# Soil Sampling Techniques

# For Hanford Nuclear Clean Up

# And Environmental Studies

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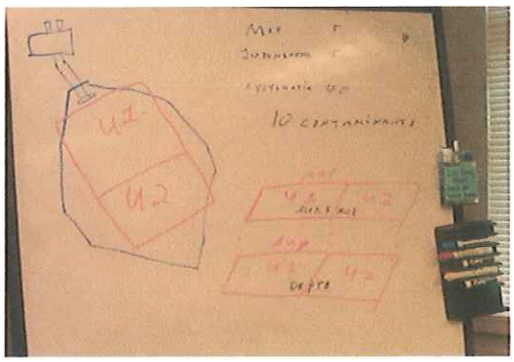
# 2010 U1 and U2 Soil Sampling Techniques

## Hanford, Washington

In this analysis, I will compare for Hanford, three different soil sampling methods. The sampling methods I will be comparing are Incremental Sampling Method (MIS), Judgmental Sampling, and Systematic Sampling. I will be analyzing two areas of the site where soil was taken from. These areas are called U1 and U2. The soil at U1 and U2 is considered contaminated. Soil samples were taken in May 2010, contaminated soil was removed, and the area was sampled again in August of 2010.




It is not practical to collect and analyze the entire plot of soil for which we need to base our decision. Samples of the entire population (soil in U1 and U2) were collected for analyses to represent that entire volume of land. The cost associated with analyzing data can be high. For this reason, I will be analyzing the data given to determine the best sampling method to use.

**Incremental Sampling Methodology (MIS)** was developed to address some of the limitations mentioned above. MIS is a composite sampling approach where many (between 30 and 100) equal-mass increments are collected and combined in an unbiased manner from throughout the entire area of the soil/volume of interest. Once the combined increments are processed at the laboratory, a subsample is taken and analyzed.

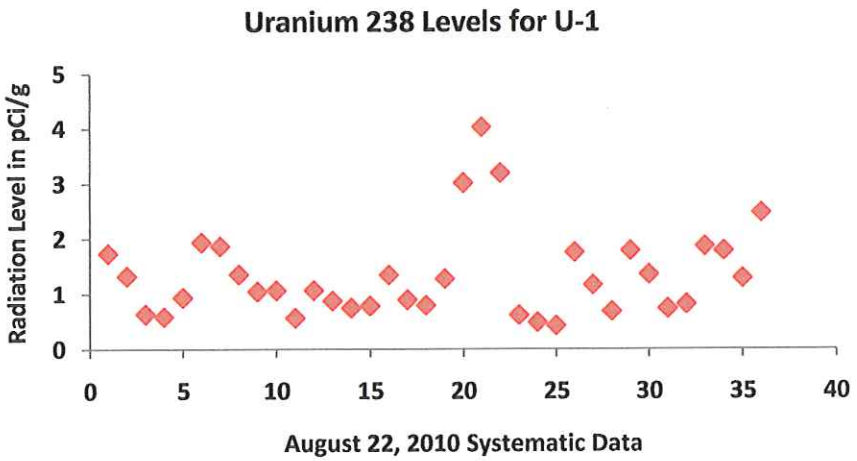
**Judgmental Sampling** is used when only a few discrete samples are collected. The number of samples collected is determined by negotiation, budget, professional judgment, or happenstance. The number of samples is often not based on statistical or other scientific rationale, and the location of the samples is often judgmental. Judgmental sampling plans are effective when source areas or migration pathways of high concentrations are being investigated.

**Systematic Sampling** requires that the area of interest be divided up into a number of grids and then a random sample is taken from each and analyzed from within each of the grids. The combined results are used to represent the area of concern. The number of samples for this type of analysis may be quite large.

# Graphing and Summarizing Data

## 1. Graphic Investigation of U-238

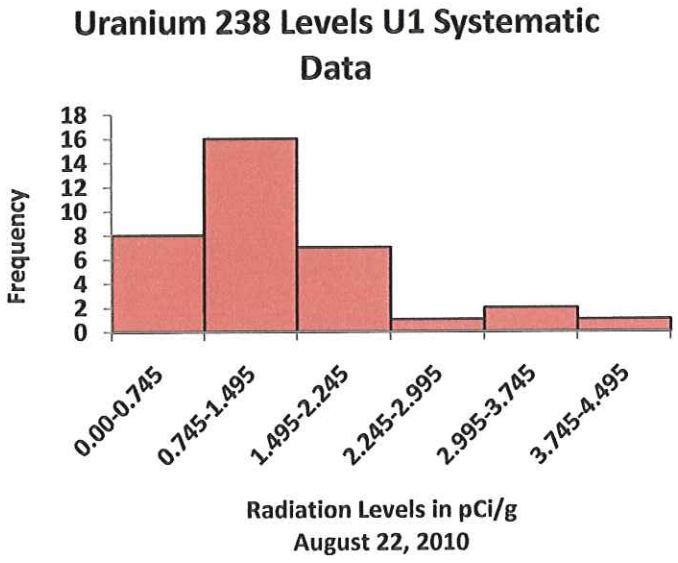
Initially the scatter plot below of the U-238 systematic data for area U1 collected August 22, 2010 was constructed to investigate the radiation levels of this element that were present at the time the sample was collected. This plot also demonstrates the heterogeneity (or homogeneity) of this radioactive element in area U1.




Further analysis of the isotope U-238 was conducted using the same systematic data from August 22, 2010. This analysis is summarized in the Frequency Table and Histogram presented below.

**Uranium 238 Area U1**

| Radiation Levels | Frequency |
|---|---|
| 0.00-0.74 | 8 |
| 0.75-1.49 | 16 |
| 1.50-2.24 | 7 |
| 2.25-2.99 | 1 |
| 3.00-3.74 | 2 |
| 3.75-4.49 | 1 |



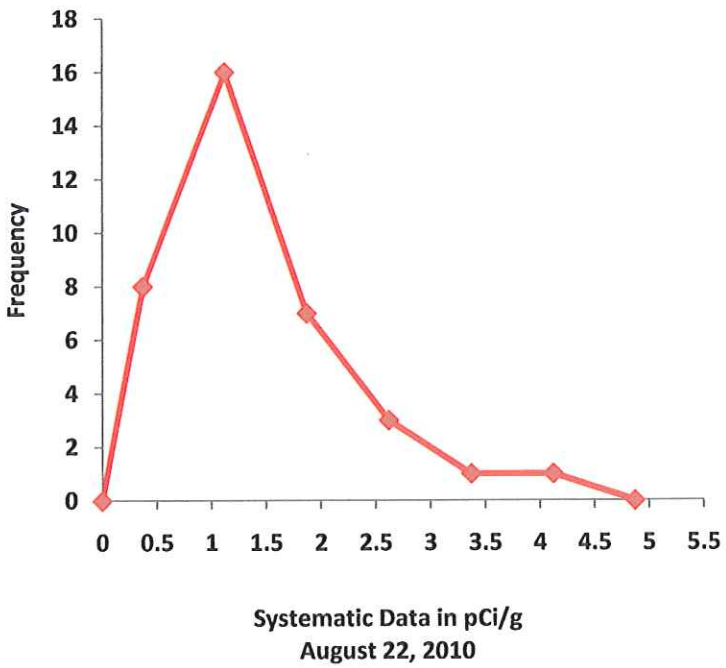
After examining the systematic data included in the charts on the previous page, it appears that the radiation levels of Uranium 238 that were taken on August 22, 2010 are fairly heterogeneous. Radiation levels are clearly higher in some areas than in others, as shown in both the scatter plot and the histogram. This does not appear to be a normal distribution, as it is skewed to the right.

## 2. Graphic Investigation of U-233/234

The Frequency Polygon pictured below was used to illustrate the radiation levels of the isotope U-233/234 from the systematic data for area U1 collected August 22, 2010. The graph was constructed using the class midpoints for the frequency distribution below. This graph also shows the nature of the distribution of this element in area U1 at the time it was collected.

**Uranium 233/234 Area U1**

| Radiation Levels In pCi/g | Frequency |
|---|---|
| 0.00 - 0.74 | 8 |
| 0.75 – 1.49 | 16 |
| 1.50 – 2.24 | 7 |
| 2.25 – 2.99 | 3 |
| 3.00 – 3.74 | 1 |
| 3.75 – 4.49 | 1 |




The radiation levels of Uranium 233/234 in area U1 on August 22, 2010 appear to be heterogeneous. There is clearly a spike in the Frequency polygon, indicating that there are higher radiation levels in some areas. This does not look like a normal distribution, as the graph is skewed to the right.

## 3. Comparison of U-238 and U-233/234

The frequency distributions for Uranium-238 and for Uranium 233/234 are quite similar. Both element distribution shapes are skewed to the right. In conclusion, it appears that using systematic sampling for the data collected on August 22, 2010 in area U1, the amounts of all elements graphed above are consistent with each other. These amounts are, of course, not exactly the same, but there is nearly the same amount of each element in the given samples.

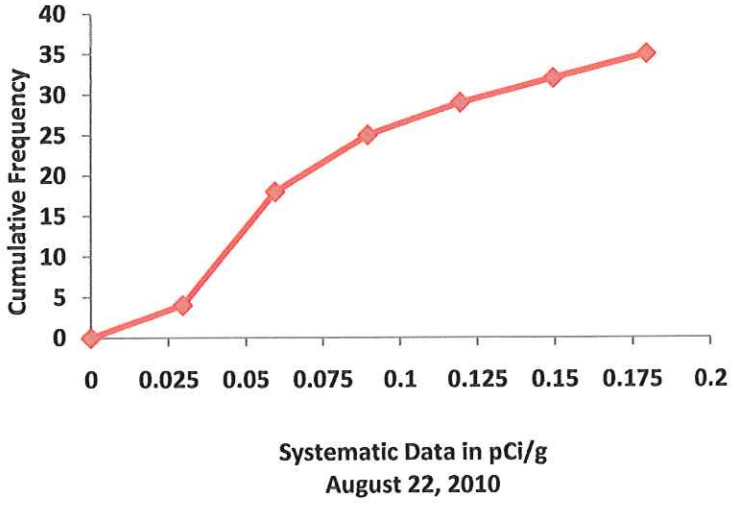
## 4. Graphic Investigation of U-235

The radioactive isotope U-235 was analyzed using a Cumulative Frequency Distribution in conjunction with an Ogive (cumulative frequency graph). The systematic data for this isotope was collected from area U1 on August 22, 2010. The single sample, B242080, had a level of 1.34 pCi/g and was left out of this analysis. This value is considered an outlier and is assumed to be unrepresentative of this area.

**Uranium 235 Levels in U1**

| Radiation Levels | Cumulative Frequency |
|---|---|
| Less than 0.030 | 4 |
| Less than 0.060 | 18 |
| Less than 0.090 | 25 |
| Less than 0.120 | 29 |
| Less than 0.150 | 32 |
| Less than 0.180 | 35 |

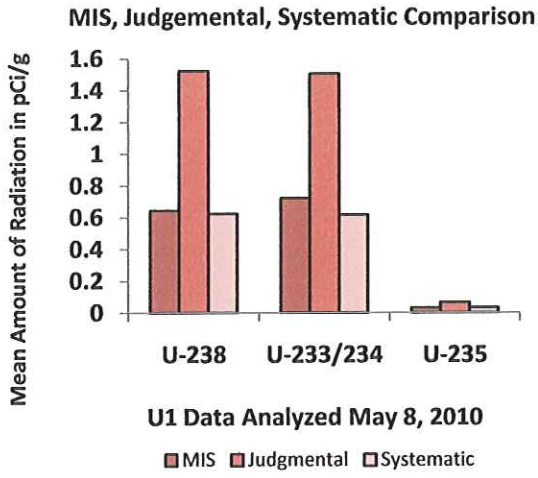
**Uranium 235 Radiation Levels in U1**

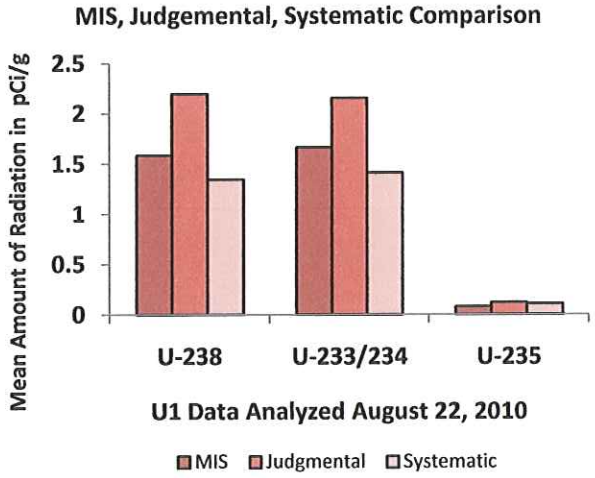



The cumulative frequency distribution and Ogive shown above indicate that all but one of the systematic samples collected had radiations level of less than 0.180 pCi/g. You can also see that the majority of the samples taken had radiation levels that were under 0.06 pCi/g. The only anomaly was the sample numbered B24208 which had a radiation level of 1.34 pCi/g. There are 22 samples out of 35 with radiation levels under 0.06 pCi/g. Thus, only 13 are over 0.06 pCi/g.

## 5. Graphic Comparison of U-238, U-233/234, and U-235

A comparison analysis was conducted on the levels of radiation in the MIS, Judgmental, and systematic data collected from area U1 for U-238, U-233/234, and U-235 on August 22, 2010 and on May 8, 2010. The Multiple Bar graphs below were used to analyze this information.




From these multiple bar graphs it is apparent that each of the sampling methods give nearly the same result. For example, you can see that the MIS samples taken in August for Uranium 238 (U-238) was just over 1.5 pCi/g. Here we want to compare the sampling type to see if each type of sample gave us the same, or nearly the same result. Now we look at the judgmental sample taken for Uranium 238 (U-238) and you can see that the average amount of radiation is just over 2 pCi/g. This is within 0.5 pCi/g of eachother. The same goes for the systematic sampling method. The graph indicates radiation levels of 1.346 pCi/g for Uranium 238 (U-238) which is within 0.85 pCi/g of the judgmental method.

The same is true for the sampling methods used in May for Uranium 238 (U-238). The MIS samples have an average of 0.644 pCi/g of radiation, as shown on the graph above. The Systematic samples average 0.62375 pCi/g of radiation. These levels are within 0.02 pCi/g of eachother. The biggest difference lies in the Judgemental Sampling. In May, the Judgmental Sample had a radiation level of 1.52333 pCi/g. This is a differnce of 0.87933. This is a difference of less than 1.0 pCi/g. Further analysis should be done to detrmine whether or not these differences are significant.

In looking at these graphs, it is apparent that all three sampling method provide close to the same results. This is especially apparent when you look at the Uranium 235 (U-235). If the question here is, which sampling method provides the most accurate result then it would appear that all of the sampling methods used provide an equal amount of accuracy.

