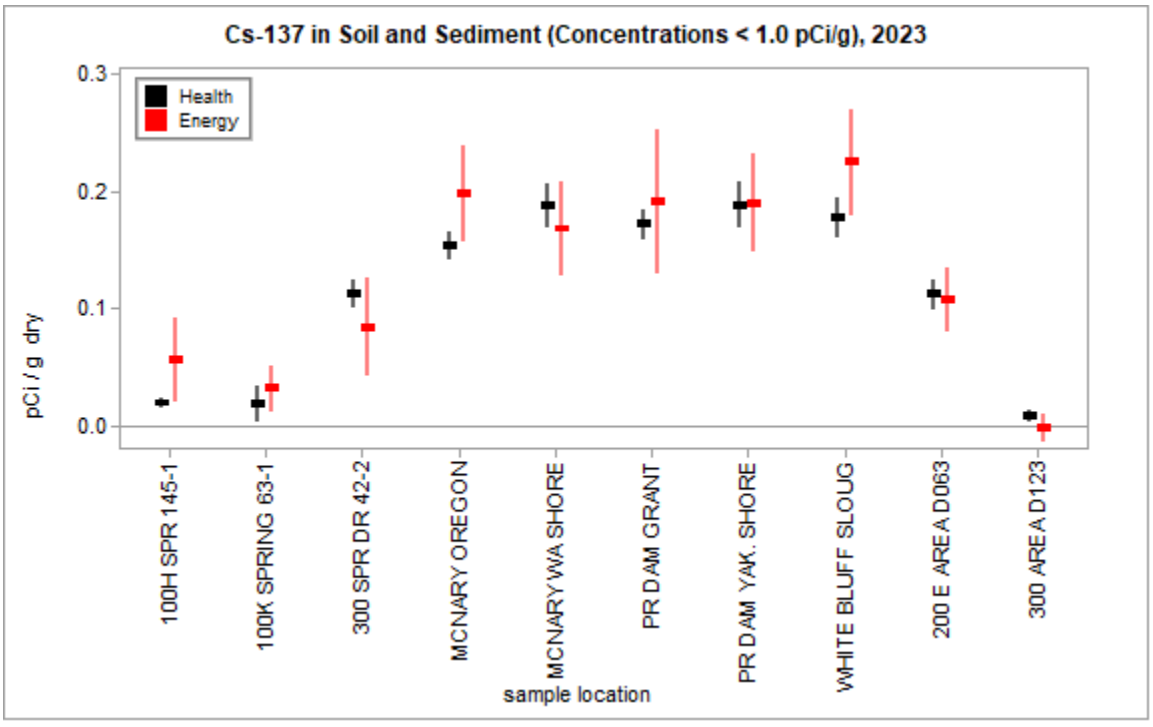


Figure 3.4.8 Cs-137 High Concentrations in Soil

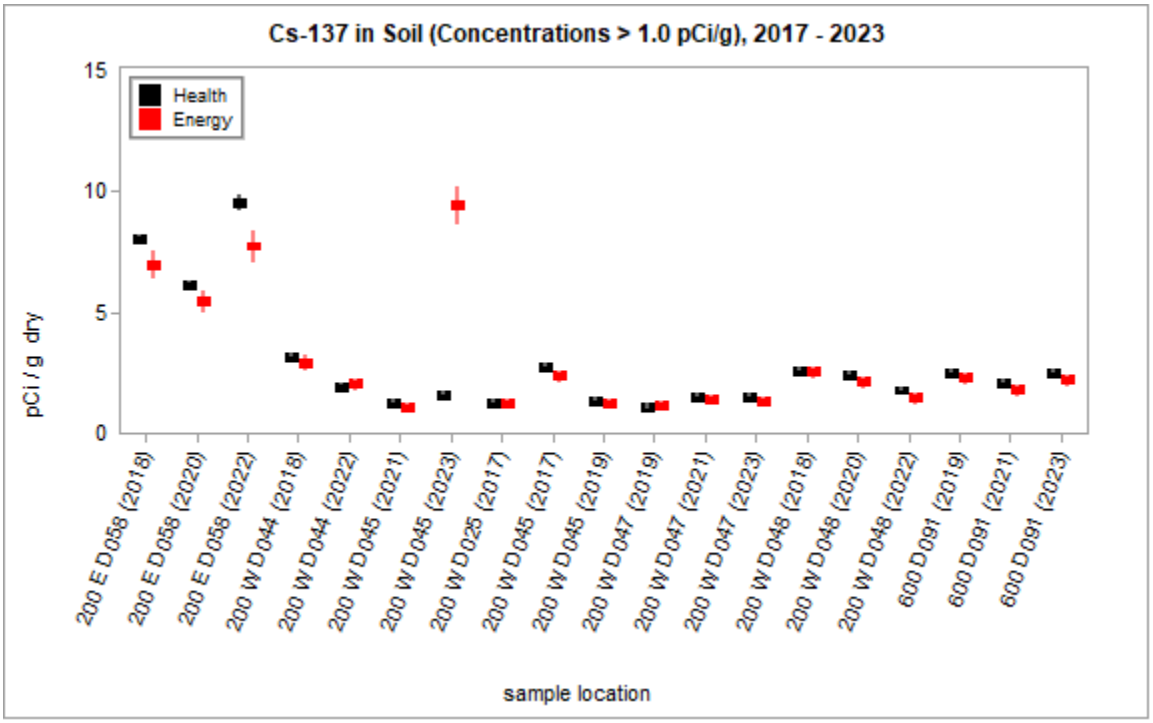


Figure 3.4.9 Pu-238 Concentrations in Soil and Sediment

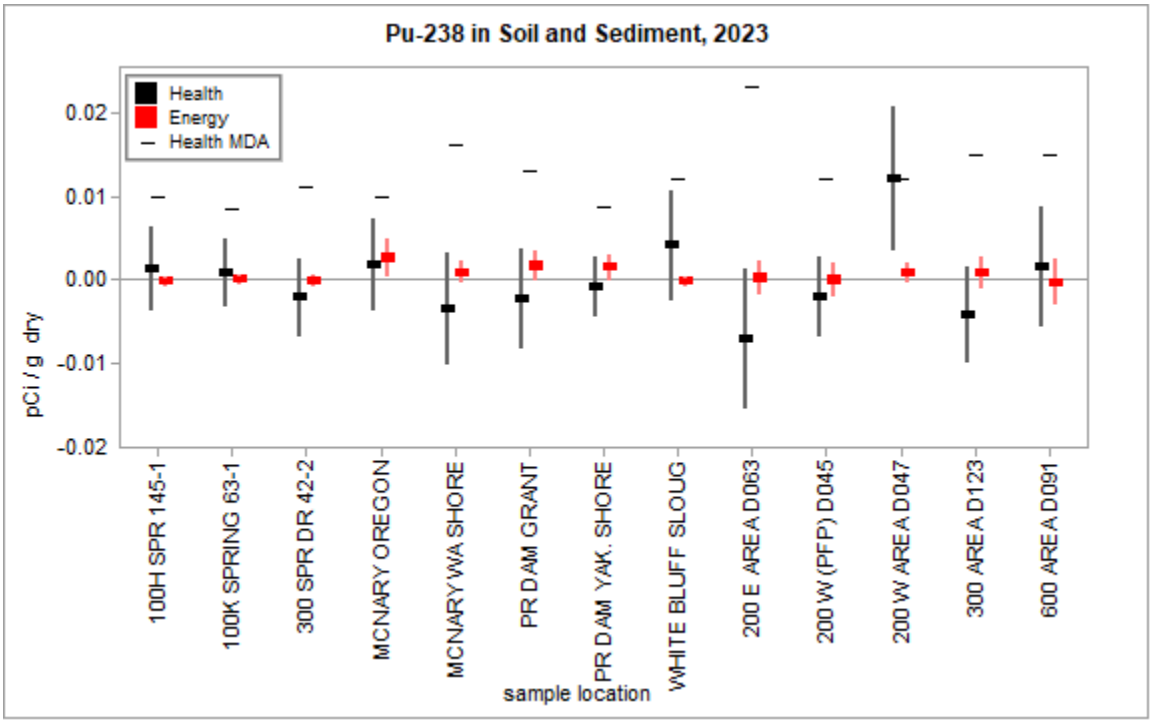


Figure 3.4.10 Pu-239/240 Concentrations in Soil and Sediment

