Environmental Study - Soil Sample Analysis For the Department of Ecology at Hanford

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Environmental Study - Soil Sample Analysis

The purpose of this project is to compare three different soil sampling methods for the Department of Ecology at Hanford. The three soil sampling methods are: Incremental Sampling Method (MIS), Judgmental sampling, and Systematic sampling. Samples were taken in May 2010 and contaminated soil was removed from the designated site known as U1 and U2. A second sample of this area was taken again in August 2010. This data has not been previously analyzed and will be important to Hanford's work effort.

Since costs associated with analyzing this type of data can be high and the number of samples collected is sometimes inadequate due to budget constraints, Hanford is considering the use of MIS, but wants to ensure that the results are at least as accurate as the ones obtained from traditional systematic sampling methods. As part of a Statistics class project, a group of Columbia Basin College (CBC) students will be individually analyzing this data for Hanford.

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.

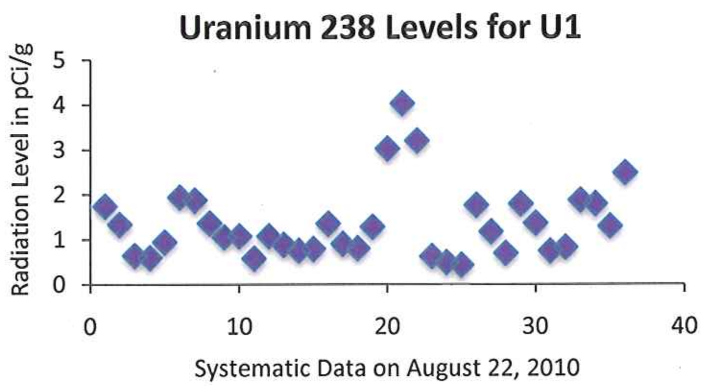
Judgmental Sampling is used when only a few discrete samples are collected. The number of samples collected is determined by negotiation, budget, professional judgment, or happenstance. The number of samples is often not based on statistical or other scientific rationale, and the location of the samples 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(s) 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

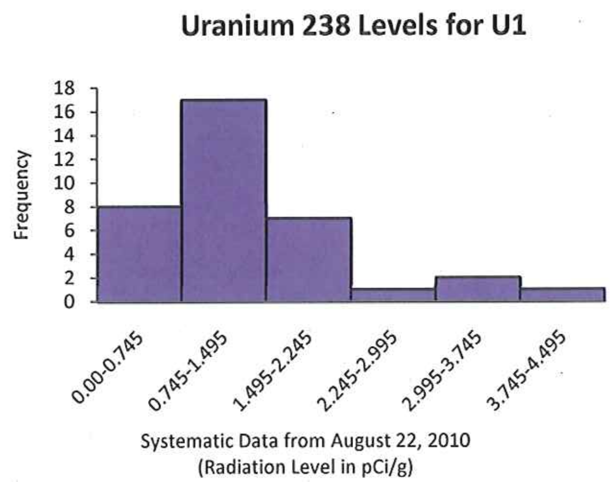
Initially the scatter plot below of the U-238 systematic data for area U1 collected August 22, 2010 was constructed to investigate the radiation levels of this element that were present at the time the sample was collected. This plot also demonstrates the heterogeneity (or homogeneity) of this radioactive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

Radiation Levels	Frequency
0.00-0.74	8
0.75-1.49	17
1.50-2.24	7
2.25-2.99	1
3.00-3.74	2
3.75-4.49	1