## 6. Graphic Investigation of Chromium

A Stem and Leaf Plot was used to investigate the levels of Chromium contained in the systematic data for area U1 collected on August 22, 2010. The plot was constructed with the stems representing the ones digit of the original data values and the leaves representing the tenths digit of the original data values. This plot not only shows the nature of the Chromium distribution in the area U1 at the time of collection but allows for the preservation of the original data values.

**Chromium mg/kg for U1 in August, 2010**

| **Stem -** *Whole Numbers* | *Leaf -* *Tenths* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 4 | *9* | | | | | | | |
| 5 | *5* | 5 | 6 | 6 | 7 | 8 | 8 | |
| 6 | *1* | 2 | 4 | 4 | 4 | 7 | 8 | 9 |
| 7 | *0* | 2 | 4 | 4 | 5 | 5 | 6 | 8 |
| 8 | *0* | 5 | 5 | 5 | 7 | 8 | | |
| 9 | *0* | 2 | 2 | 5 | 9 | | | |
| 10 | *0* | | | | | | | |

From this Stem and Leaf plot it is easy to see that the Chromium levels in the systematic data for area U1 collected on August 22, 2010 range from 4.9 to 10.0. The Stem and Leaf plot preserves the original data values. It is heterogeneous, as the Chromium levels are not dispersed evenly in the samples. This chart appears to have a normal distribution, providing a bell shape.

# Descriptive Statistics and Probability

## 1. Descriptive Statistics for U-238, U-233/234, and U-235

The first part of this report analyzed data collected primarily from area U1 on August 22, 2010. This section of the report will analyze data collected primarily from area U1 on May 8, 2010. Measures of central tendency and variation are extremely important when analyzing a data set. Thus, the following calculations were made and summarized in the table below for the isotopes U-238, U-233/234, and U-235 using the systematic data for U1 collected on May 8, 2010.

The table below summarizes the mean (average), median, standard deviation and the range for the isotopes U-238, U-233/234, and U-235 using the systematic data for U1 collected on May 8, 2010. The mean is found by adding up all of the radiation levels and dividing by the total number. For example, for Uranium 238 (U-238) the mean is 0.624 pCi/g. This is determined by finding the sum of the radiation levels for U-238 which is 24.95 pCi/g. This number is divided by 40, which is the total number of radiation levels in this data set. The median is the middle number in the data set. The formula for standard deviation is $s = \sqrt{\frac{\Sigma(x-\bar{x})^2}{n-1}}$. The range is found by subtracting the minimum value from the maximum value in the data set.

### Summary Statistics for Area U1 Systematic Data in May 8, 2010

| pCi/g | U-238 | U-233/234 | U-235 |
|---|---|---|---|
| **Mean** | 0.624 | 0.617 | 0.0327 |
| **Median** | 0.56 | 0.555 | 0.032 |
| **Standard Deviation** | 0.239 | 0.206 | 0.0164 |
| **Range** | 1.18 | 1.02 | 0.8 |

The above information was used to calculate the minimum and maximum "usual" values for each isotope. Two techniques were used for these calculations, the Empirical Rule for 95% of data values and Chebyshev's Theorem for at least 93.75% of data values.

The Empirical Rule assumes that the population is normally distributed. It states that 95% of data values fall within 2 standard deviations of the mean. These calculations are presented below.

**U-238**

minimum usual value = $\bar{X}$-2s
=0.624 - 2(0.239)
=0.146 pCi/g

maximum usual value = $\bar{X}$+2s
=0.624+2(0.239)
=1.102 pCi/g

**U-233/234**

minimum usual value = $\bar{X}$-2s
=0.617-2(0.206)
=0.205 pCi/g

maxiumum usual value = $\bar{X}$+2s
=0.617+2(0.206)
=1.029 pCi/g

**U- 235**

minimum usual value = $\bar{X}$ -2s
=0.0327-2(0.0164)
= - 0.0001 pCi/g

maximum usual value = $\bar{X}$+2s
=0.0327+2(0.0164)
=0.0655 pCi/g

Chebyshev's Theorem makes no assumptions about the distribution of the population from which the data was sampled. As a result, it provides a conservative estimate of the minimum and maximum "usual" values of a data set. This theorem states that at least 93.75% of data values fall within 4 standard deviations of the mean. These calculations are presented below.

**U-238**

minimum usual value = $\bar{X}$-4s
=0.624-4(0.239)
= - 0.332 pCi/g

maximum usual value = $\bar{X}$+4s
=0.624+4(0.239)
=1.580 pCi/g

**U-233/U 234**

minimum usual value = $\bar{X}$-4s
=0.617-4(0.206)
= - 0.207 pCi/g

maximum usual value = $\bar{X}$+4s
=0.617+4(0.206)
=1.441 pCi/g

**U-235**

minimum usual value = $\bar{X}$-4s
=0.0327-4(0.0164)
= - 0.0329 pCi/g

maximum usual value = $\bar{X}$+4s
=0.0327+4(0.0164)
=0.0983 pCi/g

The unusual data values can be identified using the above minimum and maximum "usual" values. The unusual data values using both the Empirical Rule and the Chebyshev's Theorem are presented below for U-238, U-233/234, and U-235, Systematic data collected from area U1 on May 8, 2010.

**Identified Unusual Data Values in pCi/g**

| Element | Empirical Rule | Chebyshev's Theorem |
|---|---|---|
| U-238 | 1.13<br>1.33<br>1.62 | 1.62 |
| U-233/234 | 1.03<br>1.04<br>1.19<br>1.43 | |
| U-235 | 0.066<br>0.086 | |

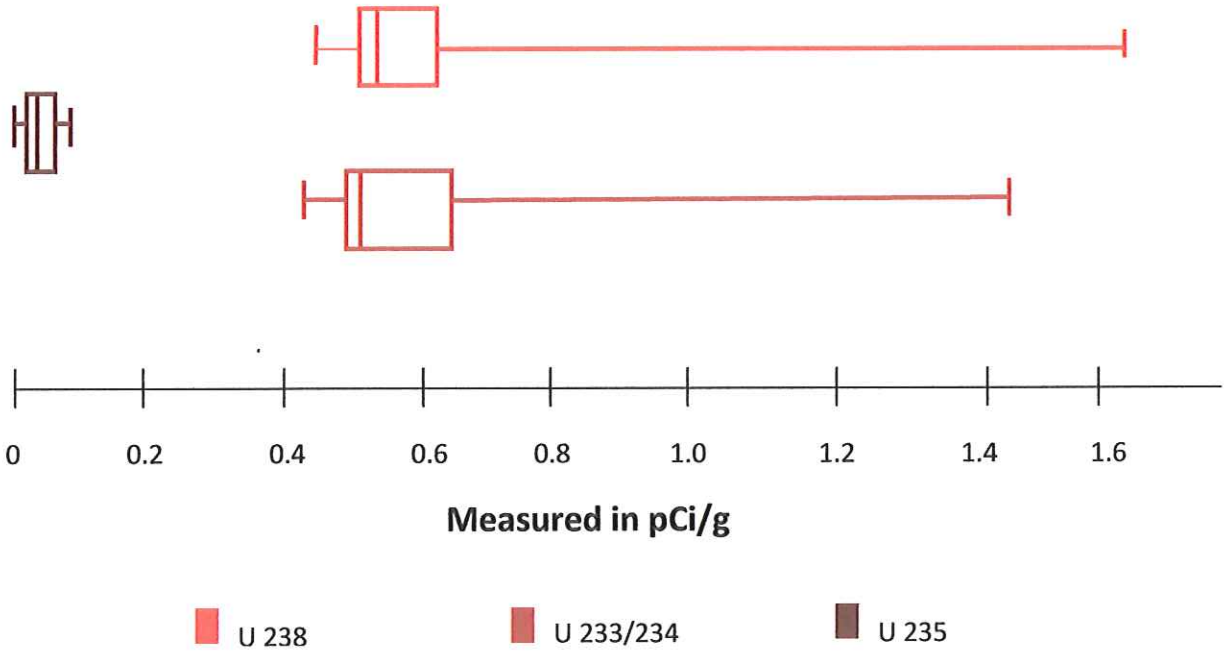
The Empirical Rule applies solely to the normal distribution, while Chebyshev's Theorem deals with all distributions. The Empirical Rule is stronger than Chebyshev's Theorem, but it applies to fewer cases. With the Empirical Rule, about 95% of the values lie within two standard deviations of the mean. This differs from Chebyshev's Theorem in that at least 75% of the values lie within two standard deviations away from the mean. In this case, Chebyshev's Theorem would be the appropriate technique to use because these distributions appear to be skewed to the right which can be seen in the boxplots presented below. Thus, the only unusual value found in these three data sets was 1.62 pCi/g and it came from U-238. All other values should be considered usual.

Descriptive statistical analysis also includes a 5-number summary consisting of the minimum value, the 25th percentile, the median, the 75th percentile, and the maximum value. These values are used to construct a boxplot representing the data set of interest. In this analysis, 5 number summaries and stacked boxplots were calculated for the systematic data collected on May 8, 2010 from area U1 for U-238, U-233/234, and U-235. This information is presented on the following page.

## Systematic Data Collected on May 8, 2010

| pCi/g | U-238 | U-233/234 | U-235 |
|---|---|---|---|
| Minimum | 0.44 | 0.41 | 0.006 |
| 25th Percentile | 0.5 | 0.53 | 0.027 |
| Median | 0.56 | 0.555 | 0.032 |
| 75th Percentile | 0.625 | 0.64 | 0.0415 |
| Maximum | 1.62 | 1.43 | 0.086 |

## Comparison Boxplots for Uranium Systematic Data Area U1 May 8, 2010




From the 5 number summary and the boxplots above, it is easy to see that the radiation levels for Uranium 238 and Uranium 233/234 are very similar. For example, Uranium 238 (U-238) has a minimum of 0.44 pCi/g. This is only 0.03 more than Uranium 238, which has a minimum of 0.41 pCi/g. Just as the two minimum values are similar, so are the 25th percentile, the median, the 75th percentile, and the maximum values of both Uranium 238 and Uranium 233/234. The biggest difference shown above is the radiation levels of Uranium 235. Here, all of the values are less than 0.086 pCi/g. This is significantly less that the radiation levels found for the other isotopes.

## 2. Selecting Subsamples of U-238

Researchers observed several anomalies in the U-238 systematic data collect from area U1 on May 8, 2010. As a result of these observations, they were tasked with performing a more in depth analysis of this data. Due to budget constraints only 10 of the original samples will be selected for this extended analysis. The number of different subsamples of size 10 was determined using the following calculation:

$$
\begin{aligned}
{}_{40}C_{10} &= \frac{40!}{(40-10)!10!} \\
&= 847,660,528
\end{aligned}
$$

The number 847,660,528 represents the number of different ways ten subsamples can be chosen from the original 40 samples of Uranium 238, using the systematic data collected from area U1 on May 8, 2010.

Once the researchers selected their 10 subsamples for extended analysis they were instructed to initially test only 4 of these subsamples. The order in which these 4 subsamples are tested is critical to their in-depth analysis. The number of different orders that 4 of the 10 subsamples can be selected and tested was determined using the following calculation:

$$
\begin{aligned}
{}_{10}P_4 &= \frac{10!}{(10-4)!} \\
&= 5,040
\end{aligned}
$$

The number 5,040 different orders from which 4 of the selected 10 subsamples of the Systematic data for U-238 from U1 on May 8, 2010 can be selected and tested.

## 3. Sample Probabilities for U-238, U-233/234, and U-235

Part of this soil sample research involves calculating different probabilities. The table on the following page presents 120 different measurements taken of the radiation levels for U-238, U-233/234, and U-235 for the systematic data from U1 collected on May 8, 2010. The information in this table was used to calculate these probabilities.

## Radiation Levels for the Systematic Data Collected on May 8, 2010 in Area U1

| pCi/g | U-238 | U-233/234 | U-235 | Total |
|---|---|---|---|---|
| **0.00-0.50** | 10 | 8 | 40 | 58 |
| **0.51-1.00** | 26 | 28 | 0 | 54 |
| **1.01-1.50** | 3 | 4 | 0 | 7 |
| **1.51-2.00** | 1 | 0 | 0 | 1 |
| **Total** | 40 | 40 | 40 | 120 |

A single measurement was selected at random for analysis. The probability that the measurement had a radiation level of 0.50 pCi/g or less where the source of the radiation was unknown was calculated as follows:

$$P(\text{radiation level } \leq 0.50 \text{ pCi/g}) = \frac{(\text{number of measurements } \leq 0.50 \text{ pCi/g})}{\text{total number of measurements}}$$

$$= \frac{58}{120}$$

$$= 0.483$$

The number 0.483 represents the probability that the measurement had a radiation level of 0.50 pCi/g or less where the source of the radiation was unknown.

Two samples of size 4 each were selected at random and only their U-238 radiation level was analyzed. The probability that all 4 samples would have a radiation level of 0.50 pCi/g or less was evaluated. The first sample was selected with replacement. The second sample was selected without replacement. The detailed calculations of each of these probabilities are presented on the following page.

**With Replacement:**

$$P(\text{all four sample radiation levels} \leq 0.50 \text{ pCi/g}) = \left(\frac{10}{40}\right)\left(\frac{10}{40}\right)\left(\frac{10}{40}\right)\left(\frac{10}{40}\right)$$

$$= 0.00391$$

**Without Replacement:**

$$P(\text{all four sample radiation levels} \leq 0.50 \text{ pCi/g}) = \left(\frac{10}{40}\right)\left(\frac{9}{39}\right)\left(\frac{8}{38}\right)\left(\frac{7}{37}\right)$$
$$=0.0023$$

A sample of size 4 was selected at random with replacement in which only the U-233/234 radiation levels were evaluated. To determine the probability that at least 1 out of these 4 samples has a radiation level that is greater than 0.50 pCi/g the following calculations were done.