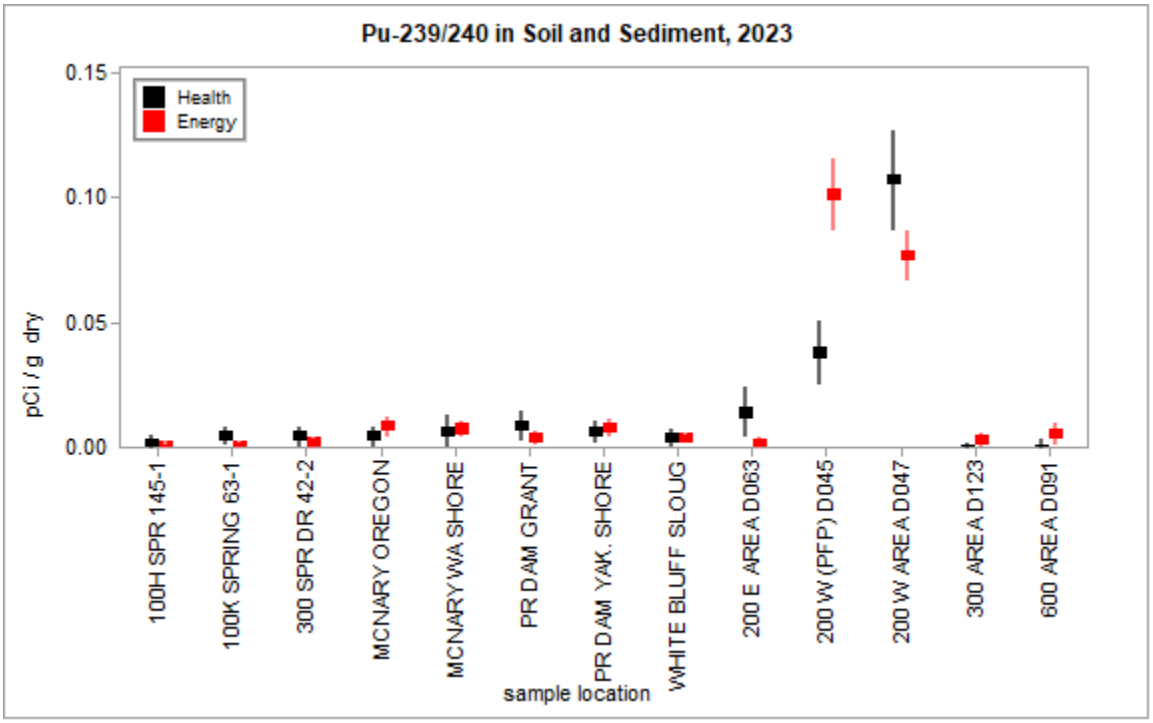


Figure 3.4.11 Pu-239/240 Low Concentrations in Soil and Sediment

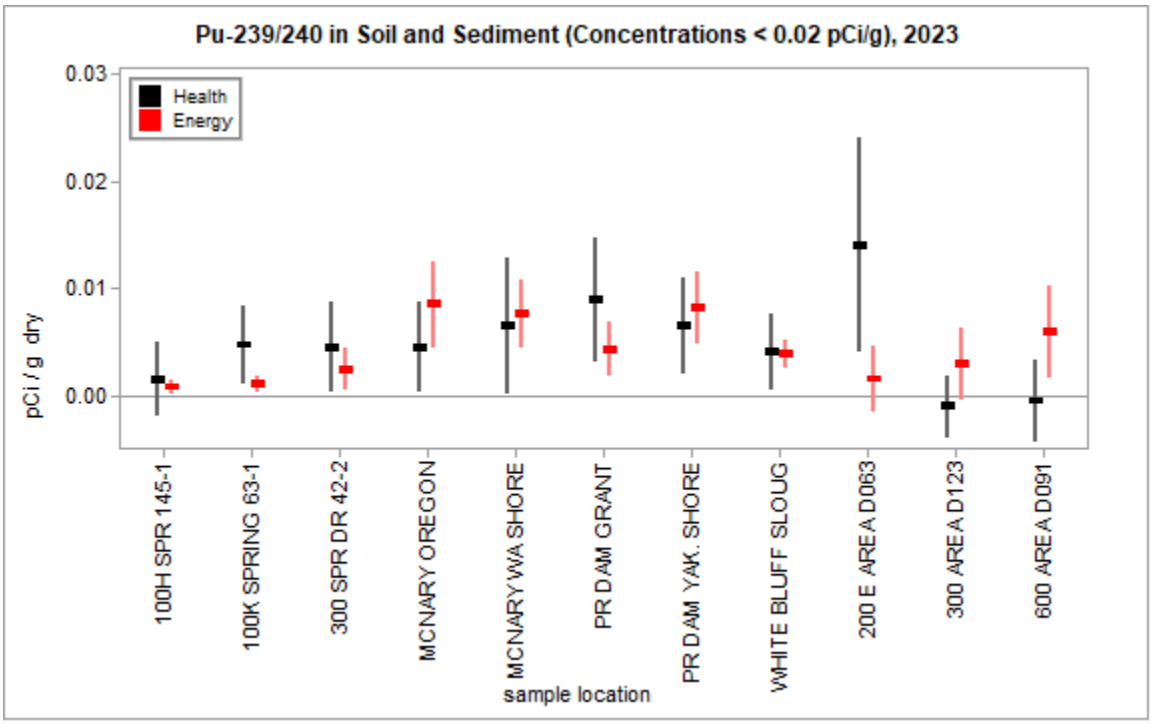


Figure 3.4.12 Pu-239/240 High Concentrations in Soil

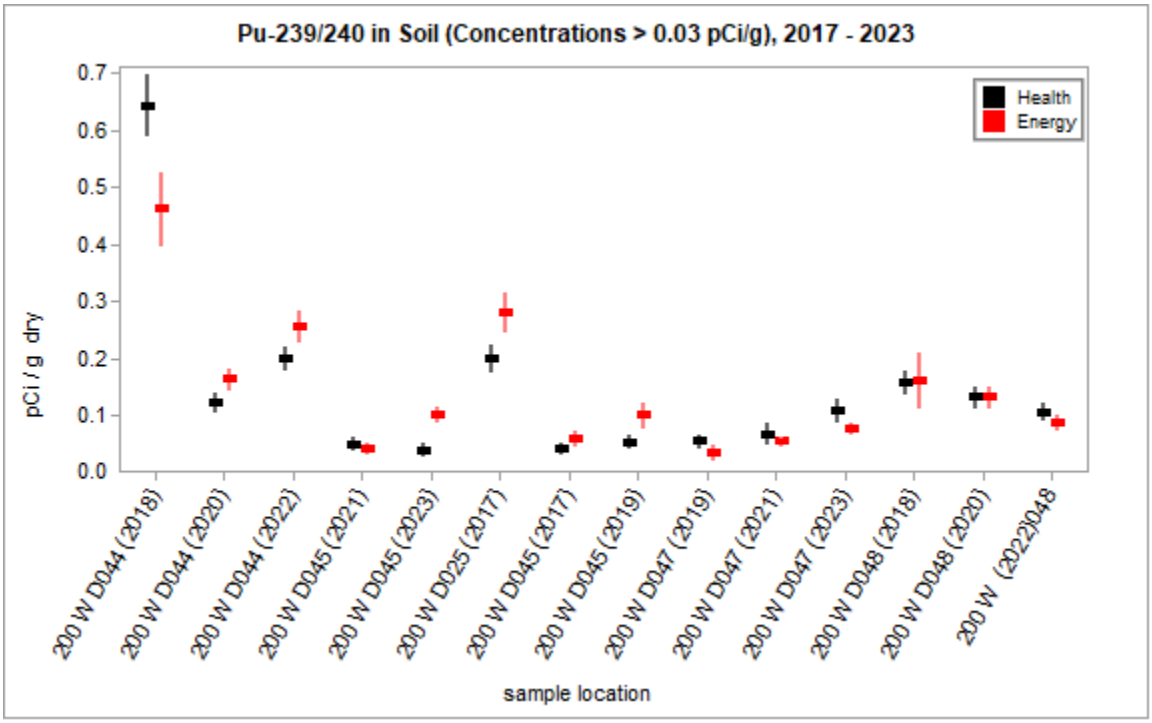