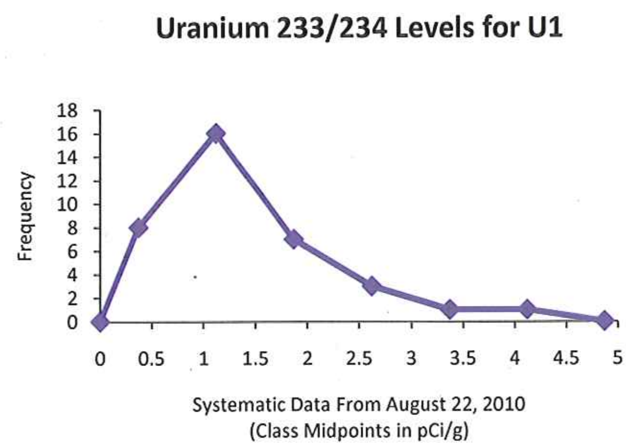
The scatter plot shows that the majority of the U-238 levels found in U1 from August 22, 2010 were below 2 pCi/g. The frequency distribution and histogram support the scatter plot information, reflecting that the radiation level of .75 -1.49 pCi/g is where most of the contamination was found. The histogram has a distribution that is heterogeneous because it is skewed to the right reflecting that the scatter plot supports the histogram. Most of the values are found within a narrow band; however, those that are not in the band are the ones that make it heterogeneous. This variability appears to be more than just a sampling error.

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 Levels for U1

Radiation Levels	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 graph above shows a distribution that is skewed to the right. Both the frequency distribution and the graph, reflect more instances of the U-233/234 contamination at levels less than 2.24 pCi/g. Fortunately, the frequency of U-233/234 at higher levels of contamination is minimal with none above 4.49 pCi/g.

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

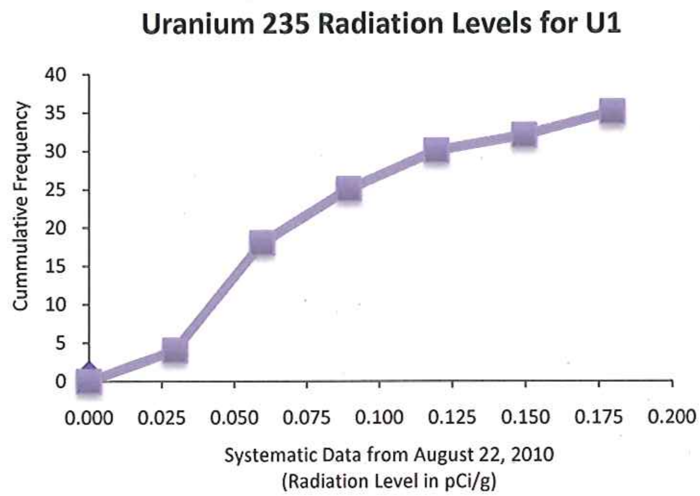
Both the U-238 and U-233/234 systematic data for U1 collected on August 22, 2010 show that the majority of contamination found was less than 2.24 pCi/g with these isotopes having a similar distribution and radiation levels. Within the range of 2.25 to 4.49 pCi/g, U-238 reflects a slightly higher frequency of contamination than U-233/234.

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 Radiation Levels for Area U1 Collected August 22, 2010

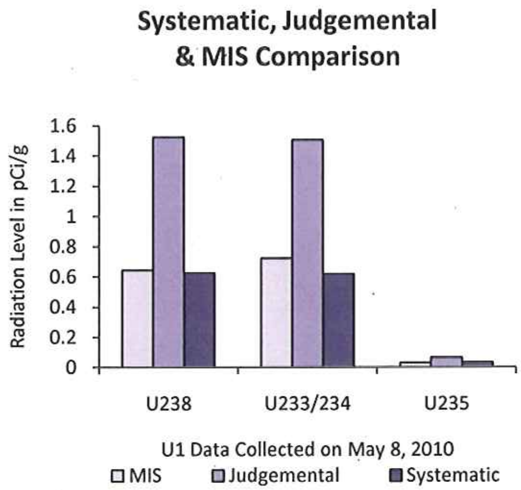
Radiation Level	Cumulative Frequency
Less than 0.03	4
Less than 0.06	18
Less than 0.09	25
Less than 0.12	30
Less than 0.15	32
Less than 0.18	35