**With Replacement:**

P(at least one radiation level > 0.50 pCi/g) = 1 - P(no radiation level > 0.50 pCi/g)

$$P(\text{one U-233/234 with radiation level} > 0.50 \text{ pCi/g}) = \frac{32}{40}$$

$$P(\text{one U-233/234 with radiation level} < 0.50 \text{ pCi/g}) = 1-\frac{32}{40}$$
$$= \frac{8}{40}$$

P (none U-233/234 with radiation level > 0.50 pCi/g) =1- P(all 4 radiation levels <0.50 pCi/g)

$$=1-\left(\frac{8}{40}\right)^4$$
$$=0.998$$

Two measurements were to be randomly selected, without replacement, from the 120 radiation level measurements. The probability that the first would have a radiation level greater than 1.00 pCi/g source unknown and second would have a radiation level of 0.50 pCi/g or less source unknown was calculated as shown below.

$$P(1^{st} \text{ has radiation level} > 1.00 \text{ pCi/g and } 2^{nd} \text{ has a radiation level} \leq 0.50) = \left(\frac{8}{120}\right)\left(\frac{58}{119}\right)$$
$$=0.0325$$

A sample was found in the lab after all the other samples had been properly stored. This sample had a radiation level between 0.00 and 0.50 pCi/g. The researchers decided to use probability to help them find the source of this radiation. The following probabilities were calculated to assist them in this determination.

$$P(\text{U238} \mid \text{radiation level between 0 and 0.50}) = \frac{\text{number of U238 values between 0.00-0.50pCi/g}}{\text{total number of values between 0.00-0.50pCi/g}}$$
$$= \frac{10}{58}$$
$$= 0.172$$

$$P(\text{U233/234} \mid \text{radiation level between 0 and 0.50}) = \frac{\text{number of U233/234 values between 0.00-0.50pCi/g}}{\text{total number of values between 0.00-0.50pCi/g}}$$
$$= \frac{8}{58}$$
$$= 0.138$$

$$P(\text{U235} \mid \text{radiation level between 0 and 0.50}) = \frac{\text{number of U235 values between 0.00-0.50pCi/g}}{\text{total number of values between 0.00-0.50pCi/g}}$$
$$= \frac{40}{58}$$
$$= 0.69$$

It is most likely that the sample found in the lab after all of the other samples were stored is a sample of Uranium 235 (U-235) because, as shown above, this sample has the highest probability.

# Analysis Samples and Probability Distributions

## 1. Ensuring Enough Samples for Analysis

The Hanford test planning team determined that the minimum number of samples required for analysis of their soil data would be 35. The test engineer is aware that samples can be excluded from the analysis for a variety of legitimate reasons. To ensure that at least 35 of the samples are fit for analysis, the test engineer proposes that they collect 40 samples. He uses the following Probability Distribution of usable data samples from a sample of size 40 to support his proposal.

**Probability Distribution of Usable Samples from a Sample Size of Size 40**

| x | P(x) | xP(x) | $x^2$ P(x) |
|---|---|---|---|
| 40 | 0.021 | 0.840 | 33.600 |
| 39 | 0.153 | 5.967 | 232.713 |
| 38 | 0.281 | 10.678 | 405.764 |
| 37 | 0.253 | 9.361 | 346.357 |
| 36 | 0.139 | 5.004 | 180.144 |
| 35 | 0.104 | 3.640 | 127.400 |
| 34 | 0.023 | 0.782 | 26.588 |
| 33 | 0.015 | 0.495 | 16.335 |
| 32 | 0.011 | 0.352 | 11.264 |
| **Totals** | **1** | **37.119** | **1380.165** |

According to this Probability Distribution of Usable Samples, the expected number (mean) of usable samples out of 40 samples, would be $\mu = \sum X_i P(X_i)$, which is 37.1 samples. In addition the standard deviation for this distribution was calculated using the following formula, $\sigma = \sqrt{\sum X_i^2 P(X_i) - [\sum X_i P(X_i)]^2}$. This calculation resulted in a standard deviation of 1.5 samples. Both the mean and standard deviation were used to calculate the minimum and maximum number of usable samples to be expected when 40 samples are collected. These values are presented below.

minimum usual value $= \mu - 2\sigma$
$= 37.119 - 2(1.5)$
$= 34.1$ samples

maximum usual value $= \mu + 2\sigma$
$= 37.119 + 2(1.5)$
$= 40.1$ samples

These results indicate that the minimum usual number of usable samples is 34.1 out of 40 samples. The maximum usual number of usable samples is 40.1 out of 40 samples. The engineer should feel comfortable choosing 40 samples because this number lies between the minimum usual value and the maximum usual value.

## 2. Results Validation and Quality Control

Critical decisions about whether or not to cleanup areas U1 and U2 are to be made as a result of this analysis. To ensure the validity and quality of these results the test analysts require data from at least at 13 duplicate tests. The test engineer is aware of the fact that any given test may fail to meet the minimum usable sample requirement of at least 35 usable samples. To ensure that 13 usable duplicate tests are collected, he proposes that they conduct 15 duplicate tests. To support his proposal, initially the test engineer calculated the probability of a given sample having at least 35 usable samples out of 40 collected samples.

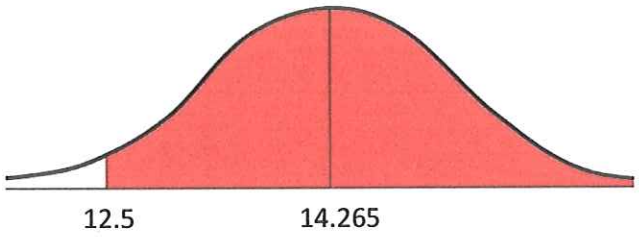
$$\begin{aligned} P(\text{at least 35 usable samples out of 40}) &= P(13)+P(14)+P(15) \\ &= P(35)+P(36)+P(37)+P(38)+P(39)+P(40) \\ &= 0.104+0.139+0.253+0.281+0.153+0.021 \\ &= 0.951 \end{aligned}$$

He then proceeded to calculate the probability of at least 13 usable tests out of 15 tests conducted using two different techniques. The first technique that he used involved the Binomial Probability Formula and the second technique that he used was the Normal Approximation to the Binomial Formula. These calculations are presented below.

**Binomial Probability Formula**

$$\begin{aligned} P(\text{at least 13 out of 15}) &= {}_{15}C_{13}\,(0.951)^{13}(0.049)^{2} + {}_{15}C_{14}\,(0.951)^{14}(0.049)^{1} + {}_{15}C_{15}\,(0.951)^{15}(0.049)^{0} \\ &= 0.131198291+0.363759694+0.470660502 \\ &= 0.965618487 \\ &= 0.966 \end{aligned}$$

**Normal Approximation to the Binomial Formula**




**Normal Distribution for Duplicates Samples**

$p = 0.951 \quad q = 0.049 \quad n = 15$

$\mu = np \qquad \sigma = \sqrt{npq}$

$= 15(0.951) \qquad = \sqrt{15(0.951)(0.049}$

$= 14.265 \qquad = 0.836$

$$\begin{aligned} P(\text{at least 13 out of 15}) &= P(x \geq 13) \\ &= P(x > 12.5) \\ &= 1 - P(x < 12.5) \\ &= 1 - P\left(z < \frac{x - \mu}{\sigma}\right) \\ &= 1 - P\left(z < \frac{12.5 - 14.265}{0.836053228}\right) \\ &= 1 - P(z < -2.11) \\ &= 1 - 0.0174 \\ &= 0.983 \end{aligned}$$

The engineer should feel quite comfortable with his choice of conducting 15 duplicate tests. According to his calculations, he will have the correct number of duplicate tests approximately 96.6% of the time. In this case, it is in appropriate to use the Normal Approximation to the Binomial Formula calculations above. This particular data set fails the requirement that $nq \geq 5$ since $nq = 15(0.049)$ which is $0.735$.

## 3. Probabilities Involving Uranium Radiation Levels

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) requires the cleanup of surface soil having a radiation level of 5 pCi/g or more. The table below lists the samples that exceed that level.

**Sample with Radiation above 5pCi/g on August 22, 2010**

| Area | ID Number | Radiation Level in pCi/g |
|---|---|---|
| U1 | B24208 | 7.16 |
| | B24209 | 8.441 |
| | B24210 | 6.375 |
| | B24226 | 5.267 |
| U2 | B24260 | 5.694 |
| | B24268 | 5.389 |

**Sample with Radiation above 5pCi/g on May 8, 2010**

| Area | ID Number | Radiation Level in pCi/g |
|---|---|---|
| U1 | none | none |
| U2 | none | none |

On May 8, 2010 there were 40 samples collected from area U1. None of these samples were above the radiation level of 5 pCi/g. However, of the 36 samples collected from the same area on August 22, 2010 there were 4 samples with radiation levels greater than 5 pCi/g. This result indicated that approximately 11% of the August samples exceed the radiation clean up level of 5 pCi/g. Further analysis and perhaps cleanup should be done prior to considering this area clean.

On May 8, 2010 there were 40 samples collected from area U2. None of these samples were above the radiation level of 5 pCi/g. However, of the 40 samples collected from the same area on August 22, 2010 there were 2 samples with radiation levels greater than 5 pCi/g. This result indicated that approximately 5% of the August samples exceed the radiation clean up level of 5 pCi/g. Further analysis and perhaps cleanup should be done prior to considering this area clean.

As a follow up to the reporting of sample radiation it has been determined that the August 22, 2010 sample data needs to be analyzed in greater detail. Due to budget constraints not all these samples can be analyzed again. Therefore the following probabilities were calculated to determine the probability of selecting one sample with a radiation level that may result in cleanup of the area U1. The probability was also calculated of selecting four samples with a mean radiation level that may result in the cleanup of area U1.

**Mean and Standard Deviation for U1 for August 22, 2010**

$\bar{X} = 2.866$ pCi/g

s = 1.733568 pCi/g

**Single Sample**

$P(x > 5 \text{ pCi/g}) = 1 - P(x < 5)$

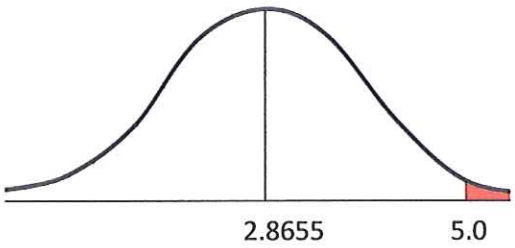
$= 1 - P\left(z < \frac{5 - 2.866}{1.733568}\right)$

$= 1 - P\left(z < \frac{2.134}{1.733568}\right)$

$= 1 - P(z < 1.23)$

$= 1 - 0.8907$

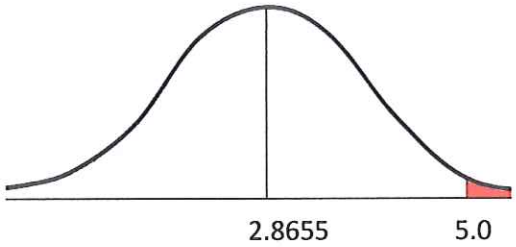
$= 0.109$




**U1 Radiation Level-Single Sample 8/22/2010**

**Four random samples**

$$P(\bar{X}>5 \text{ pCi/g}) = 1-P(\bar{X}<5)$$
$$= 1- P\left(z < \frac{5-2.8655}{0.866784}\right)$$
$$= 1- P\left(z < \frac{2.134}{0.866784}\right)$$
$$= 1- P(z<2.46)$$
$$= 1- 0.9931$$
$$= 0.007$$



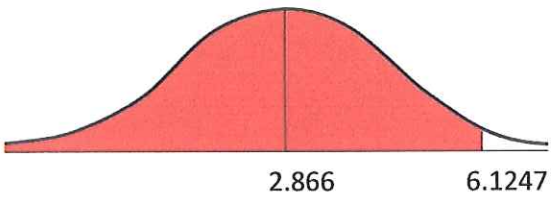

**U1 Radiation Level-Four Samples 8/22/2010**

## 4. Percentiles Involving Uranium Radiation Levels

The assumption of normality was made with respect to the radiation levels of Uranium in areas U1 and U2 collected on August 22, 2010 in order to calculate the ninety-seventh percentile. This value represents the radiation level that separates the bottom 97% of radiation levels from the top 3%. A decision to declare an area clean will be made if at least 97% of the data values fall below 5 pCi/g. Otherwise, further testing will be conducted to determine if cleanup is required.

**Calculating U1 97$^{th}$ Percentile Value**

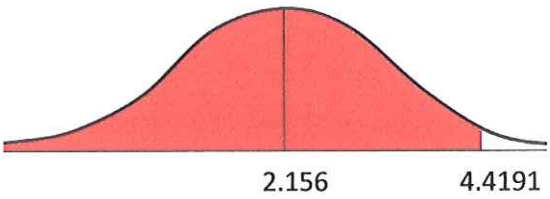
$$x = \bar{X}+zs$$
$$= 2.866+1.88(1.733568)$$
$$= 6.1247 \text{ pCi/g}$$




**U1 97$^{th}$ Percentile August 22, 2010**

**Calculating U1 97$^{th}$ Percentile Value**

$$x = \bar{X}+z\sigma$$
$$= 2.156+(1.88)(1.203982)$$
$$= 4.4191 \text{ pCi/g}$$




**U2 97$^{th}$ Percentile August 22, 2010**

According to the data above, for area U1, the value 6.1247 pCi/g represents the 97$^{th}$ percentile. This value is larger than the 5 pCi/g level. This indicates that the area requires further study and possible cleanup. On the other hand, the value 4.4191 pCi/g represents the 97$^{th}$ percentile for area U2. This level is below the 5 pCi/g indicating that this area can now be declared clean and no further study or cleanup is required.

# Confidence Intervals and Hypothesis Tests

In 2008, the Washington State Department of Ecology in cooperation with the Department of Energy (DOE) and the CH2M HILL Plateau Remediation Company (CHPRC) collected two samples from a single location immediately adjacent to the pipe discharge point for the pond designated 216-S-19. These samples were designated as "screening" samples in order to determine if the site would be a suitable location to conduct a comparison of three sampling designs (Judgmental, MIS, and Systematic). Based on the results of this screening effort, contaminants of potential concern (COPCs) were identified. The contaminants were Nitrate, Copper, Chromium, Zinc, Uranium-233/234, Uranium-238, Uranium-235, Plutonium-239/240, Plutonium-238, and Americium-241. This section of the report will be looking at the total radiation levels of Uranium and Nitrate.

## 1. Confidence Intervals on the Proportion of the Pond with High Radiation Levels of Uranium

DOE is concerned about the proportion of this pond that contains Uranium radiation levels above the CERCLA standard of 5 pCi/g. The Systematic sample data collected on August 22, 2010 from both areas U1 and U2 was used to address this concern. For the proportion of the contaminant in each area, a 90% confidence interval was constructed. It was assumed that all requirements for constructing this type of confidence interval were satisfied.