Figure 3.4.13 Sr-90 Concentrations in Soil and Sediment

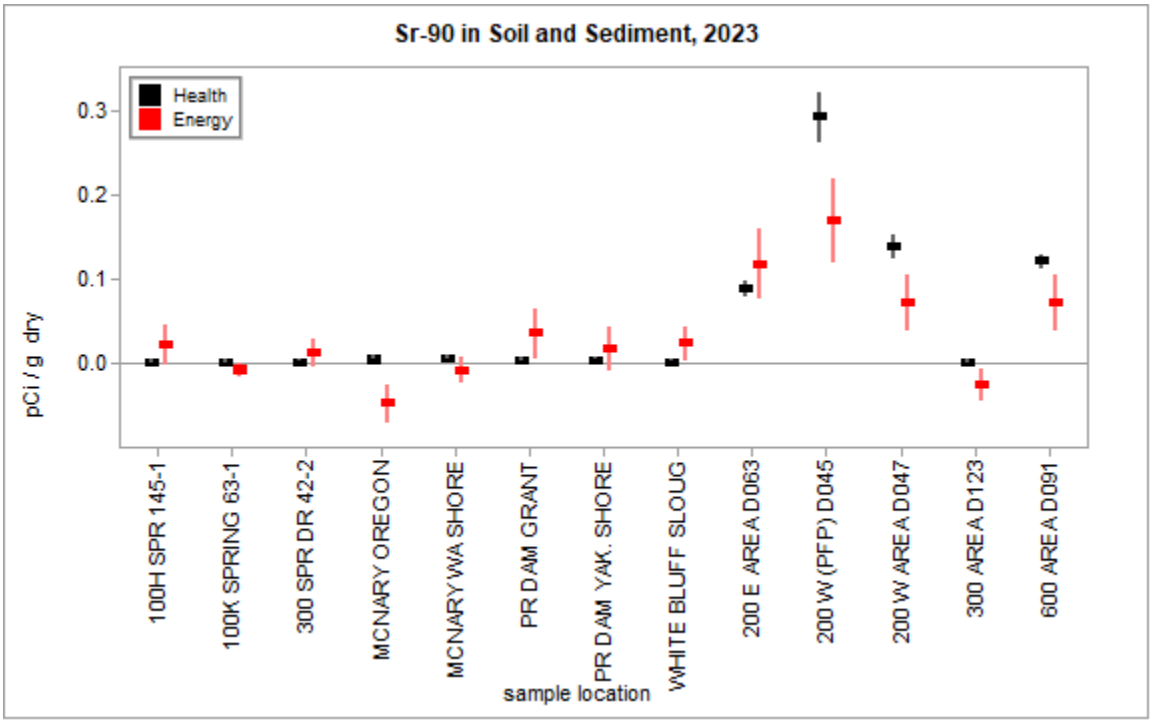


Figure 3.4.14 Sr-90 Higher Range Concentrations in Soil

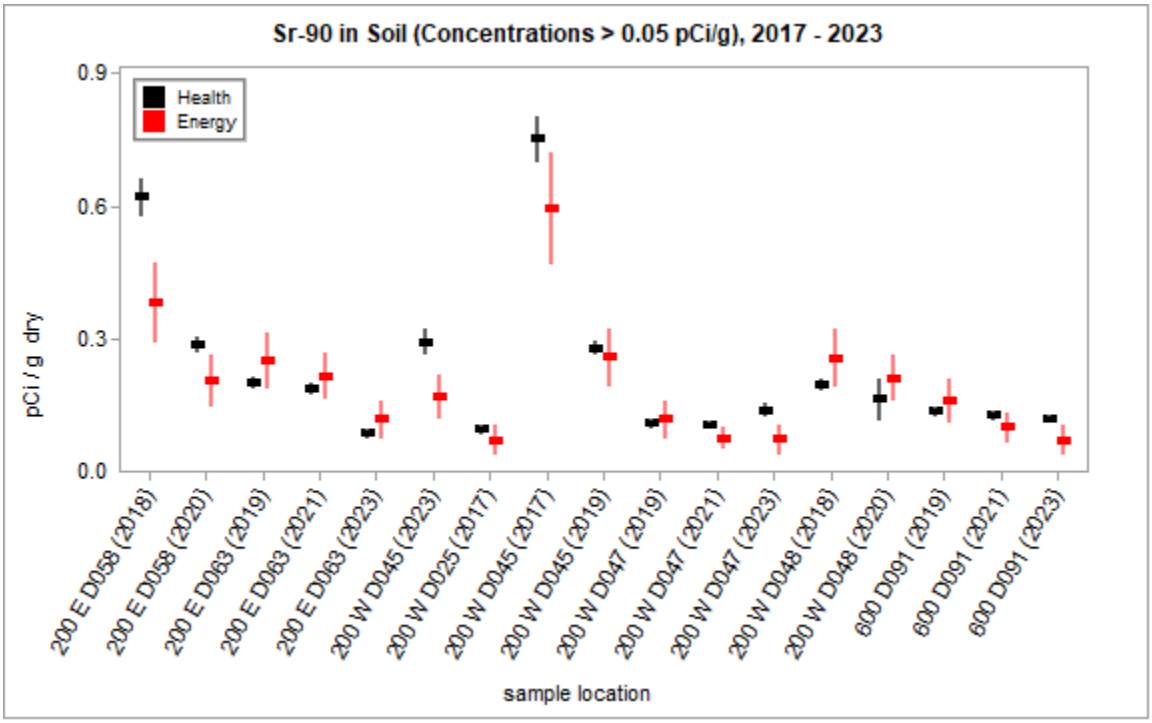


Figure 3.4.15 U-238 Concentrations in Soil and Sediment

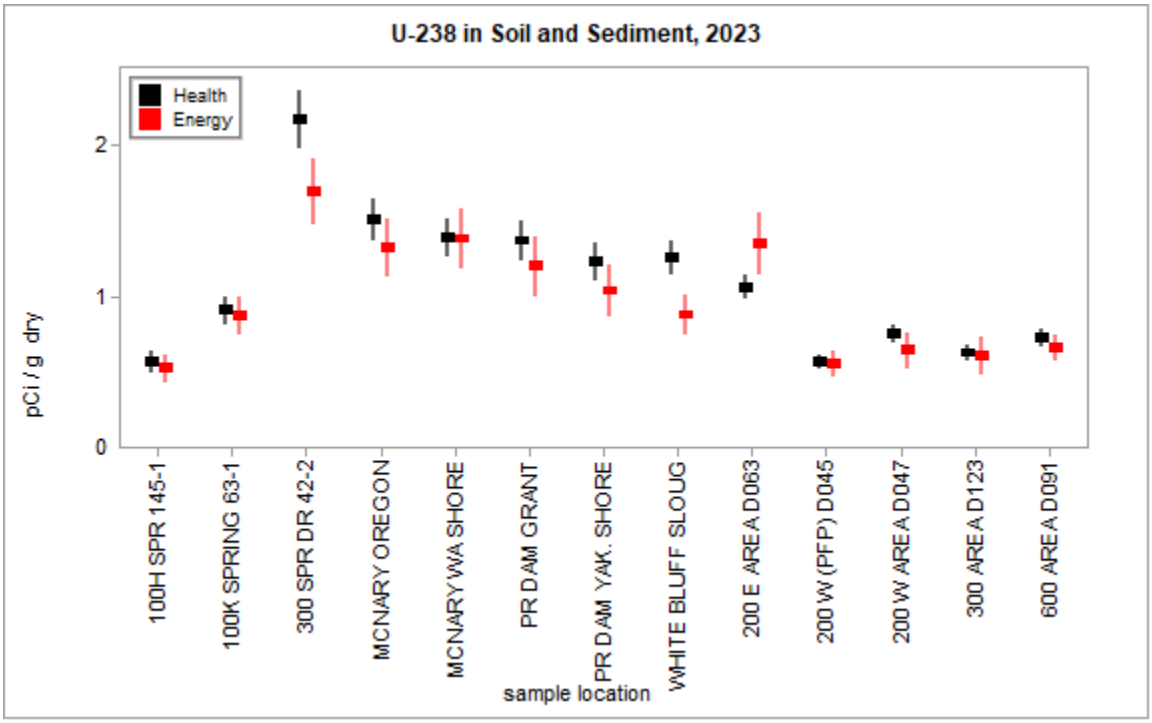