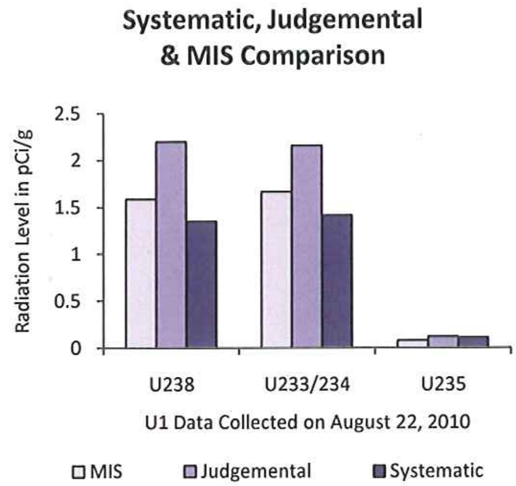


In reviewing the U-235 data, each increase of .030 pCi/g of the cumulative frequency diminishes significantly. Keep in mind that the outlier of 1.34 pCi/g has been excluded from the data above. The cumulative frequency distribution as well as the ogive for the U-235 systematic data collected from U1 on August 22, 2010 are beneficial in determining the number of samples below a given radiation level. For instance, 35 of the 36 samples had radiation levels below 0.1795 pCi/g. The only inconsistency was the sample numbered B24208 which had a radiation level of 1.34 pCi/g.

5. Graphic Comparison of Sampling Methods for 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 on the following page were used to analyze this information.





In comparing the multiple bar graphs above, the MIS and systematic data collected in May and August 2010 shows similar results. This is encouraging because the graphs appear to support the fact that the MIS data is an equally reliable collection method when compared with the systematic method. Since the MIS collection method is a more cost effective method of soil sampling, this would more than likely result in a considerable cost savings to Hanford.

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 Levels for U1

Stem	Leaf
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

For the August 22, 2010 systematic data collected from U1, the chromium stem and leaf plot shown on the previous page provides insight into the distribution of this element. By turning this plot sideways, it is evident that the chromium has a bell-shaped (probably normal) distribution with the highest levels concentrated in the 6.0 to 7.0 range. In addition, all of the original data values are preserved in the plot.

Descriptive Statistics and Probability

1. Descriptive Statistics for U-238, U2344/234, 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, 2020. Results were rounded to three decimal places. This comparison is helpful in summarizing the mean, median, standard deviation and range of the three isotopes.

U1 Systematic Data 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	0.08

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.

Uranium 238: 95% Min Usual Value $\bar{x} - 2s$: 0.624 -2(0.239) = 0.146 pCi/g
95% Max Usual Value $\bar{x} + 2s$: 0.624 +2(0.239) = 1.102 pCi/g

Uranium 233/234: 95% Min Usual Value $\bar{x} - 2s$: 0.617 -2(0.206) = 0.205 pCi/g
95% Max Usual Value $\bar{x} + 2s$: 0.617 +2(0.206) = 1.029 pCi/g

Uranium 235: 95% Min Usual Value $\bar{x} - 2s$: 0.0327 -2(0.0164) = -0.0001 pCi/g
95% Max 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.

Uranium 238: 93.75% Min Usual Value $\bar{x} - 4s$: 0.624 -4(0.239) = -0.332 pCi/g
93.75% Max Usual Value $\bar{x} + 4s$: 0.624 +4(0.239) = 1.580 pCi/g

Uranium 233/234: 93.75% Min Usual Value $\bar{x} - 4s$: 0.617 -4(0.206) = -.207 pCi/g
93.75% Max Usual Value $\bar{x} + 4s$: 0.617 +4(0.206) = 1.441 pCi/g

Uranium 235: 93.75% Min Usual Value $\bar{x} - 4s$: 0.0327 -4(0.0164) = -0.0329 pCi/g
93.75% Max Usual Value $\bar{x} + 4s$: 0.0327 +4(0.0164) = .0983 pCi/g

Unusual data values were identified by using the above minimum and maximum "usual" values. It is evident that the distribution of the population plays a key role in the determining which technique to use. Using both the empirical rule and Chebyshev's theorem, the unusual data values are presented below for U-238, U-233/234 and U235 systematic data from area U1 collected on May 8, 2010.