**Area U1:** The best point estimate for Uranium with radiation levels greater than 5pCi/g is calculated below:

$$\hat{p} = \frac{number\ of\ Uranium\ samples\ in\ area\ U1\ with\ radiation\ level\ greater\ than\ 5\ pCi/g}{total\ number\ of\ samples\ taken\ from\ area\ U1}$$

$$\hat{p} = \frac{4}{36}$$

$$\hat{p} = \frac{1}{9} \qquad \hat{p} \approx 0.111$$

The margin of error for Uranium is calculated using $\alpha = 0.10$ confidence level which is presented as follows:

$$E = z_{\frac{\alpha}{2}}\sqrt{\frac{\hat{p}\hat{q}}{n}} \qquad z_{\frac{\alpha}{2}} = z_{\frac{0.10}{2}} = z_{0.05} = 1.645$$

$$E = 1.645\sqrt{\frac{\left(\frac{1}{9}\right)\left(\frac{8}{9}\right)}{36}}$$
$$= 0.086124561$$
$$= 0.0861$$

The calculation for the 90% confidence interval is presented below:

$$\hat{p} - E < p < \hat{p} + E$$
$$0.111 - 0.0861 < p < 0.111 + 0.0861$$
$$0.0249 < p < 0.1971$$

**Area U2:** The best point estimate for Uranium with radiation levels greater than 5pCi/g is calculated below:

$$\hat{p} = \frac{number\ of\ Uranium\ samples\ in\ area\ U2\ with\ radiation\ level\ greater\ than\ 5\ pCi/g}{total\ number\ of\ samples\ taken\ from\ area\ U2}$$

$$\hat{p} = \frac{2}{39} \qquad \hat{p} \approx 0.0513$$

The margin of error for Uranium is calculated using $\alpha = 0.10$ confidence level which is presented as follows:

$$E = z_{\frac{\alpha}{2}}\sqrt{\frac{\hat{p}\,\hat{q}}{n}} \qquad z_{\frac{\alpha}{2}} = z_{\frac{0.10}{2}} = z_{0.05} = 1.645$$

$$E = 1.645\sqrt{\frac{\left(\frac{2}{39}\right)\left(\frac{37}{39}\right)}{39}}$$
$$= 0.058110784$$
$$= 0.0581$$

The calculation for the 90% confidence interval is presented below:

$$\hat{p} - E < p < \hat{p} + E$$
$$0.0513 - 0.0581 < p < 0.0513 + 0.0581$$
$$-0.007 < p < 0.1094$$
$$-0.007 < p < 0.109$$

EPA guidance states that "because of the uncertainty associated with estimating the true proportion of a contaminant at a site, the 95% upper confidence limit (UCL) of the proportion should be used". The lower bound of a confidence interval for the proportion of COPCs is not that significant. However, the upper bound of a confidence interval for the proportion of COPCs is significant. We are 95% confident that the true proportion of the Uranium radiation levels in area U1 above 5 pCi/g is less than 0.1971 pCi/g. In area U2 we are 95% confident that the true proportion of the Uranium radiation levels above 5 pCi/g is less than 0.1094 pCi/g.

## 2. Confidence Intervals for the Nitrate Level in the 216-S-19 Pond

During the "screening" process of the 216-S-19 pond, Nitrate was identified as one of the COPCs. Prior to the excavation of this pond, data was collected in both areas U1 and U2 on May 8, 2010. Three different sampling techniques were used; Systematic, MIS, and Judgmental. Separate 90% confidence intervals for the mean Nitrate levels contained in each area were calculated for the Systematic data and again for the MIS data. These confidence intervals were used to address the different sampling techniques as well as the mean levels of Nitrate in the soil in areas U1 and U2. All confidence intervals were constructed using a Student's-t distribution. The key underlying assumptions necessary to use this distribution were validated. The calculations are presented below.

**Area U1 Systematic Data:** The best point estimate for Nitrate using Systematic Data on May 8, 2010 is calculated below:

$$\overline{x} = \frac{\sum x}{n}$$
$$= \frac{850.2}{40}$$
$$= 21.255 \text{ mg/kg}$$

The margin of error for Nitrate using Systematic Data on May 8, 2010 is calculated using $\alpha = 0.10$ confidence level which is presented as follows:

$$E = t_{\frac{\alpha}{2}} \frac{s}{\sqrt{n}} \qquad t_{\frac{\alpha}{2}} = t_{\frac{0.10}{2}} = t_{0.05} = 1.685$$

$$E = 1.685\left(\frac{17.399}{\sqrt{40}}\right)$$
$$= 4.635474514$$
$$= 4.635 mg/kg$$

The calculation for the 90% confidence interval for Nitrate using Systematic Data on May 8, 2010 is calculated below:

$$\bar{X} - E < \mu < \bar{X} + E$$
$$21.255 - 4.635 < \mu < 21.255 + 4.635$$
$$16.62\, mg/kg < \mu < 25.89\, mg/kg$$

**Area U1 MIS:** The best point estimate for Nitrate using MIS Data on May 8, 2010 is calculated below:

$$\bar{x} = \frac{\sum x}{n}$$
$$= \frac{50.5}{5}$$
$$= 10.1\ mg/kg$$

The margin of error for Nitrate using MIS Data on May 8, 2010 is calculated using $\alpha = 0.10$ confidence level which is presented as follows:

$$E = t_{\frac{\alpha}{2}} \frac{s}{\sqrt{n}} \qquad t_{\frac{\alpha}{2}} = t_{\frac{0.10}{2}} = t_{0.05} = 2.132$$

$$E = 2.132\left(\frac{0.857}{\sqrt{5}}\right)$$
$$= 0.817114693$$
$$= 0.817\ mg/kg$$

The calculation for the 90% confidence interval for Nitrate using MIS Data on May 8, 2010 is calculated below:

$$x - E < \mu < x + E$$
$$10.1 - 0.817 < \mu < 10.1 + 0.817$$
$$9.283\ mg/kg < \mu < 10.917\ mg/kg$$

**Area U2 Systematic:** The best point estimate for Nitrate using Systematic Data on May 8, 2010 is calculated below:

$$\bar{X} = \frac{\sum x}{n}$$
$$= \frac{532.6}{40}$$
$$= 13.315\ mg/kg$$

The margin of error for Nitrate using Systematic Data on May 8, 2010 is calculated using $\alpha = 0.10$ confidence level which is presented as follows:

$$E = t_{\frac{\alpha}{2}} \frac{s}{\sqrt{n}} \qquad t_{\frac{\alpha}{2}} = t_{\frac{0.10}{2}} = t_{0.05} = 1.685$$
$$E = 1.685\left(\frac{13.1729}{\sqrt{40}}\right)$$
$$= 3.509548953$$
$$= 3.510\ mg/kg$$

The calculation for the 90% confidence interval for Nitrate using Systematic Data on May 8, 2010 is calculated below:

$$\bar{X} - E < \mu < \bar{X} + E$$
$$13.315 - 3.510 < \mu < 13.315 + 3.510$$
$$9.805\ mg/kg < \mu < 16.825\ mg/kg$$

**Area U2 MIS**: The best point estimate for Nitrate using MIS Data on May 8, 2010 is calculated below:

$$\begin{aligned}\overline{x} &= \frac{\sum x}{n} \\ &= \frac{59.1}{5} \\ &= 11.82 \text{ mg/kg}\end{aligned}$$

The margin of error for Nitrate using MIS Data on May 8, 2010 is calculated using $\alpha = 0.10$ confidence level which is presented as follows:

$$E = t_{\frac{\alpha}{2}} \frac{s}{\sqrt{n}} \qquad t_{\frac{\alpha}{2}} = t_{\frac{0.10}{2}} = t_{0.05} = 2.132$$

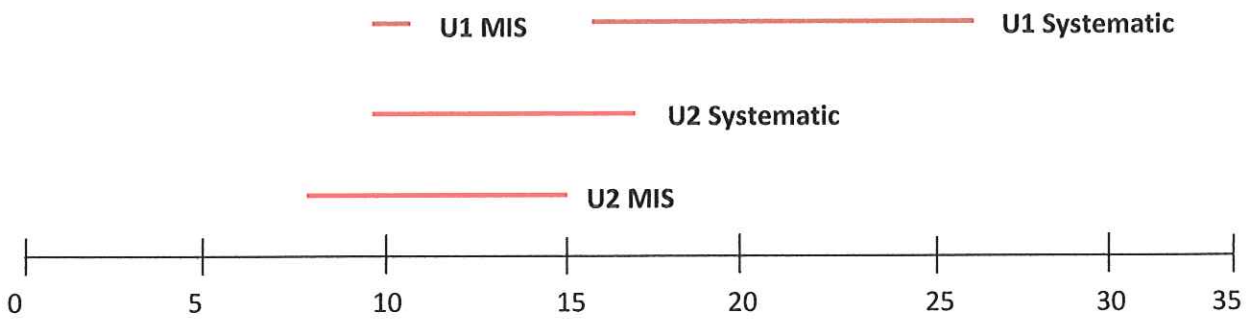
$$\begin{aligned}E &= 2.132\left(\frac{3.076}{\sqrt{5}}\right) \\ &= 2.9284107 \ mg/kg \\ &= 2.933 \ mg/kg\end{aligned}$$

The calculation for the 90% confidence interval for Nitrate using MIS Data on May 8, 2010 is calculated below:

$$\begin{aligned}\overline{X} - E < \mu < \overline{X} + E \\ 11.82 - 2.933 < \mu < 11.82 + 2.933 \\ 8.887 mg/kg < \mu < 14.753 mg/kg\end{aligned}$$

The graph on the following page shows confidence intervals for the mean radiation levels of Nitrate in area U1 and in U2 using both Systematic data samples and MIS data samples on May 8, 2010.

**Confidence Intervals for Mean Nitrate Levels for May of 2010**




**Measured in mg/kg**

The graph of the Nitrate levels is used to informally compare the difference between the mean Nitrate levels calculated using the MIS data versus the Systematic data for the same time period. There appears to be a significant difference in the mean Nitrate levels in area U1 with respect to the sampling technique because there is no overlap in the intervals. However, the confidence intervals for the mean Nitrated levels in area U2 for the MIS versus the Systematic data do overlap. Therefore, in area U2 there does not appear to be a significant difference between the two sampling techniques, Systematic versus MIS, when calculating the mean Nitrate levels.

Again, EPA guidance states that "because of the uncertainty associated with estimating the true average concentration of a contaminant at a site, the 95% upper confidence limit (UCL) of the arithmetic mean should be used". We are 95% confident that the data collected in area U1 for Systematic sampling on May 8, 2010 has a mean Nitrate level less than 25.89 mg/kg. During this same time frame we are 95% confident that the data collected in area U1 for MIS has a mean Nitrate level less than 10.917 mg/kg. For May 21, 2010 we are 95% confident that the data collected in area U2 for Systematic sampling has a mean Nitrate level less than 16.825 mg/kg. During this same time frame we are 95% confident that the data collected in area U2 for MIS has a mean Nitrate level less than 14.753 mg/kg.

## 3. Hypothesis Tests for Nitrate Levels in the 216-S-19 Pond

According to Hanford Contamination Levels, Nitrate levels of 40 mg/kg or more are a cause for concern that could lead to area cleanup. There were no MIS samples collected on May 8, 2010 in either area U1 or U2 that exceeded this level. However, during the same time period there

were 7 Systematic samples out of 40 in area U1 and 3 Systematic samples out of 40 in area U2 that exceeded this contamination level. These samples are identified in the chart below.

**Nitrate Levels over 40 mg/kg**
**Systematic May 8, 2010**

| Area | ID Number | Nitrate Level in mg/kg |
|---|---|---|
| U1 | B241K4 | 44 |
| | B241K8 | 42 |
| | B241L0 | 47 |
| | B241L9 | 71 |
| | B241M0 | 60 |
| | B241P0 | 48 |
| | B241P2 | 48 |
| U2 | B241R3 | 49 |
| | B241R4 | 61 |
| | B241W1 | 43 |

**Nitrate Levels over 40 mg/kg**
**MIS May 8, 2010**

| Area | ID Number | Nitrate Level in mg/kg |
|---|---|---|
| U1 | none | none |
| U2 | none | none |

Hypothesis tests were conducted to formally test the claim that the mean Nitrate levels for the May 8, 2010 Systematic data in areas U1 and U2 are below the Hanford Contamination Level. These two tests are presented below.

**Systematic Nitrate Data for Area U1 on May 8, 2010**

$H_0 : \mu = 40\,\text{mg/kg}$

$H_1 : \mu < 40\ \text{mg/kg}\ \ (claim)$

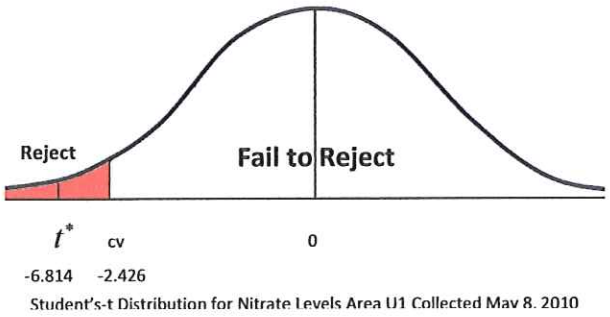
$$t^* = \frac{\bar{x} - \mu}{\frac{s}{\sqrt{n}}}$$

$$t^* = \frac{21.255 - 40}{\frac{17.399}{\sqrt{40}}}$$

$$t^* = -6.813822776$$

$$t^* = -6.814$$

$$t^*_{.01}{}^{(39)} = -2.426$$



Student's-t Distribution for Nitrate Levels Area U1 Collected May 8, 2010

Since the test statistic of -6.814 is less than the significance level of -2.426 reject the null hypothesis. There is sufficient evidence to support the claim that the mean Nitrate level in area U1 on May 8, 2010 is less than the contamination action level of 40 mg/kg.

**Systematic Nitrate Data for Area U2 on May 8, 2010**

$H_0 : \mu = 40\,\text{mg/kg}$

$$t^* = \frac{\bar{x} - \mu}{\frac{s}{\sqrt{n}}}$$

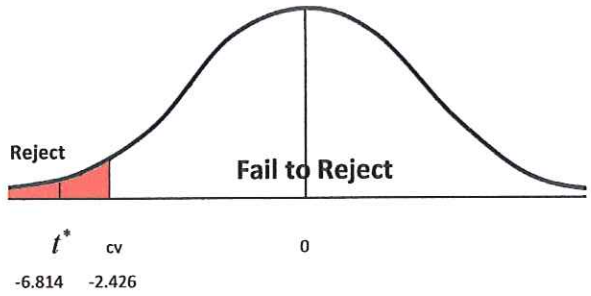
$t^*_{.01}{}^{(39)} = -2.426$

$H_1 : \mu < 40\ \text{mg/kg}\ \ (claim)$

$$t^* = \frac{13.315 - 40}{\frac{13.17287}{\sqrt{40}}}$$

$$t^* = -12.8119669$$

$$t^* = -12.812$$




Student's-t Distribution for Nitrate Levels Area U1 Collected May 8, 2010

Since the test statistic of -12.812 is less than the significance level of -2.426 reject the null hypothesis. There is sufficient evidence to support the claim that the mean Nitrate level in area U2 on May 8, 2010 is less than the contamination action level of 40 mg/kg.