Figure 3.4.16 U-236 Concentrations in Sediment at 300 SPR DR 42-2

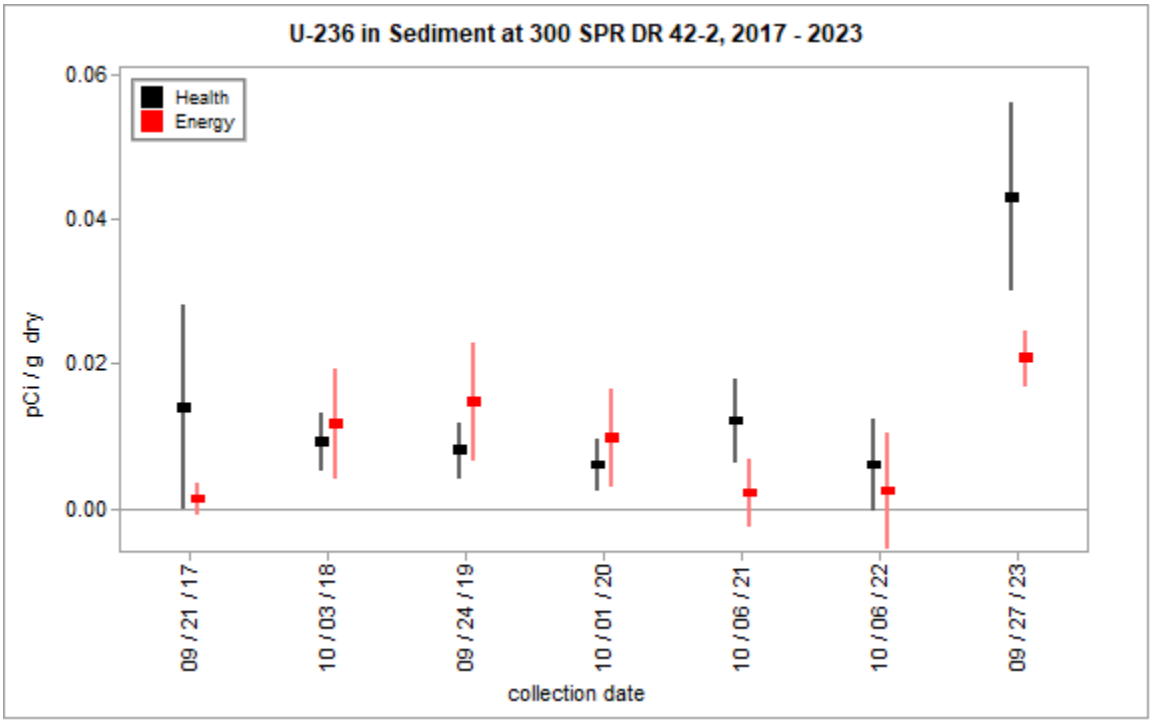


Figure 3.4.17 Sr-90 Concentrations in Sediment at River Dams

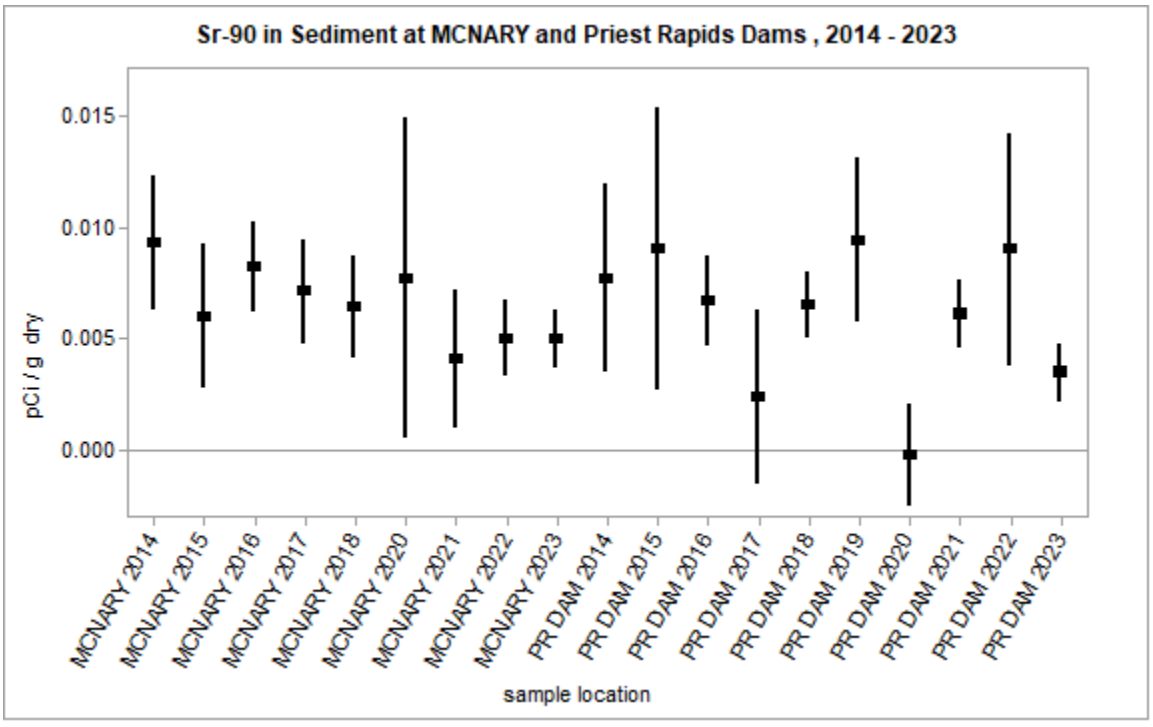
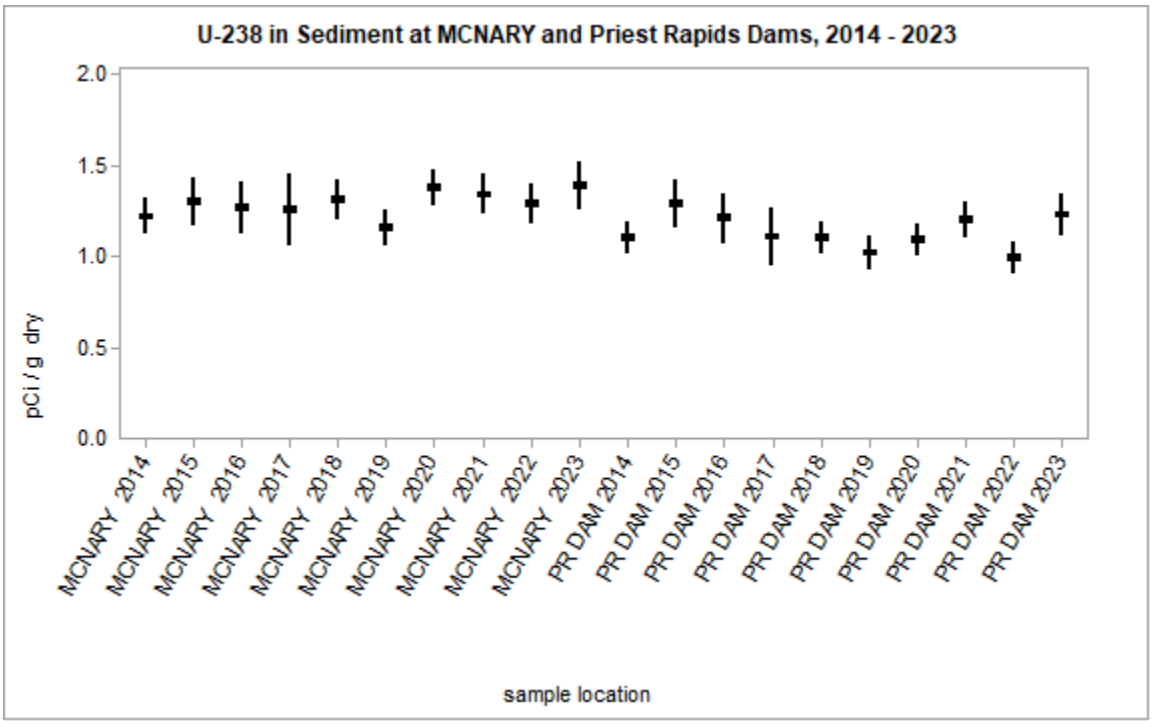


Figure 3.4.18 U-238 Concentrations in Sediment at River Dams



3.5 Biota Monitoring

Major Findings:

- Most Health and Energy radionuclide concentrations are in good agreement. The agreement for Sr-90 in biota samples is fair, and the agreement for C-14 and H-3 in wine is poor.
- Most Health radionuclide concentrations are below detection limits. Tritium (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. Hanford contaminants may transfer to vegetation via airborne deposition, soil to plant transfer, and water to plant transfer.

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. Hanford contaminants may transfer to vegetation via 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

Farm product samples include three cherry samples, three corn samples, one leafy vegetable sample, two melon samples, two potato samples, and four 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 walleye and one whitefish from the 100 Area, and one walleye from the 300 Area. Game birds include two geese: one from the 100 Area and one from the 300 Area. Wildlife includes one elk from the 200 Area.

Five vegetation samples were collected on the Hanford Site: two rabbit brush samples from the 200 Area and one from the 300 Area, and one sage brush sample from the 200 Area and one from the 600 Area. 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).

The text following the table discusses 1) cases in which the agreement between Health and Energy data is not good (i.e. is fair or poor), 2) cases in which some of the Health data are anomalous compared to historical results, or 3) other data topics of interest.

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	< 0.001	no
C-14	annual	6	good	< 1.0	no
Co-60	annual	23	good	< 0.04	no
Cs-134	annual	23	good	< 0.04	no
Cs-137	annual	23	good	< 0.04	no
Eu-152	annual	23	good	< 0.1	no
Eu-154	annual	23	good	< 0.1	no
Eu-155	annual	23	good	< 0.1	no
Pu-238	annual	9	good	< 0.001	no
Pu-239/240	annual	9	good	< 0.0008 to 0.001	no
Sr-90	annual	25	**fair**	< 0.004 to 1.1	no
U-234	annual	8	good	< 0.0004 to 0.014	no
U-235	annual	8	good	< 0.0008 to 0.0015	no
U-238	annual	8	good	< 0.0003 to 0.014	no

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	4	**poor**	< 140 to 1,700	no
Co-60	annual	4	good	< 10	no
Cs-134	annual	4	good	< 10	no
Cs-137	annual	4	good	< 10	no
Eu-152	annual	4	good	< 30	no
Eu-154	annual	4	good	< 30	no
Eu-155	annual	4	good	< 30	no
H-3	annual	4	**poor**	< 84 to 150	no

Health and Energy concentrations in split biota samples are in good agreement for all radionuclides listed in Table 3.5.1, except for Sr-90 where the results are in fair agreement. Most results are below detection limits, while a few samples have detectable concentrations of Pu-239/240, U-234, U-235, and U-238 that are consistent with historical results and in many cases only slightly above detection limits.

Figure 3.5.1 shows the Pu-239/240 results in elk, fish, and vegetation, where all results are in good agreement and either below the sample specific detection limit or only slightly above the sample specific detection limit.

Figure 3.5.2 shows the Sr-90 results for concentrations less than 0.5 pCi/g in fish, farm products, game birds, and vegetation. Several of the samples had detectable concentrations of Sr-90. While most of the Sr-90 data are in good agreement, several of the detectable results had a relative percent difference (RPD, see Section 2.2.4.3) greater than 33%, resulting in fair agreement for the set of Health and Energy results. For the elk sample collected from the 200 E Area (not shown in Figure 3.5.2), Energy reported a Sr-90 concentration of 0.06 pCi/g while Health reported 1.1 pCi/g, resulting in poor agreement for this sample.

Figure 3.5.3 shows the U-234 results in fish and vegetation, where all results are in good agreement and either below the detection limit or only slightly above the detection limit. The data for U-235 and U-238 are similar. Note that U-234 concentrations in 200 and 300 Area vegetation are similar to those at the background location in the 600 Area.

All the Health and Energy concentrations for gamma emitting radionuclides in split wine samples (Table 3.5.2) are in good agreement, and all results are below detection limits.

Health undertook the analysis of wine samples for C-14 in 2021. Figure 3.5.4 shows the C-14 results in wine. All the Energy results are flagged as undetected, with a detection limit of 275 pCi/L while Health's results suggest activity in one sample detected above an apparent MDA of 650 pCi/L. As a reference, drinking water standard for C-14 is 2,000 pCi/L.

Analyzing C-14 in wine poses a significant challenge due to the presence of other beta emitters including tritium which are difficult to distinguish spectroscopically using liquid scintillation counting. Health recognizes these challenges and will continue to investigate improvements.

Figure 3.5.5 shows the H-3 (tritium) results in wine, in which both Health and Energy report low concentrations of tritium. Energy reports results in the range from 13 to 106 pCi/L, with a detection limit of 6 pCi/L. Health reports results in the range from 84 to 150 pCi/L, with a detection limit of 60 pCi/L. Some of the historical results for H-3 in wine samples are shown in Figure 3.5.6, where the agreement is poor. For both the 2023 and historical results, more than one-third of the data have a relative percent difference greater than 33%.

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 and Energy have historical data for Pu-239/240 concentrations in vegetation collected from background locations, which include the cities of George, Othello, and Wanapum. These background data are shown in Figure 3.5.7, where all results are flagged as not detected. Figure 3.5.1 shows the 2023 results for the five vegetation samples collected on the Hanford Site. Energy's result at V047 is considered an estimated value wherein the result/precision may have been impacted by minor quality control factors. Other Energy results are flagged as not detected. Health's vegetation result at V045 is detected slightly above the detection limit, (Note: the soil sample from the same location also had detectable Pu-239/240), while all other Health results are not detected. Analysis of the 2023 onsite results to historical background results indicates that most onsite results are consistent with the non-detect background data.