## 4. Calculating Sample Size

In order to meet EPA standards, the Hanford test designers determined that they want the estimates of the mean Nitrate level in areas U1 and U2 to be within 5 mg/kg of the true population mean Nitrate level. The number of usable systematic samples that need to be randomly collected from each of the areas U1 and U2 were calculated using a 95% confidence level. The population standard deviation is assumed to be 15.0 mg/kg.

$$Given: \alpha = 0.05, E = 5.0\,mg/kg, \sigma = 15.0\,mg/kg$$

$$n = \left[\frac{z_{\frac{\alpha}{2}}\sigma}{E}\right]^2 \qquad z_{\frac{\alpha}{2}} = z_{\frac{.05}{2}} = 1.96$$

$$= \left[\frac{(1.96)(15)}{5}\right]^2$$

$$= 34.5744$$

$$= 35\,samples$$

As a result of these calculations, the test planners requested 35 usable systematic samples from each area, U1 and U2 for both May and August of 2010 for analysis.

## Hypothesis Tests Comparing MIS, Systematic, and Judgmental Sampling

In 2008, Washington Department of Ecology in cooperation with DOE (Department of Energy) and CHPRC (CH2M Hill Plateau Remediation Company) collected two soil samples from a single location immediately adjacent to the Point of Discharge of the 216-S-19 Pond, a waste site of the 200-MG-1 Operable Unit. These samples were designed as "screening" in order to determine if the site would be a suitable location to conduct a comparison of three (Judgmental, Systematic Random, and Multi-Incremental) sampling designs. Based on the results of the Washington State Department of Ecology screening effort, COPCs (Chemical of Potential Concern) were selected and are the following: Chromium, Copper, Zinc, Mercury, Uranium-238, Uranium-233/234, Uranium-235, Plutonium-238, Plutonium-239/240, Americium-241, and Nitrate.

MIS sample points were selected by dividing each Decision Unit into grids with 100 units. One sample increment was collected from each grid unit for a total of 100 increments to comprise a single, multi-incremental "parent" sample. Four field replicate samples were also collected from each of the 100 grid-units in each Decision Unit.

Systematic Random sample points were selected using the 100-grid locations established in the MIS scheme above. Discrete sampling locations were proportioned out evenly within each Decision Unit using a random start point. In order to achieve a uniform distribution over each Decision Unit, 42 sample locations were identified rather than 40 as specified in the SAP.

Judgmental sample points were selected primarily based on field observations, professional judgment, and radiological field screening measurements. One location of highest expected (encountered) concentration will be selected, with the remaining four locations fanning out from that position. A total of five locations within each of the two Decision Units were identified and sampled.

Comparison testing of the mean concentration level of each of the elements listed above was done for these three different sampling techniques. Due to the nature of MIS sampling, the Central Limit Theorem applies, and this data can be assumed to be normally distributed as can the Systematic sampling data. The same assumption was made for the Judgmental sample data. However, any results involving Judgmental sampling should be viewed with caution as the assumption of normality is questionable. Due to time constraints, only the data collected on August 22, 2010 from area U1 were used in this analysis.

All comparison tests were conducted using a Student's t Distribution. The results for each test are summarized by element in various tables presented on the following pages. All 33 hypothesis tests used the following general format, test statistic, significance level, and critical value.

## General Approach: Testing a Claim about Two Independent Population Means

**Claim:** There is no difference, when sampling the same area, between the mean element levels obtained from MIS sampling, Systematic sampling, and Judgmental sampling.

Hypothesis Test:

$H_o : \mu_1 - \mu_2 = 0 \quad (Claim)$

$H_1 : \mu_1 - \mu_2 \neq 0$

Test Statistic:

$$t^* = \frac{\left(\bar{x}_1 - \bar{x}_2\right) - \left(\mu_1 - \mu_2\right)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

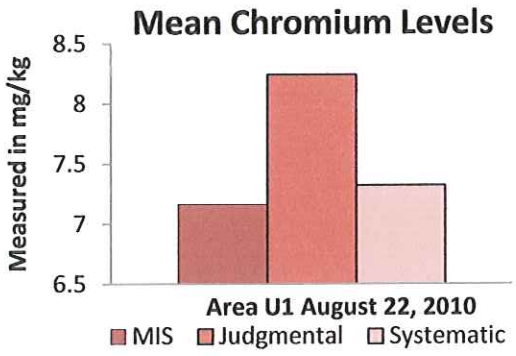
Significance Level: $\alpha = 0.05$ Critical Value: $t_{0.05/2} = \pm 2.776$ Degrees of Freedom: 4

Each element section is also accompanied by a bar graph which provides a visual comparison of the three sampling techniques and a table displaying the sample statistics used each hypothesis test. The results of these hypothesis tests are presented in a table along with the outcomes and written conclusions for each set of comparisons.

## 1. Comparison Tests Involving Chromium

### Chromium Summary Statistics in mg/kg

| Sampling Method | Mean | Standard Deviation |
|---|---|---|
| MIS | 7.16 | 0.384707 |
| Judgmental | 8.24 | 0.559464 |
| Systematic | 7.3194444 | 1.4089144 |



## Chromium Hypothesis Test Results

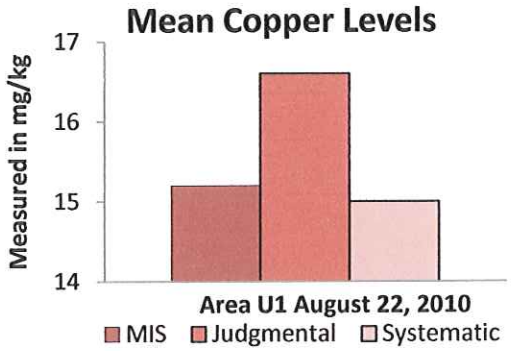
| Hypothesis Test | Test Statistic | Outcome |
|---|---|---|
| **MIS vs Systematic** | -0.548 | Fail to Reject $H_0$ |
| **MIS vs Judgmental** | -3.557 | Reject $H_0$ |
| **Systematic vs Judgmental** | -2.683 | Fail to Reject $H_0$ |

**Conclusion:** Since the test statistics for both the comparison of MIS and Systematic sampling as well as Systematic and Judgmental sampling (-0.548 and -2.683 respectively) are greater than the critical value of -2.776 and less than the critical value of 2.776, fail to reject $H_0$. There is insufficient evidence to reject the claim that there is no difference between mean Chromium levels obtained from MIS and Systematic sampling as well as Systematic and Judgmental sampling. However, the test statistic for the comparison of MIS and Judgmental sampling (-3.557) is less than the critical value of -2.766, reject $H_0$. There is sufficient evidence to reject the claim that there is no difference between Chromium levels obtained from MIS and Judgmental sampling.

## 2. Comparison Tests Involving Copper

### Copper Summary Statistics in mg/kg

| Sampling Method | Mean | Standard Deviation |
|---|---|---|
| **MIS** | 15.2 | 1.64316673 |
| **Judgmental** | 16.6 | 2.607680962 |
| **Systematic** | 15.02777778 | 1.79660173 |




## Copper Hypothesis Test Results

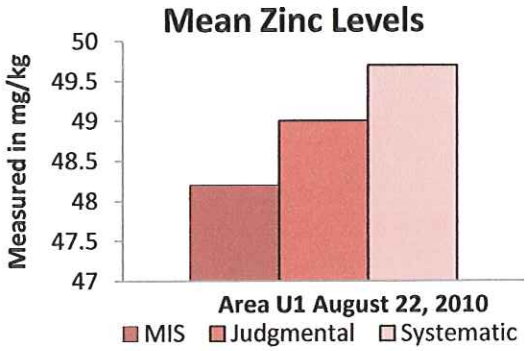
| Hypothesis Test | Test Statistic | Outcome |
|---|---|---|
| **MIS vs Systematic** | 0.217 | Fail to Reject $H_0$ |
| **MIS vs Judgmental** | -1.016 | Fail to Reject $H_0$ |
| **Systematic vs Judgmental** | -1.306 | Fail to Reject $H_0$ |

**Conclusion:** Since the test statistics for all three of the comparison of MIS and Systematic, MIS and Judgmental sampling as well as Systematic and Judgmental sampling (0.217, -1.0157 and -1.306 respectively) are greater than the critical value of -2.776 and less than the critical value of 2.776, fail to reject $H_0$. There is insufficient evidence to reject the claim that there is no difference between mean Copper levels obtained from MIS and Systematic sampling, MIS and Judgmental as well as Systematic and Judgmental sampling.

## 3. Comparison Tests Involving Zinc

### Zinc Summary Statistics in mg/kg

| Sampling Method | Mean | Standard Deviation |
|---|---|---|
| MIS | 48.2 | 1.095444512 |
| Judgmental | 49 | 2.34520788 |
| Systematic | 49.69444444 | 2.955087085 |




### Zinc Hypothesis Test Results

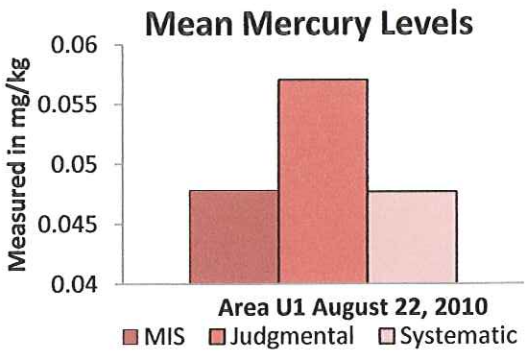
| Hypothesis Test | Test Statistic | Outcome |
|---|---|---|
| MIS vs Systematic | -2.151 | Fail to Reject $H_0$ |
| MIS vs Judgmental | -0.691 | Fail to Reject $H_0$ |
| Systematic vs Judgmental | 0.596 | Fail to Reject $H_0$ |

**Conclusion:** Since the test statistics for all three of the comparison of MIS and Systematic, MIS and Judgmental sampling as well as Systematic and Judgmental sampling (-2.151, -0.691 and 0.596 respectively) are greater than the critical value of -2.776 and less than the critical value of 2.776, fail to reject $H_0$. There is insufficient evidence to reject the claim that there is no difference between mean Zinc levels obtained from MIS and Systematic sampling, MIS and Judgmental as well as Systematic and Judgmental sampling

## 4. Comparison Tests Involving Mercury

### Mercury Summary Statistics in mg/kg

| Sampling Method | Mean | Standard Deviation |
|---|---|---|
| MIS | 0.0478 | 0.006016644 |
| Judgmental | 0.057 | 0.017392527 |
| Systematic | 0.047666667 | 0.030792392 |




### Mercury Hypothesis Test Results

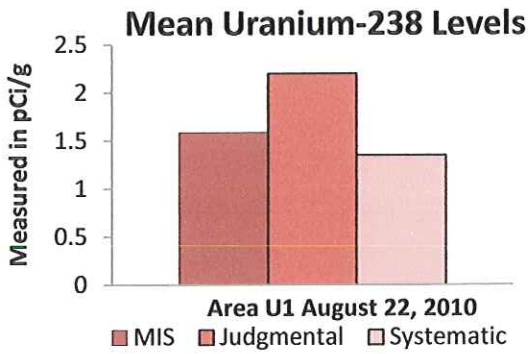
| Hypothesis Test | Test Statistic | Outcome |
|---|---|---|
| MIS vs Systematic | 0.0230 | Fail to Reject $H_0$ |
| MIS vs Judgmental | -1.118 | Fail to Reject $H_0$ |
| Systematic vs Judgmental | -1.002 | Fail to Reject $H_0$ |

**Conclusion:** Since the test statistics for all three of the comparison of MIS and Systematic, MIS and Judgmental sampling as well as Systematic and Judgmental sampling (0.0230, -1.118, and -1.002 respectively) are greater than the critical value of -2.776 and less than the critical value of 2.776, fail to reject $H_0$. There is insufficient evidence to reject the claim that there is no difference between mean Mercury levels obtained from MIS and Systematic sampling, MIS and Judgmental as well as Systematic and Judgmental sampling

## 5. Comparison Tests Involving Uranium-238

### Uranium-238 Summary Statistics in pCi/g

| Sampling Method | Mean | Standard Deviation |
|---|---|---|
| MIS | 1.584 | 0.085322916 |
| Judgmental | 2.196 | 1.52671103 |
| Systematic | 1.346388889 | 0.810996399 |



## Uranium-238 Hypothesis Test Results

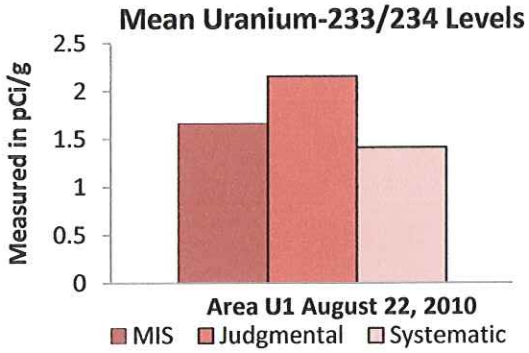
| Hypothesis Test | Test Statistic | Outcome |
|---|---|---|
| **MIS vs Systematic** | 1.692 | Fail to Reject $H_0$ |
| **MIS vs Judgmental** | -0.895 | Fail to Reject $H_0$ |
| **Systematic vs Judgmental** | -1.221 | Fail to Reject $H_0$ |

**Conclusion:** Since the test statistics for all three of the comparison of MIS and Systematic, MIS and Judgmental sampling as well as Systematic and Judgmental sampling (1.692, -0.895 and -1.221 respectively) are greater than the critical value of -2.776 and less than the critical value of 2.776, fail to reject $H_0$. There is insufficient evidence to reject the claim that there is no difference between mean Uranium-238 levels obtained from MIS and Systematic sampling, MIS and Judgmental as well as Systematic and Judgmental sampling.

## 6. Comparison Tests Involving Uranium-233/234

### Uranium-233/234 Summary Statistics in pCi/g

| Sampling Method | Mean | Standard Deviation |
|---|---|---|
| **MIS** | 1.662 | 0.094710084 |
| **Judgmental** | 2.154 | 1.320219679 |
| **Systematic** | 1.410555556 | 0.815534687 |




## Uranium-233/234 Hypothesis Test Results

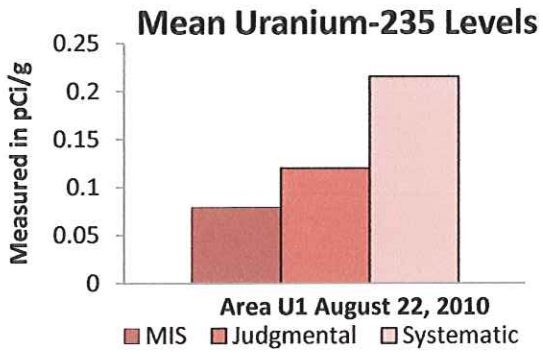
| Hypothesis Test | Test Statistic | Outcome |
|---|---|---|
| **MIS vs Systematic** | 1.767 | Fail to Reject $H_0$ |
| **MIS vs Judgmental** | -0.831 | Fail to Reject $H_0$ |
| **Systematic vs Judgmental** | -1.227 | Fail to Reject $H_0$ |

**Conclusion:** Since the test statistics for all three of the comparison of MIS and Systematic, MIS and Judgmental sampling as well as Systematic and Judgmental sampling (1.767. -0.831 and -1.227 respectively) are greater than the critical value of -2.776 and less than the critical value of 2.776, fail to reject $H_0$. There is insufficient evidence to reject the claim that there is no difference between mean Uranium-233/234 levels obtained from MIS and Systematic sampling, MIS and Judgmental as well as Systematic and Judgmental sampling.