Figure 3.5.1 Pu-239/240 Concentrations in Biota

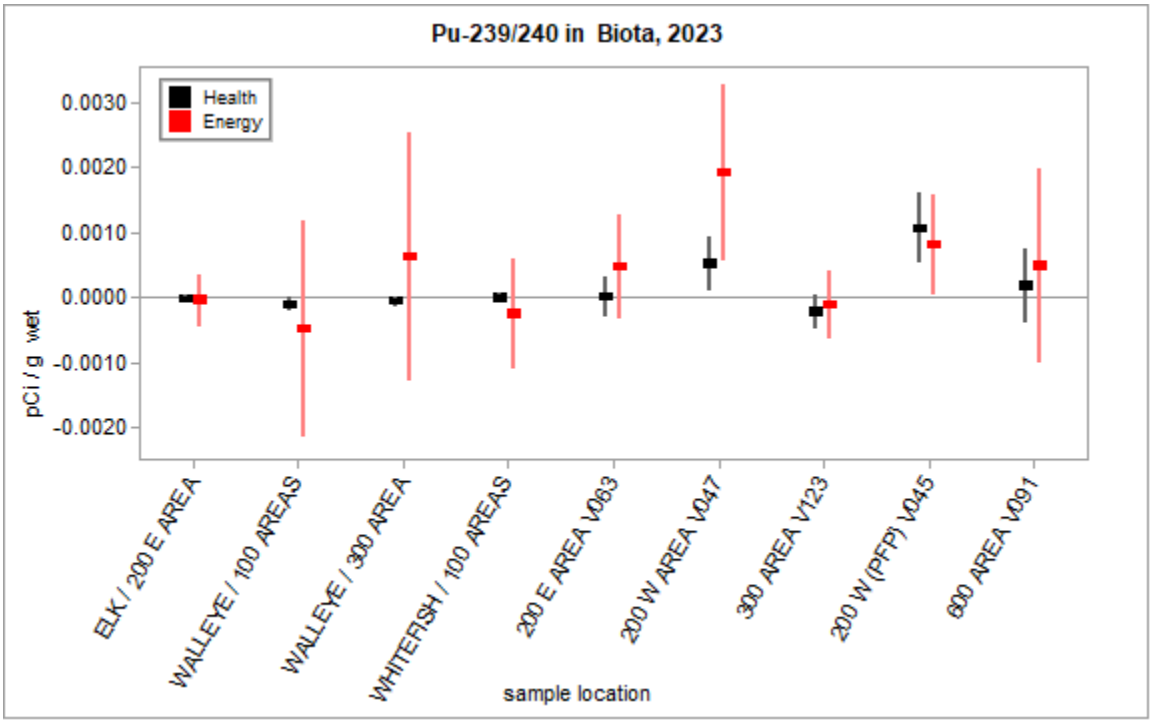


Figure 3.5.2 Sr-90 Concentrations in Biota

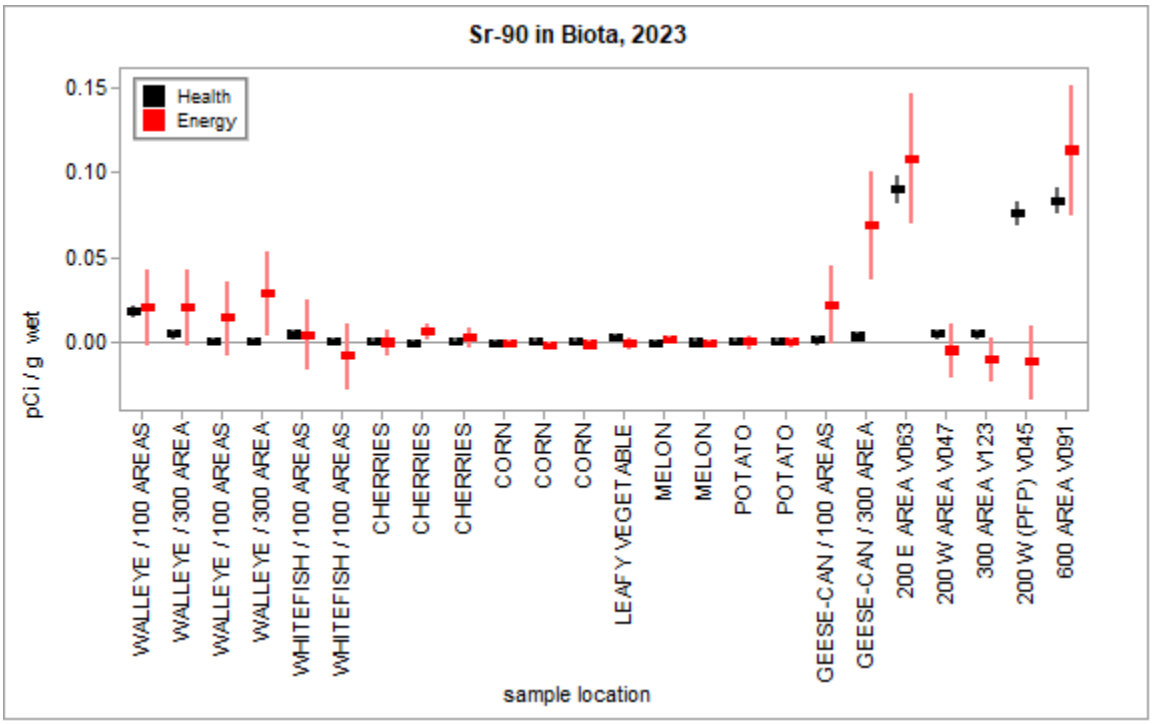


Figure 3.5.3 U-234 Concentrations in Biota

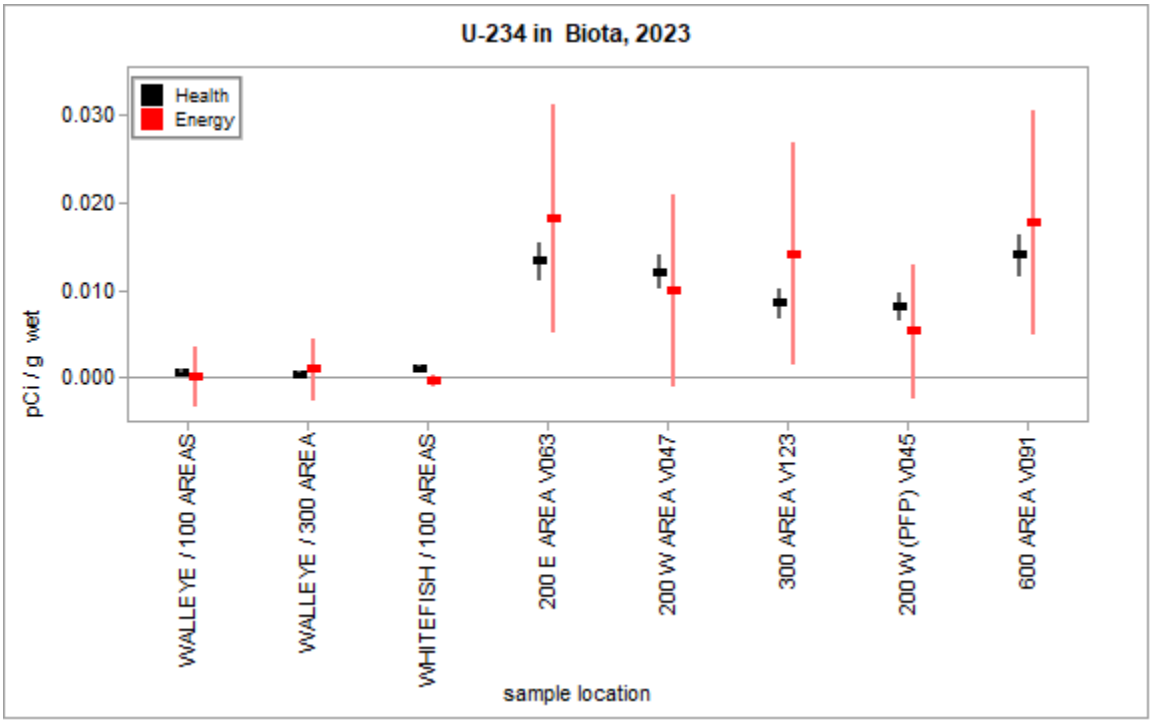


Figure 3.5.4 C-14 Concentrations in Wine

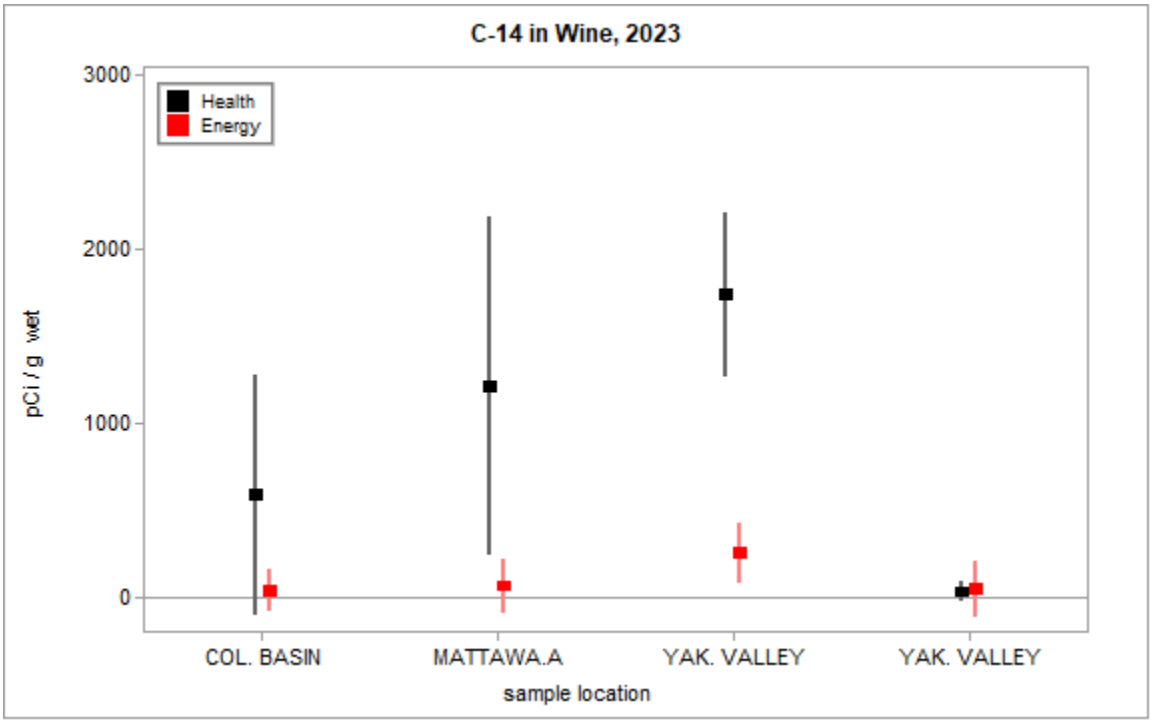


Figure 3.5.5 H-3 Concentrations in Wine

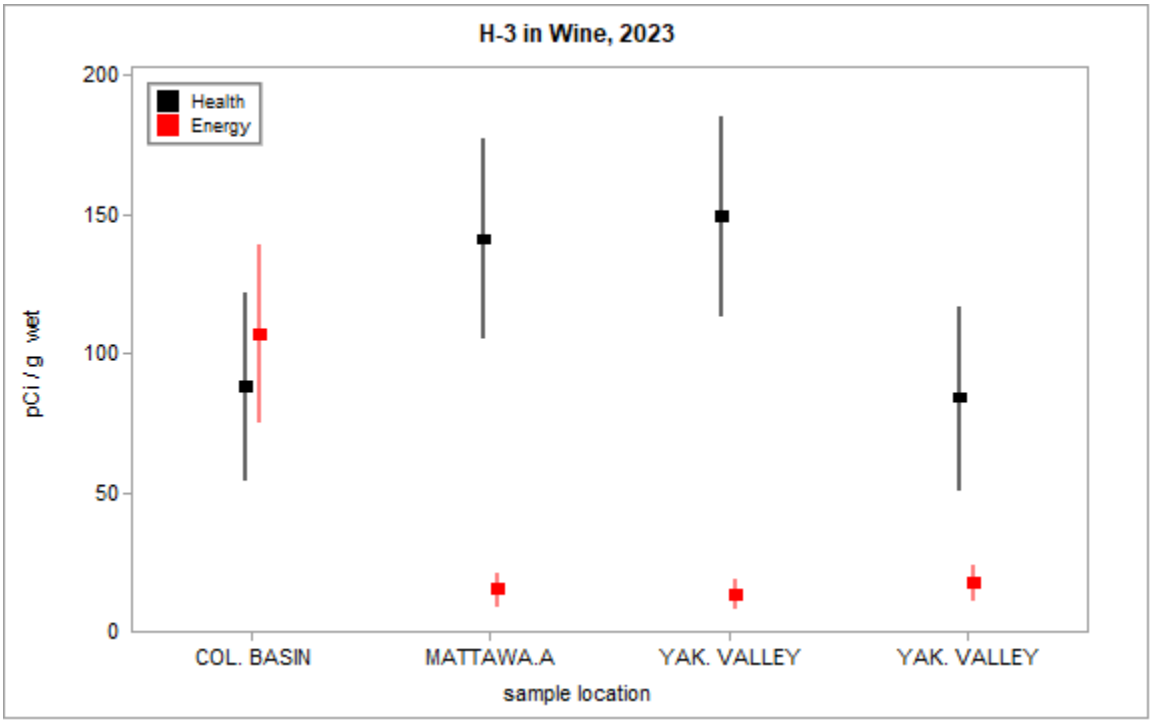


Figure 3.5.6 – H-3 Historical Concentrations in Wine

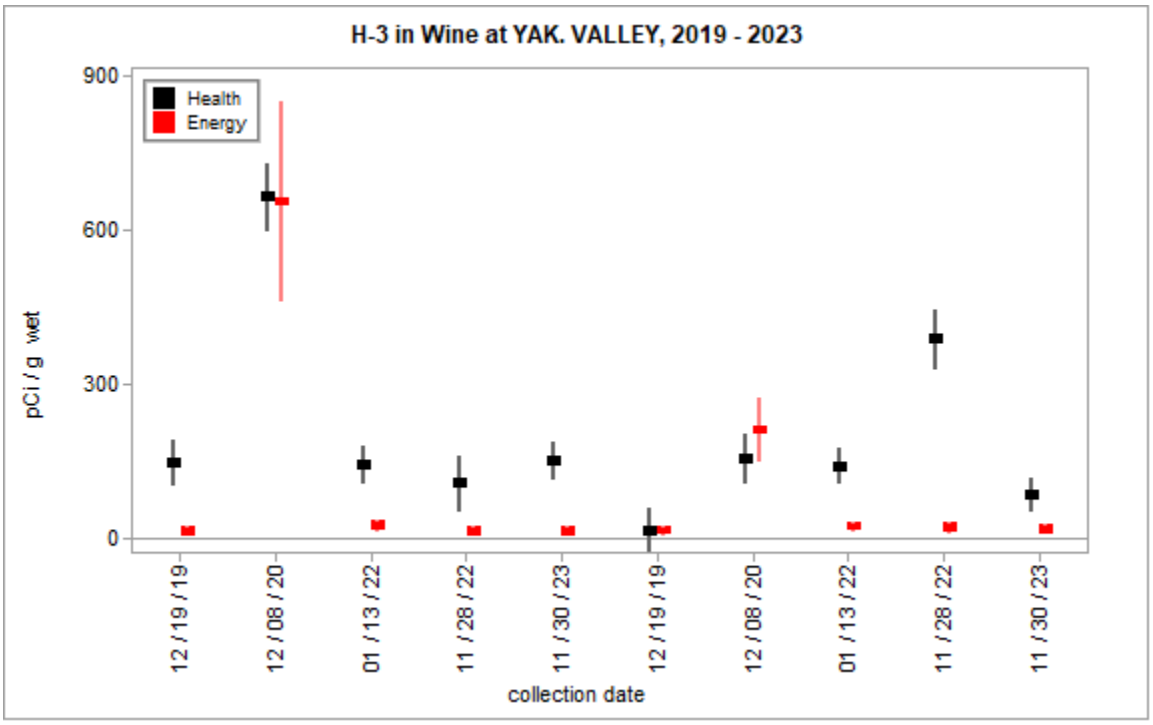
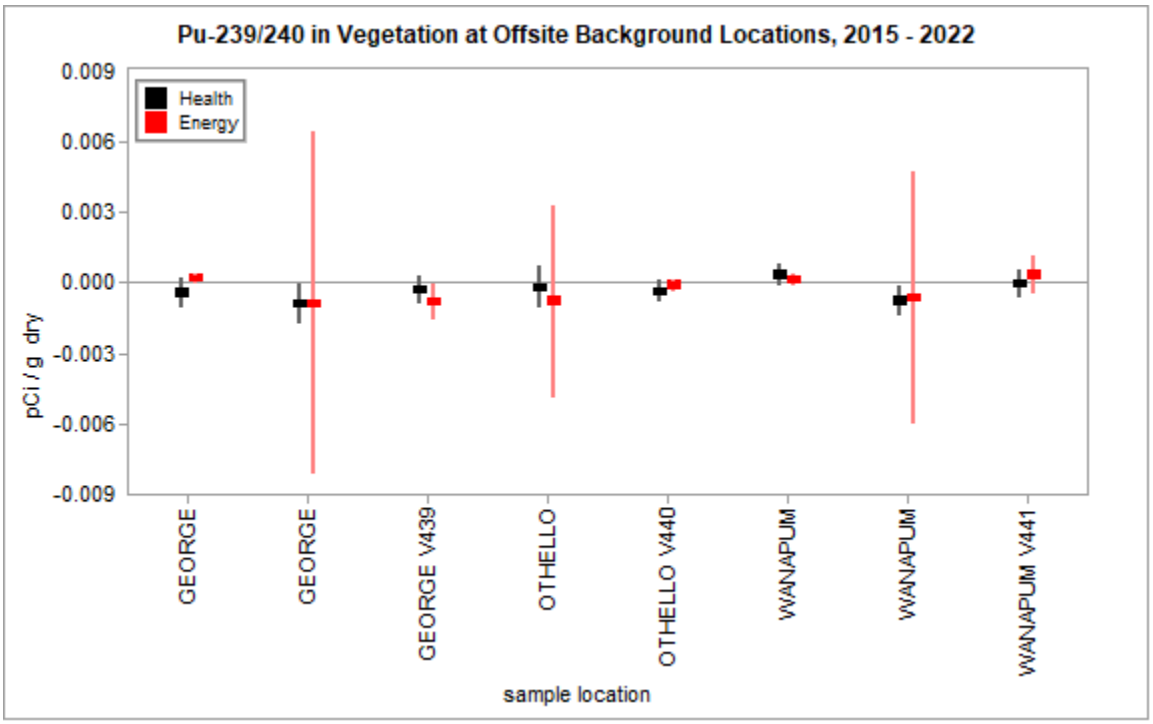