## 7. Comparison Tests Involving Uranium-235

### Uranium-235 Summary Statistics in pCi/g

| Sampling Method | Mean | Standard Deviation |
|---|---|---|
| MIS | 0.079 | 0.015700318 |
| Judgmental | 0.1198 | 0.06422772 |
| Systematic | 0.108555556 | 0.215240257 |




### Uranium-235 Hypothesis Test Results

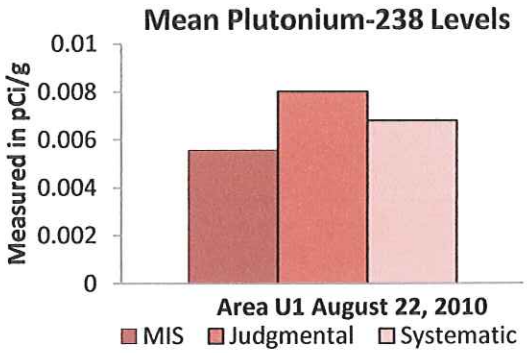
| Hypothesis Test | Test Statistic | Outcome |
|---|---|---|
| MIS vs Systematic | -0.809 | Fail to Reject $H_0$ |
| MIS vs Judgmental | -1.379 | Fail to Reject $H_0$ |
| Systematic vs Judgmental | -0.245 | Fail to Reject $H_0$ |

**Conclusion:** Since the test statistics for all three of the comparison of MIS and Systematic, MIS and Judgmental sampling as well as Systematic and Judgmental sampling (-0.809, -1.379 and -0.245 respectively) are greater than the critical value of -2.776 and less than the critical value of 2.776, fail to reject $H_0$. There is insufficient evidence to reject the claim that there is no difference between mean Uranium-235 levels obtained from MIS and Systematic sampling, MIS and Judgmental as well as Systematic and Judgmental sampling.

## 8. Comparison Tests Involving Plutonium-238

### Plutonium-238 Summary Statistics in pCi/g

| Sampling Method | Mean | Standard Deviation |
|---|---|---|
| MIS | 0.00556 | 0.00432583 |
| Judgmental | 0.008 | 0.00509902 |
| Systematic | 0.006794444 | 0.004738411 |




### Plutonium-238 Hypothesis Test Results

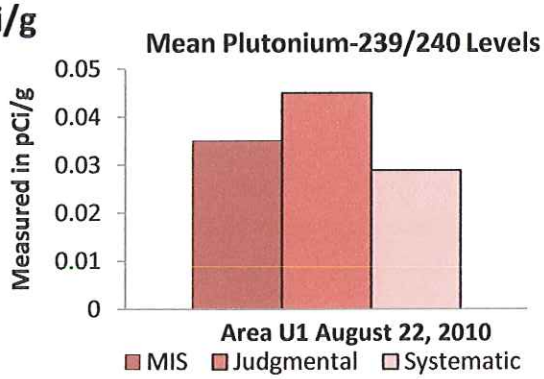
| Hypothesis Test | Test Statistic | Outcome |
|---|---|---|
| MIS vs Systematic | -0.591 | Fail to Reject $H_0$ |
| MIS vs Judgmental | -0.816 | Fail to Reject $H_0$ |
| Systematic vs Judgmental | -0.501 | Fail to Reject $H_0$ |

**Conclusion:** Since the test statistics for all three of the comparison of MIS and Systematic, MIS and Judgmental sampling as well as Systematic and Judgmental sampling (-0.591, -0.816 and -0.501 respectively) are greater than the critical value of -2.776 and less than the critical value of 2.776, fail to reject $H_0$. There is insufficient evidence to reject the claim that there is no difference between mean Plutonium-238 levels obtained from MIS and Systematic sampling, MIS and Judgmental as well as Systematic and Judgmental sampling.

## 9. Comparison Tests Involving Plutonium-239/240

### Plutonium-239/240 Summary Statistics in pCi/g

| Sampling Method | Mean | Standard Deviation |
|---|---|---|
| MIS | 0.035 | 0.008154753 |
| Judgmental | 0.045 | 0.031024184 |
| Systematic | 0.028888889 | 0.033041418 |



## Plutonium-239/240 Hypothesis Test Results

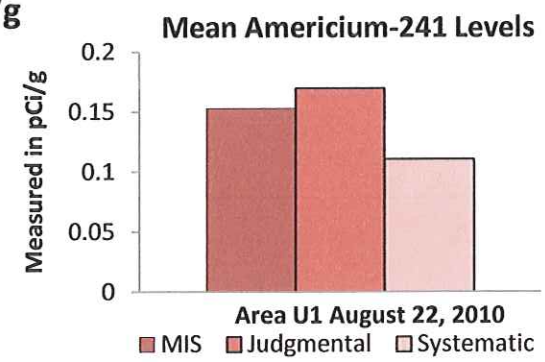
| Hypothesis Test | Test Statistic | Outcome |
|---|---|---|
| **MIS vs Systematic** | 0.925 | Fail to Reject $H_0$ |
| **MIS vs Judgmental** | -0.697 | Fail to Reject $H_0$ |
| **Systematic vs Judgmental** | -1.079 | Fail to Reject $H_0$ |

**Conclusion:** Since the test statistics for all three of the comparison of MIS and Systematic, MIS and Judgmental sampling as well as Systematic and Judgmental sampling (0.925, -0.697 and -1.079 respectively) are greater than the critical value of -2.776 and less than the critical value of 2.776, fail to reject $H_0$. There is insufficient evidence to reject the claim that there is no difference between mean Plutonium-239/240 levels obtained from MIS and Systematic sampling, MIS and Judgmental as well as Systematic and Judgmental sampling.

## 10. Comparison Tests Involving Americium-241

### Americium-241 Summary Statistics in pCi/g

| Sampling Method | Mean | Standard Deviation |
|---|---|---|
| **MIS** | 0.1528 | 0.023805462 |
| **Judgmental** | 0.1696 | 0.111215107 |
| **Systematic** | 0.110388889 | 0.186870357 |




## Americium-241 Hypothesis Test Results

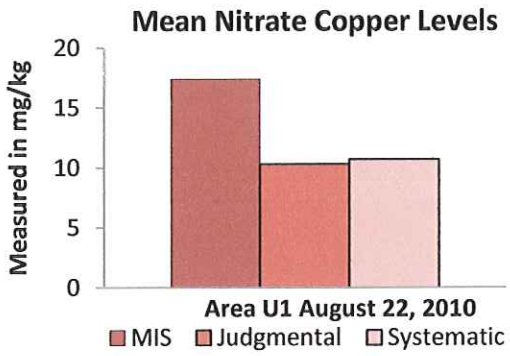
| Hypothesis Test | Test Statistic | Outcome |
|---|---|---|
| **MIS vs Systematic** | 1.289 | Fail to Reject $H_0$ |
| **MIS vs Judgmental** | -0.330 | Fail to Reject $H_0$ |
| **Systematic vs Judgmental** | -1.009 | Fail to Reject $H_0$ |

**Conclusion:** Since the test statistics for all three of the comparison of MIS and Systematic, MIS and Judgmental sampling as well as Systematic and Judgmental sampling (1.289. -0.330 and -1.009 respectively) are greater than the critical value of -2.776 and less than the critical value of 2.776, fail to reject $H_0$. There is insufficient evidence to reject the claim that there is no difference between mean Americium-241 levels obtained from MIS and Systematic sampling, MIS and Judgmental as well as Systematic and Judgmental sampling.

## 11. Comparison Tests Involving Nitrate

### Nitrate Summary Statistics in mg/kg

| Sampling Method | Mean | Standard Deviation |
|---|---|---|
| MIS | 17.4 | 1.816590212 |
| Judgmental | 10.28 | 11.4305293 |
| Systematic | 10.691666667 | 8.949425361 |




### Nitrate Hypothesis Test Results

| Hypothesis Test | Test Statistic | Outcome |
|---|---|---|
| MIS vs Systematic | 3.950 | Reject $H_0$ |
| MIS vs Judgmental | 1.376 | Fail to Reject $H_0$ |
| Systematic vs Judgmental | 0.07731 | Fail to Reject $H_0$ |

**Conclusion:** Since the test statistics for MIS and Judgmental sampling as well as Systematic and Judgmental sampling (1.376 and 0.07731 respectively) are greater than the critical value of -2.776 and less than the critical value of 2.776, fail to reject $H_0$. There is insufficient evidence to reject the claim that there is no difference between mean Nitrate levels obtained MIS and Judgmental as well as Systematic and Judgmental sampling. However, the test statistic for the comparison of MIS and Systematic sampling (3.950) is greater than the critical value of 2.766, reject $H_0$. There is sufficient evidence to reject the claim that there is no difference between Zinc levels obtained from MIS and Systematic sampling.

**Comparison Summary:** The significance level, represented by $\alpha$, is the probability that the test statistic will fall in the critical region when the null hypothesis is actually true. The critical region, also known as the rejection region, is the set of all values of the test statistic which, if they occur, will lead us to decide that there is a difference. That is, cause the null hypothesis to be rejected in favor of the alternative hypothesis. The critical value is any value that separates the critical region (where we reject the null hypothesis) from the values of the test statistic that do not lead to rejection of the null hypothesis.

The hypothesis tests above all have a significance level of $\alpha = 0.05$. This means that five times out of 100 we will reject this claim when in fact it is true. We ran 33 hypothesis tests. Out of the 33 tests, all of them failed to reject the claim that there is no difference, when sampling the same area, between the mean element levels obtained from MIS sampling, Systematic sampling, and Judgmental sampling except for two of them. There were 11 tests involving MIS and Systematic sampling. Of those, only one, Nitrate, was rejected. Because of the significance level, it is impossible to know if we rejected the claim when we should have or not. This rejection should be further analyzed to determine if it truly is a rejection of the claim and if it has significance.

In the comparison test involving Chromium for MIS vs Judgmental, the hypothesis test results indicate a rejected claim. Here we can disregard the rejected claim as judgmental sampling is biased and should not be considered in concluding the validity of the hypothesis testing.