Figure 3.5.7 – Pu-239/240 Background Concentrations in Vegetation



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 summarizes results with fair or poor agreement, and 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 gross alpha results in air samples are in fair agreement because of the many instances where Health reports higher concentrations than Energy. 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 gross beta results in air samples are in poor agreement because of the many instances where Health reports lower concentrations than Energy. The data are similar and follow the same trends over time, but the concentrations reported by Health are systematically less than those reported by Energy. 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) results in air samples are in fair agreement. Historically, the agreement ranges from good to fair to poor. Significant differences between the Health and Energy concentrations occur, where Energy often reports 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/m^3, while Health's detection limit, normally in the range of 1pCi/m^3, 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 and Energy C-14 results in water samples are in poor agreement. 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 alpha results in water samples are in fair agreement, while gross beta results are in poor agreement for the same media. In both cases, when concentrations are in the lower range, the agreement is good; however, when concentrations are in the higher range, Health often reports higher concentrations than Energy. This trend is consistent with historical results. The same issues described about the measurement of gross alpha and 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 results in water samples are in poor agreement, and Pu-238 and Pu-239/240 results are in fair agreement. These comparisons are based on a small number of samples (only 5 samples for each analysis) with only a few detectable results.

Health and Energy external radiation exposure rates are in fair agreement. Health reports radiation rates lower than those reported by Energy. Interestingly, in some years it is the opposite, in which Health reports radiation rates higher than those reported by Energy.

Health and Energy Sr-90 results in soil and sediment are in fair agreement. The agreement is good at lower concentrations, but is poor for higher concentration data, resulting in an overall fair agreement. Health often reports higher concentrations than Energy in the range of data with higher concentrations.

Health and Energy U-234 and U-238 results in soil and sediment samples are in good agreement for samples collected in 2023. Historically however, the agreement is often fair, in which the results follow the same trend, but there is a systematic bias in which Health reports higher concentrations than those reported by Energy. Historically, Energy's U-234 and U-238 concentrations can differ by as much as one-half of the value reported by Health.

Health and Energy Sr-90 results in biota samples are in fair agreement. For several samples, either Health or Energy detected Sr-90 while the other agency did not. This could be due to sample error, as discussed above for air samples, as biota samples are often collocated as opposed to split samples.

The Health and Energy C-14 and H-3 samples in wine are in poor agreement. Health will investigate this discrepancy and will discuss findings in a future report.

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/m^3)

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

Air Filter (pCi/m^3)

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

Quarterly Composite Air Filter (pCi/m^3)

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

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

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

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

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

Food (pCi/g)

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

Milk (pCi/l)

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

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

Milk (pCi/l)

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

Meat (pCi/g)

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

Shellfish (pCi/g)

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

Soil/Sediment (pCi/g)

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

Soil/Sediment (pCi/g)

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

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

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

Water (pCi/l)

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

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

Water (pCi/l)

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

*LLD for Air Cartridge is 3 days

METHOD

Preparation Methods

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

Counting Methods

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

Appendix C - Formulas

A. **Random Uncertainty**

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

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

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

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

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

D. **Definitions**

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

T_1	=	sample count time
T_2	=	background count time
$T_{1/2}$	=	half-life of radionuclide counted
U	=	uncertainty (standard error) of the sample mean
V	=	volume in liters (or mass in grams) of sample
Y	=	fractional radiochemical yield (when applicable)

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

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

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

Where:

q = sample volume

k = 3.7E+07 (Bq/pCi)

E = Efficiency

abn = gamma ray abundance

T = Live time in seconds

e^ = natural log raised to the power of…

Tr = elapsed real time in seconds

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

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

Appendix D - Glossary of Terms

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 *a posteriori* determination of the activity level in a sample where there a 5% probability of making type I and type 2 errors
Optically Stimulated Luminescence (OSL)	A radiation monitoring device used to measure accumulated ambient radiation dose OSLs are similar to the thermoluminescence dosimeters, TLDs, but use light rather than heat to release the stored energy and measure the dose of ionizing radiation received.
pCi (picocurie)	10^{-12} curies (one trillionth of a curie)
Quality Assurance	All those planned and systematic actions necessary to provide adequate confidence that a facility, structure, system, or component will perform satisfactorily and safely in service.
Quality Control	A component of Quality Assurance; comprises all those actions necessary to control and verify that a material, process, or product meets specified requirements.
Quality Factor (Q)	A numerical factor assigned to describe the average effectiveness of a particular kind (and sometimes energy) of radiation in producing biological effects on humans.
mR	Milliroentgen, one thousandth of a Roentgen
Rad	The special unit of absorbed dose. It is a measure of the energy absorbed per mass of material. One rad is equal to an absorbed dose of 0.01 J kg^{-1} (1 rad = 0.01 gray).

Radioactivity	The process of undergoing spontaneous transformation of the nucleus, generally with the emission of alpha or beta particles, often accompanied by gamma rays. The term is also used to designate radioactive materials.
Radioisotope	A radioactive isotope; i.e., an unstable isotope that undergoes spontaneous transformation, emitting radiation. Approximately 2500 natural and artificial radioisotopes have been identified.
Radionuclide	A radioactive nuclide.
Rem	The special unit of dose equivalent. The dose equivalent in rem is equal to the absorbed dose in rad multiplied by a quality factor that accounts for the biological effect of the radiation (1 rem = 0.01 sievert).
Replicate Sample	Two or more samples from one location that are analyzed by the same laboratory.
Roentgen	A unit of exposure to ionizing radiation. It is that amount of gamma or x-rays required to produce ions carrying 1 electrostatic unit of electrical charge in 1 cubic centimeter of dry air under standard conditions. Named after Wilhelm Roentgen, German scientist who discovered x-rays in 1895.
Split Sample	A sample from one location that is divided into two samples and analyzed by different laboratories.
TLD	Thermoluminescent Dosimeters
X-Ray	Electromagnetic waves or photons emitted from the outer shell of the atom instead of the nucleus. They have no charge and are best shielded by thick layers of lead or steel. X-Ray energy may cause an external or internal radiation hazard.

Appendix E – List of Analytes

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