| Location | Date | ID | Chromium | Copper | Zinc | Mercury | U 238 | U233/234 | U235 | Pu238 | Pu239/240 | Am 241 | Nitrate | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U1 | 8/22/2010 | B23NF3 | 7 | 14 | 48 | 0.047 | 1.62 | 1.73 | 0.085 | 0.0007 | 0.036 | 0.149 | 18 | |
| | | B23NH6 | 7 | 15 | 47 | 0.058 | 1.71 | 1.68 | 0.07 | 0.01 | 0.027 | 0.152 | 17 | |
| | | B23NH7 | 7.2 | 14 | 48 | 0.046 | 1.57 | 1.55 | 0.093 | 0.009 | 0.039 | 0.188 | 15 | MIS closeout |
| | MIS closeout | B23NH8 | 7.8 | 15 | 50 | 0.042 | 1.49 | 1.58 | 0.091 | 0.0068 | 0.027 | 0.154 | 20 | |
| | | B23NH9 | 6.8 | 18 | 48 | 0.046 | 1.53 | 1.77 | 0.056 | 0.0013 | 0.046 | 0.121 | 17 | |
| | colmn means | | 7.16 | 15.2 | 48.2 | 0.0478 | 1.584 | 1.662 | 0.079 | 0.00556 | 0.035 | 0.1528 | 17.4 | |
| | clmn StDev | | 0.3847077 | 1.6432 | 1.095 | 0.00602 | 0.08532 | 0.09471 | 0.0157 | 0.00433 | 0.0081548 | 0.02381 | 1.81659 | |
| U1 | | B23NP4 | 8.4 | 20 | 51 | 0.059 | 1.92 | 2.06 | 0.112 | 0.004 | 0.036 | 0.281 | 9.3 | |
| | | B23NP5 | 8.2 | 17 | 50 | 0.055 | 4.6 | 4.18 | 0.194 | 0.002 | 0.023 | 0.094 | 0.8 | Judgemental |
| | Judgemental | B23NP6 | 7.3 | 14 | 46 | 0.056 | 1.29 | 1.42 | 0.118 | 0.014 | 0.094 | 0.147 | 5.5 | closeout |
| | | B23NP7 | 8.6 | 18 | 51 | 0.082 | 2.56 | 2.45 | 0.154 | 0.008 | 0.055 | 0.287 | 30 | |
| | | B23NP8 | 8.7 | 14 | 47 | 0.033 | 0.61 | 0.66 | 0.021 | 0.012 | 0.017 | 0.039 | 5.8 | |
| | column mean | | 8.24 | 16.6 | 49 | 0.057 | 2.196 | 2.154 | 0.1198 | 0.008 | 0.045 | 0.1696 | 10.28 | |
| | Clmn StDev | | 0.559464 | 2.6077 | 2.345 | 0.01739 | 1.52677 | 1.32022 | 0.06423 | 0.0051 | 0.0310242 | 0.11122 | 11.4305 | |
| U1 | Systematic | B241X6 | 7 | 15 | 46 | 0.051 | 1.74 | 2.05 | 0.089 | 0.003 | 0.018 | 0.072 | 6.1 | Systematic |
| | | B241X7 | 9.9 | 20 | 55 | 0.044 | 1.33 | 1.5 | 0.11 | 0.003 | 0.035 | 0.047 | 16 | closeout |
| | | B241X8 | 7.4 | 14 | 47 | 0.036 | 0.64 | 0.74 | 0.06 | 0.008 | 0.034 | 0.113 | 2.5 | |
| | | B241X9 | 7.6 | 13 | 49 | 0.05 | 0.59 | 0.55 | 0.038 | 0.01 | 0.15 | 1.09 | 2.7 | |
| | | B241Y0 | 6.4 | 13 | 47 | 0.034 | 0.94 | 1.15 | 0.069 | 0.0072 | 0.028 | 0.111 | 15 | |
| | | B241Y1 | 8.8 | 16 | 52 | 0.035 | 1.94 | 2.04 | 0.098 | 0.013 | 0.0008 | 0.009 | 34 | |
| | | B241Y2 | 8.5 | 15 | 52 | 0.041 | 1.87 | 1.73 | 0.086 | 0.0053 | 0.019 | 0.063 | 35 | |
| | | B241Y3 | 6.4 | 14 | 48 | 0.033 | 1.36 | 1.31 | 0.092 | 0 | 0.027 | 0.059 | 18 | |
| | | B241Y4 | 9.5 | 19 | 54 | 0.036 | 1.05 | 1.15 | 0.049 | 0.015 | 0.024 | 0.035 | 34 | |
| | | B241Y5 | 7.5 | 15 | 51 | 0.048 | 1.07 | 1.13 | 0.043 | 0.0028 | 0.068 | 0.164 | 16 | |
| | | B241Y6 | 9.2 | 17 | 52 | 0.034 | 0.57 | 0.68 | 0.02 | 0.0051 | 0.0053 | 0.003 | 2.8 | |
| | | B241Y7 | 6.9 | 14 | 50 | 0.034 | 1.07 | 1.22 | 0.032 | 0.009 | 0.021 | 0.143 | 14 | |
| | | B241Y8 | 8 | 16 | 52 | 0.034 | 0.88 | 0.96 | 0.058 | 0.012 | 0.029 | 0.085 | 12 | |
| | | B24200 | 10 | 17 | 56 | 0.035 | 0.75 | 0.71 | 0.025 | 0.009 | 0.012 | 0.066 | 19 | |
| | | B24201 | 7.4 | 16 | 52 | 0.034 | 0.79 | 0.8 | 0.032 | 0 | 0.007 | 0.037 | 18 | |
| | | B24202 | 6.4 | 13 | 48 | 0.033 | 1.35 | 1.42 | 0.143 | 0.017 | 0 | 0.042 | 7.2 | |
| | | B24203 | 8.7 | 17 | 55 | 0.035 | 0.9 | 0.92 | 0.057 | 0.0007 | 0.0061 | 0.053 | 15 | |
| | | B24204 | 8.5 | 16 | 52 | 0.092 | 0.8 | 0.8 | 0.037 | 0.011 | 0.084 | 0.307 | 12 | |
| | | B24207 | 8.5 | 16 | 49 | 0.041 | 1.28 | 1.34 | 0.093 | 0.0067 | 0.03 | 0.09 | 4.4 | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B24208 | 9.2 | 17 | 52 | 0.2 | 3.02 | 2.8 | 1.34 | 0.009 | 0.059 | 0.241 | 5.5 | |
| | B24209 | 9 | 18 | 52 | 0.035 | 4.03 | 4.24 | 0.171 | 0.003 | 0.009 | 0.032 | 4.3 | |
| | B24210 | 7.5 | 15 | 50 | 0.034 | 3.2 | 3.01 | 0.165 | 0.0024 | 0.013 | 0.015 | 7.4 | |
| | B24211 | 5.6 | 14 | 50 | 0.033 | 0.62 | 0.69 | 0.026 | 0.0007 | 0.027 | 0.024 | 6.8 | |
| | B24212 | 6.8 | 14 | 48 | 0.034 | 0.49 | 0.6 | 0.053 | 0.0045 | 0.0068 | 0.006 | 7.9 | |
| | B24213 | 5.8 | 13 | 48 | 0.033 | 0.43 | 0.43 | 0.014 | 0.004 | 0.012 | 0.029 | 3.8 | |
| | B24215 | 6.7 | 13 | 48 | 0.047 | 1.76 | 1.78 | 0.114 | 0.015 | 0.039 | 0.121 | 7.5 | |
| | B24216 | 5.6 | 13 | 47 | 0.038 | 1.17 | 1.32 | 0.076 | 0.011 | 0.027 | 0.107 | 4.6 | |
| | B24217 | 5.8 | 13 | 47 | 0.033 | 0.69 | 0.66 | 0.052 | 0.005 | 0.003 | 0.021 | 13 | |
| | B24218 | 5.5 | 16 | 49 | 0.042 | 1.79 | 1.69 | 0.076 | 0.016 | 0.131 | 0.38 | 2.2 | |
| | B24219 | 6.2 | 13 | 50 | 0.033 | 1.36 | 1.28 | 0.049 | 0.0066 | 0.011 | 0.127 | 2 | |
| | B24220 | 7.8 | 15 | 50 | 0.098 | 0.74 | 0.77 | 0.052 | 0.001 | 0.011 | 0.035 | 10 | |
| | B24221 | 5.5 | 14 | 47 | 0.084 | 0.82 | 1 | 0.049 | 0.0061 | 0.01 | 0.071 | 3.2 | |
| | B24222 | 5.7 | 15 | 49 | 0.059 | 1.87 | 2.41 | 0.146 | 0.004 | 0.033 | 0.074 | 2.2 | |
| | B24224 | 6.1 | 14 | 46 | 0.055 | 1.79 | 1.85 | 0.078 | 0.0098 | 0.025 | 0.063 | 4.3 | |
| | B24225 | 4.9 | 14 | 42 | 0.033 | 1.29 | 1.42 | 0.059 | 0.0027 | 0.008 | 0.016 | 13 | |
| | B24226 | 7.2 | 14 | 47 | 0.045 | 2.48 | 2.63 | 0.157 | 0.006 | 0.017 | 0.023 | 3.5 | |
| | column mean | 7.3194444 | 15.028 | 49.69 | 0.04767 | 1.34639 | 1.410556 | 0.10856 | 0.00679 | 0.0288889 | 0.11039 | 10.6917 | |
| | clmn StDev | 1.4089144 | 1.7966 | 2.955 | 0.03079 | 0.811 | 0.815535 | 0.21524 | 0.00474 | 0.0330414 | 0.18687 | 8.94943 | |

| Location | Date | ID | Chromium | Copper | Zinc | Mercury | U 238 | U233/234 | U235 | Pu238 | Pu239/240 | Am 241 | Nitrate | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U2 | 8/22/2010 | B23NJ0 | 3.6 | 15 | 29 | 0.073 | 1.66 | 1.63 | 0.121 | 0.023 | 0.111 | 0.189 | 26 | |
| | | B23NJ1 | 6.8 | 14 | 47 | 0.042 | 1.06 | 1.07 | 0.077 | 0.0076 | 0.07 | 0.159 | 26 | MIS Closeout |
| | | B23NJ2 | 6.4 | 14 | 46 | 0.052 | 1.05 | 1.14 | 0.061 | 0.0076 | 0.127 | 0.127 | 24 | |
| | MIS Closeout | B23NJ3 | 6.3 | 14 | 47 | 0.049 | 1.25 | 1.13 | 0.082 | 0.0065 | 0.096 | 0.186 | 20 | |
| | | B23NJ4 | 6.1 | 23 | 42 | 0.043 | 1.2 | 1.13 | 0.044 | 0.0034 | 0.064 | 0.132 | 24 | |
| | column mean | | 5.84 | 16 | 42.2 | 0.0518 | 1.244 | 1.22 | 0.077 | 0.00962 | 0.0936 | 0.1586 | 24 | |
| | clmn StDev | | 1.2778889 | 3.937 | 7.662 | 0.01256 | 0.24825 | 0.230868 | 0.02875 | 0.00767 | 0.0267264 | 0.02907 | 2.44949 | |
| U2 | | B23NP9 | 6.3 | 14 | 47 | 0.047 | 0.86 | 0.93 | 0.045 | 0.029 | 0.264 | 0.54 | 9.9 | |
| | | B23NR1 | 7.9 | 15 | 49 | 0.034 | 1.13 | 1.16 | 0.089 | 0.01 | 0.042 | 0.155 | 45 | Judgmental |
| | Judgmental | B23NR2 | 7.2 | 15 | 49 | 0.033 | 1.3 | 1.38 | 0.088 | 0.012 | 0.088 | 0.183 | 11 | closeout |
| | | B23NR3 | 6.8 | 15 | 46 | 0.034 | 0.8 | 0.91 | 0.071 | 0.01 | 0.024 | 0.037 | 9.7 | |
| | | B23NR4 | 7.9 | 15 | 50 | 0.035 | 1.66 | 1.59 | 0.039 | 0 | 0.021 | 0.117 | 27 | |
| | colmn mean | | 7.22 | 14.8 | 48.2 | 0.0366 | 1.15 | 1.194 | 0.0664 | 0.0122 | 0.0878 | 0.2064 | 20.52 | |
| | clmn StDev | | 0.6978539 | 0.4472 | 1.643 | 0.00586 | 0.34986 | 0.292797 | 0.02349 | 0.0105 | 0.1020745 | 0.1944 | 15.506 | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U2 | Systematic | B24227 | 6.3 | 10 | 42 | 0.034 | 0.51 | 0.5 | 0.02 | 0 | 0.015 | 0.014 | 16 | |
| | | B24228 | 6.3 | 16 | 47 | 0.035 | 0.52 | 0.55 | 0.023 | 0.014 | 0.018 | 0.045 | 15 | Systematic |
| | | B24229 | 5.5 | 14 | 47 | 0.035 | 0.45 | 0.46 | 0.016 | 0.0026 | 0.0079 | 0.009 | 13 | closeout |
| | | B24230 | 6.5 | 17 | 49 | 0.034 | 0.45 | 0.46 | 0.008 | 0.0014 | 0.01 | 0.002 | 5.9 | |
| | | B24232 | 6 | 13 | 47 | 0.034 | 0.432 | 0.47 | 0.041 | 0.005 | 0.008 | 0.011 | 5.8 | |
| | | B24233 | 4.6 | 13 | 46 | 0.034 | 0.53 | 0.54 | 0.035 | 0.007 | -0.0012 | 0.006 | 2.1 | |
| | | B24234 | 6.9 | 14 | 47 | 0.035 | 0.58 | 0.72 | 0.044 | 0.012 | 0.035 | 0.044 | 6.8 | |
| | | B24235 | 6.1 | 14 | 46 | 0.034 | 1.21 | 1.08 | 0.066 | 0.02 | 0.029 | 0.096 | 5.5 | |
| | | B24236 | 7.9 | 14 | 48 | 0.035 | 1.09 | 1.08 | 0.05 | 0.01 | 0.008 | 0.053 | 5.6 | |
| | | B24237 | 5.3 | 14 | 46 | 0.033 | 0.86 | 0.9 | 0.047 | 0.003 | 0.038 | 0.038 | 5.6 | |
| | | B24238 | 6.8 | 13 | 45 | 0.034 | 0.86 | 0.92 | 0.052 | 0.011 | 0.012 | 0.022 | 5.9 | |
| | | B24239 | 7.1 | 14 | 47 | 0.047 | 1.15 | 1.07 | 0.072 | -0.0002 | 0.033 | 0.116 | 4.3 | |
| | | B24240 | 6.2 | 14 | 46 | 0.034 | 0.88 | 0.92 | 0.076 | 0.019 | 0.013 | 0.057 | 5.4 | |
| | | B24241 | 6.6 | 14 | 46 | 0.035 | 0.55 | 0.52 | 0.044 | 0.01 | 0.041 | 0.047 | 12 | |
| | | B24243 | 6.8 | 14 | 46 | 0.034 | 1.08 | 1.02 | 0.068 | 0.011 | 0.019 | 0.151 | 18 | |
| | | B24244 | 7 | 14 | 47 | 0.035 | 1.34 | 1.38 | 0.07 | 0.0067 | 0.012 | 0.138 | 12 | |
| | | B24245 | 6.8 | 14 | 49 | 0.035 | 1 | 1.02 | 0.054 | 0.0052 | 0.035 | 0.119 | 15 | |
| | | B24246 | 7.4 | 14 | 50 | 0.035 | 1.38 | 1.31 | 0.05 | 0.008 | 0.026 | 0.121 | 8.7 | |
| | | B24247 | 7.5 | 14 | 50 | 0.035 | 1.42 | 1.59 | 0.071 | -0.001 | 0.028 | 0.08 | 24 | |
| | | B24248 | 5.9 | 12 | 43 | 0.034 | 0.55 | 0.56 | 0.014 | 0.017 | 0.007 | 0.002 | 2 | |
| | | B24249 | 5.8 | 15 | 49 | 0.034 | 0.56 | 0.67 | 0.042 | 0.009 | 0.063 | 0.059 | 6.1 | |
| | | B24250 | 7.2 | 15 | 49 | 0.048 | 1.14 | 1.18 | 0.143 | 0.012 | 0.09 | 0.197 | 12 | |
| | | B24252 | 7.4 | 13 | 50 | 0.035 | 0.66 | 0.62 | 0.029 | 0.012 | 0.031 | 0.053 | 15 | |
| | | B24253 | 8.6 | 16 | 49 | 0.036 | 0.84 | 0.88 | 0.055 | 0.01 | 0.026 | 0.103 | 6.6 | |
| | | B24254 | 7.7 | 15 | 49 | 0.035 | 0.79 | 0.75 | 0.037 | 0.0007 | 0.018 | 0.038 | 9.9 | |
| | | B24255 | 9 | 16 | 53 | 0.041 | 1.62 | 1.7 | 0.023 | 0.0042 | 0.055 | 0.249 | 14 | |
| | | B24256 | 9.6 | 14 | 49 | 0.035 | 0.79 | 0.78 | 0.027 | 0.0017 | 0.008 | 0.021 | 5.5 | |
| | | B24257 | 5 | 18 | 49 | 0.033 | 0.46 | 0.412 | 0.015 | -0.0009 | 0.004 | 0.009 | 4.2 | |
| | | B24258 | 7.6 | 16 | 50 | 0.083 | 1.66 | 1.83 | 0.115 | 0.006 | 0.159 | 0.252 | 15 | |
| | | B24259 | 6.9 | 14 | 48 | 0.072 | 1.99 | 1.9 | 0.097 | 0.0074 | 0.108 | 0.191 | 17 | |
| | | B24260 | 8.3 | 16 | 49 | 0.14 | 2.82 | 2.72 | 0.154 | 0.008 | 0.179 | 0.403 | 6.6 | |
| | | B24261 | 6.2 | 13 | 48 | 0.034 | 0.8 | 0.73 | 0.043 | 0.008 | 0.048 | 0.031 | 4.3 | |
| | | B24262 | 7.3 | 14 | 47 | 0.046 | 1.01 | 0.89 | 0.074 | 0.013 | 0.032 | 0.132 | 7.1 | |
| | | B24263 | 6.5 | 14 | 47 | 0.034 | 0.72 | 0.62 | 0.045 | 0.011 | 0.039 | 0.114 | 11 | |
| | | B24264 | 5.9 | 13 | 47 | 0.034 | 0.65 | 0.71 | 0.05 | 0.019 | 0.096 | 0.089 | 2.7 | |
| | | B24265 | 7 | 16 | 48 | 0.051 | 0.96 | 0.96 | 0.059 | 0.008 | 0.225 | 0.303 | 10 | |
| | | B24267 | 5.7 | 13 | 49 | 0.038 | 1.79 | 1.92 | 0.152 | 0.002 | 0.013 | 0.014 | 12 | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | B24268 | 7.2 | 16 | 50 | 0.16 | 2.6 | 2.66 | 0.129 | 0.005 | 0.064 | 0.118 | 15 | |
| | | B24269 | 9.3 | 16 | 50 | 0.1 | 1.97 | 2.04 | 0.143 | 0.007 | 0.028 | 0.041 | 3 | |
| | column mean | | 6.8641026 | 14.333 | 47.79 | 0.0459 | 1.04287 | 1.052359 | 0.06033 | 0.00782 | 0.0430692 | 0.092 | 9.37436 | |
| | clmn StDev | | 1.1157927 | 1.4749 | 2.054 | 0.02841 | 0.58296 | 0.590636 | 0.03966 | 0.00558 | 0.0497862 | 0.09079 | 5.21732 | |
| Location | Date | ID | Chromium | Copper | Zinc | Mercury | U 238 | U233/234 | U235 | Pu238 | Pu239/240 | Am 241 | Nitrate | |
| U1 | 5/8/2010 | B23NF2 | 11 | 13 | 45 | 0.056 | 0.55 | 0.71 | 0.031 | 0 | 0.081 | 0.119 | 11 | |
| | | B23NF7 | 6 | 7.2 | 27 | 0.08 | 0.77 | 0.98 | 0.03 | 0.028 | 1.19 | 0.331 | 9.7 | |
| | MIS | B23NF8 | 15 | 15 | 52 | 0.15 | 0.62 | 0.67 | 0.055 | 0.004 | 0.305 | 0.46 | 9.7 | MIS |
| | | B23NF9 | 17 | 21 | 51 | 0.23 | 0.73 | 0.72 | 0.021 | 0.023 | 0.297 | 0.36 | 9.1 | |
| | | B23NH0 | 9.9 | 14 | 49 | 0.053 | 0.55 | 0.53 | 0.012 | -0.011 | 0.083 | 0.099 | 11 | |
| | column mean | | 11.78 | 14.04 | 44.8 | 0.1138 | 0.644 | 0.722 | 0.0298 | 0.0088 | 0.3912 | 0.2738 | 10.1 | |
| | clmn StDev | | 4.334974 | 4.9303 | 10.31 | 0.07582 | 0.10188 | 0.163003 | 0.01605 | 0.0163 | 0.4597817 | 0.15803 | 0.85732 | |
| U1 | | B23NN2 | 11 | 19 | 39 | 0.15 | 0.85 | 0.64 | 0.037 | 0.026 | 1.04 | 0.5 | 6 | |
| | | B23NN3 | 7.7 | 12 | 36 | 0.086 | 0.64 | 0.63 | 0.027 | 0.017 | 0.74 | 0.319 | 5.3 | |
| | Judgmental | B23NN4 | 77 | 150 | 60 | 37 | 6.3 | 6.3 | 0.246 | 2.41 | 57.1 | 123 | 23 | Judgmental |
| | | B23NN5 | 6.3 | 12 | 37 | 0.035 | 0.55 | 0.54 | 0.017 | -0.006 | 0.007 | 0.007 | 38 | |
| | | B23NN6 | 6.3 | 12 | 36 | 0.035 | 0.4 | 0.45 | 0.036 | -0.002 | 0.016 | 0.042 | 30 | |
| | | B23NN7 | 6.4 | 11 | 35 | 0.037 | 0.4 | 0.47 | 0.026 | -0.003 | 0.052 | 0.052 | 12 | |
| | column mean | | 19.116667 | 36 | 40.5 | 6.22383 | 1.52333 | 1.505 | 0.06483 | 0.407 | 9.8258333 | 20.6533 | 19.05 | |
| | clmn StDev | | 28.414603 | 55.925 | 9.649 | 15.0772 | 2.34612 | 2.350377 | 0.08906 | 0.98135 | 23.163593 | 50.1398 | 13.4438 | |
| | Systematic | B241J9 | 7.7 | 11 | 49 | 0.043 | 0.56 | 0.64 | 0.032 | -0.0013 | 0.018 | 0.01 | 15 | |
| | | B241K1 | 7.6 | 10 | 46 | 0.036 | 0.62 | 0.55 | 0.024 | -0.0011 | 0.0019 | 0.018 | 14 | |
| | | B241K2 | 7.6 | 9.6 | 46 | 0.035 | 0.59 | 0.55 | 0.017 | 0.0023 | 0.015 | 0.018 | 22 | |
| | | B241K3 | 7.5 | 8.9 | 45 | 0.039 | 0.47 | 0.54 | 0.011 | 0 | 0.01 | 0.021 | 19 | |
| | | B241K4 | 23 | 14 | 50 | 0.14 | 0.6 | 0.65 | 0.017 | 0.0082 | 0.208 | 0.063 | 44 | Systematic |
| | | B241K5 | 7.4 | 12 | 47 | 0.035 | 0.57 | 0.53 | 0.036 | 0.0006 | 0.0102 | 0.007 | 11 | |
| | | B241K6 | 7.5 | 11 | 47 | 0.037 | 0.6 | 0.48 | 0.032 | 0.001 | 0.0121 | 0.01 | 26 | |
| | | B241K7 | 7 | 9.9 | 47 | 0.036 | 0.56 | 0.46 | 0.027 | -0.0022 | 0.016 | 0.003 | 3.3 | |
| | | B241K8 | 7.7 | 10 | 46 | 0.044 | 0.63 | 0.64 | 0.042 | 0.008 | 0.198 | 0.125 | 42 | |
| | | B241K9 | 7 | 8.3 | 45 | 0.036 | 0.53 | 0.57 | 0.048 | 0 | 0.0058 | 0.019 | 3.5 | |
| | | B241L0 | 8.6 | 8.9 | 47 | 0.035 | 0.44 | 0.53 | 0.017 | 0 | 0.01 | 0.042 | 47 | |
| | | B241L1 | 16 | 12 | 48 | 0.053 | 0.55 | 0.63 | 0.022 | -0.0004 | 0.037 | 0.047 | 8.6 | |
| | | B241L3 | 16 | 13 | 52 | 0.072 | 0.64 | 0.65 | 0.043 | -0.0013 | 0.103 | 0.015 | 3.1 | |
| | | B241L4 | 7.8 | 9.4 | 49 | 0.043 | 0.49 | 0.56 | 0.035 | 0.0062 | 0.014 | 0.008 | 11 | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B241L5 | 19 | 19 | 50 | 0.073 | 0.63 | 0.53 | 0.031 | 0.045 | 0.394 | 0.407 | 11 |
| | B241L6 | 7.7 | 8.9 | 47 | 0.034 | 0.47 | 0.47 | 0.007 | -0.002 | 0.053 | 0.064 | 32 |
| | B241L7 | 9 | 10 | 47 | 0.037 | 0.61 | 0.56 | 0.034 | -0.0004 | 0.026 | 0.04 | 34 |
| | B241L8 | 7.9 | 8.2 | 46 | 0.035 | 0.51 | 0.58 | 0.041 | -0.002 | 0.0034 | 0.002 | 23 |
| | B241L9 | 13 | 12 | 49 | 0.084 | 0.52 | 0.53 | 0.006 | -0.003 | 0.12 | 0.036 | 71 |
| | B241M0 | 17 | 12 | 48 | 0.076 | 0.57 | 0.55 | 0.024 | 0.01 | 0.159 | 0.054 | 60 |
| | B241M1 | 14 | 18 | 55 | 2.3 | 1.62 | 1.43 | 0.086 | 0.029 | 0.91 | 0.18 | 7.7 |
| | B241M2 | 7.7 | 10 | 48 | 0.037 | 0.64 | 0.67 | 0.058 | -0.0013 | 0.069 | 0.026 | 5.1 |
| | B241M3 | 8.4 | 9.1 | 47 | 0.036 | 0.56 | 0.51 | 0.025 | 0.003 | 0.034 | 0.038 | 5 |
| | B241M4 | 8.1 | 9.7 | 49 | 0.044 | 0.61 | 0.53 | 0.031 | -0.0023 | 0.029 | 0.014 | 36 |
| | B241M5 | 8 | 8.3 | 47 | 0.035 | 0.56 | 0.65 | 0.036 | -0.0021 | 0.017 | 0.011 | 4 |
| | B241M6 | 7.6 | 8.6 | 48 | 0.034 | 0.49 | 0.57 | 0.015 | -0.0036 | 0.03 | 0.013 | 29 |
| | B241M7 | 25 | 56 | 63 | 4.8 | 1.01 | 1.04 | 0.058 | 0.57 | 4.75 | 15.9 | 9.6 |
| | B241M9 | 7.8 | 9.9 | 47 | 0.037 | 0.55 | 0.5 | 0.03 | 0.0007 | 0.038 | 0.031 | 4.2 |
| | B241N0 | 7.8 | 11 | 52 | 0.036 | 0.44 | 0.43 | 0.035 | 0.009 | 0.049 | 0.044 | 4.2 |
| | B241N1 | 8.1 | 9.2 | 47 | 0.037 | 0.68 | 0.6 | 0.043 | -0.005 | 0.078 | 0.098 | 8.1 |
| | B241N2 | 9.7 | 36 | 51 | 0.1 | 1.13 | 1.19 | 0.043 | 0.225 | 2.53 | 5.27 | 15 |
| | B241N3 | 7.3 | 7.6 | 45 | 0.035 | 0.52 | 0.53 | 0.032 | 0.0009 | 0.0091 | 0.002 | 14 |
| | B241N4 | 6.9 | 8.7 | 46 | 0.035 | 0.49 | 0.5 | 0.036 | -0.0023 | 0.041 | 0.24 | 6.8 |
| | B241N5 | 76 | 16 | 57 | 0.29 | 0.65 | 0.73 | 0.02 | 0.0111 | 0.428 | 0.062 | 39 |
| | B241N6 | 8 | 9.9 | 48 | 0.036 | 0.52 | 0.6 | 0.011 | -0.0011 | 0.057 | 0.045 | 11 |
| | B241N8 | 8 | 9.8 | 48 | 0.037 | 0.49 | 0.58 | 0.052 | 0.004 | 0.039 | 0.044 | 18 |
| | B241N9 | 12 | 21 | 51 | 0.51 | 1.33 | 1.03 | 0.066 | 0.14 | 4.17 | 5.6 | 22 |
| | B241P0 | 8.3 | 13 | 51 | 0.036 | 0.44 | 0.45 | 0.026 | 0.008 | 0.035 | 0.098 | 48 |
| | B241P1 | 8.2 | 12 | 51 | 0.042 | 0.48 | 0.41 | 0.019 | 0 | 0.007 | 0.009 | 15 |
| | B241P2 | 8.3 | 12 | 50 | 0.036 | 0.58 | 0.53 | 0.038 | 0.01 | 0.021 | 0.018 | 48 |
| | column mean | | 11.68 | 12.848 | 48.8 | 0.2394 | 0.62375 | 0.617 | 0.03265 | 0.02652 | 0.3688875 | 0.7188 | 21.255 |
| | clmn StDev | | 11.338028 | 8.5558 | 3.473 | 0.82396 | 0.23931 | 0.206002 | 0.01642 | 0.09748 | 1.0407214 | 2.7344 | 17.399 |

| Location | Date | ID | Chromium | Copper | Zinc | Mercury | U 238 | U233/234 | U235 | Pu238 | Pu239/240 | Am 241 | Nitrate | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U2 | 5/21/2011 | B23NH1 | 6.4 | 12 | 44 | 0.031 | 0.63 | 0.58 | 0.027 | 0.0096 | 0.115 | 0.068 | 7.1 | |
| | | B23NH2 | 7.7 | 13 | 47 | 0.046 | 0.56 | 0.58 | 0.023 | 0.0063 | 0.22 | 0.171 | 12 | MIS |
| | MIS | B23NH3 | 7.2 | 13 | 49 | 0.027 | 0.54 | 0.64 | 0.025 | 0.0035 | 0.105 | 0.062 | 14 | |
| | | B23NH4 | 11 | 20 | 57 | 0.25 | 1.22 | 1.21 | 0.057 | 0.028 | 1.58 | 0.384 | 15 | |
| | | B23NH5 | 7.9 | 16 | 51 | 0.047 | 0.69 | 0.67 | 0.033 | 0.012 | 0.239 | 0.096 | 11 | |
| | column mean | | 8.04 | 14.8 | 49.6 | 0.0802 | 0.728 | 0.736 | 0.033 | 0.01188 | 0.4518 | 0.1562 | 11.82 | |
| | clmn StDev | | 1.7529974 | 3.2711 | 4.879 | 0.09533 | 0.28137 | 0.267825 | 0.01393 | 0.00957 | 0.6335524 | 0.13453 | 3.07604 | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B241V3 | 8.1 | 12 | 53 | 0.037 | 0.48 | 0.54 | 0.057 | 0.0052 | 0.014 | 0.044 | 7.5 |
| B241V5 | 7.6 | 11 | 53 | 0.037 | 0.46 | 0.53 | 0.014 | 0.016 | 0.067 | 0.072 | 4.7 |
| B241V6 | 8.4 | 11 | 53 | 0.037 | 0.46 | 0.5 | 0.031 | 0.004 | 0.002 | 0.026 | 4.5 |
| B241V7 | 7.4 | 13 | 52 | 0.036 | 0.57 | 0.51 | 0.006 | 0.0039 | 0.006 | 0.022 | 22 |
| B241V8 | 9.4 | 13 | 53 | 0.036 | 0.48 | 0.57 | 0.04 | 0 | -0.0016 | 0.014 | 8.2 |
| B241V9 | 7.4 | 11 | 52 | 0.036 | 0.46 | 0.49 | 0.026 | -0.0019 | 0.017 | 0.008 | 12 |
| B241W0 | 7.2 | 10 | 51 | 0.037 | 0.6 | 0.66 | 0.037 | 0.003 | 0.047 | 0.032 | 3.7 |
| B241W1 | 8.5 | 13 | 54 | 0.13 | 0.83 | 0.89 | 0.05 | 0.006 | 0.275 | 0.295 | 43 |
| B241W3 | 10 | 12 | 51 | 0.037 | 0.5 | 0.59 | 0.041 | 0.0087 | 0.087 | 0.083 | 13 |
| B241W4 | 7.6 | 10 | 51 | 0.036 | 0.54 | 0.64 | 0.045 | -0.0019 | 0.0037 | 0.025 | 12 |
| B241W5 | 7.4 | 9.2 | 52 | 0.036 | 0.6 | 0.51 | 0.006 | -0.002 | 0.025 | 0.022 | 25 |
| B241W6 | 7.6 | 11 | 51 | 0.037 | 0.5 | 0.46 | 0.038 | -0.0037 | 0.017 | 0.025 | 21 |
| column mean | 7.9375 | 12.57 | 52.23 | 0.07295 | 0.62175 | 0.64825 | 0.03955 | 0.00622 | 0.22012 | 0.09988 | 13.315 |
| clmn StDev | 1.3590509 | 3.5448 | 1.641 | 0.13236 | 0.29309 | 0.291397 | 0.02555 | 0.01345 | 0.5685825 | 0.18044 | 13.1729 |