U1 Systematic Data May 8, 2010

pCi/g	Empirical 95%	Chebyshev 93.75%
Uranium 238	1.13	1.62
	1.33	
	1.62	
Uranium 233/234	1.03	
	1.04	
	1.19	
	1.43	
Uranium 235	.066	
	.086	

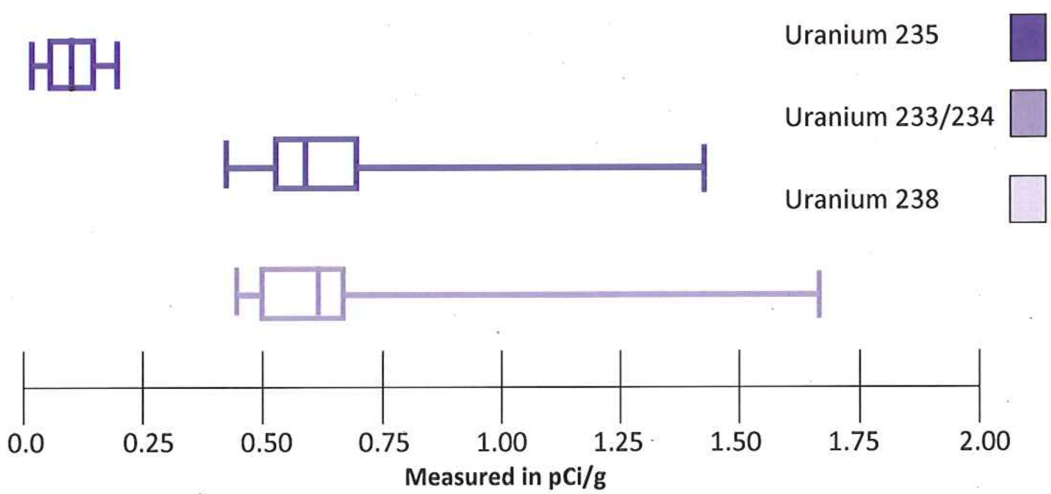
It appears that the distribution of each of these isotopes is skewed to the right. Therefore, the identification of unusual values should be made using Chebyshev's theorem. Furthermore, of the three data sets analyzed, the only unusual value found was the value of 1.62 pCi/g from the U-238 data. All of the remaining values should be considered "usual".

Descriptive statistical analysis also includes a 5-number 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 below.

Five Number Summaries of U1 Systematic Data May 8, 2010

(pCi/g)	Uranium 238	Uranium 233/234	Uranium 235
Min Value	0.44	0.41	0.006
25th Percentile	0.50	0.53	0.021
Median	0.56	0.555	0.032
75th Percentile	0.625	0.64	0.0415
Max Value	1.62	1.43	0.086

Comparison Box Plots for U1 Collected on May 8, 2010



In reviewing the box plots above, it shows that the distributions of U-238 and U-233/234 are skewed to the right. The U-238 shows the highest levels of radiation with Uranium 233/234 reflecting similar levels. Despite, U-235 having significantly lower radiation levels than both the U-238 and U-233/234, it is also skewed to the right. Since the values are so small, it is hard to see in the boxplot above.

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:

$$nCr = \frac{n!}{(n-r)!\,r!}$$

$$_{10}C_{40} = \frac{40!}{(40-10)!10!}$$

$$= 847{,}660{,}528$$

Therefore, there are 847, 660, 528 ways that 10 subsamples can be randomly selected out of 40 samples 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:

$$nPr = \frac{n!}{(n-r)!\,r!}$$

$$_{n}P_{r} = {}_{10}P_{4} = \frac{10!}{(10-4)!}$$

$$= 5{,}040$$

So, there are 5,040 different orders that 4 samples can be randomly selected out of a total of 10 subsamples for extensive testing.

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

Part of this soil sample research involves calculating different probabilities. The table below 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 table on the following page illustrates how this information was used to calculate these probabilities.

Radiation Levels for the Systematic Data Collect 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
1.01-1.51	3	4	0	7
1.51-2.00	1	0	0	1
Totals	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:

$$P(Radiation\ level\ \leq 0.50\ pCi/g) = \frac{\#\ of\ radiation\ levels\ \leq 0.50}{total\ \#\ of\ samples}$$
$$= \frac{58}{120}$$
$$= 0.483$$

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 below.

With Replacement:

$$P(All\ 4\ U-238\ samples\ \leq 0.50\ pCi/g\ ) = \left(\frac{10}{40}\right)\left(\frac{10}{40}\right)\left(\frac{10}{40}\right)\left(\frac{10}{40}\right)$$
$$= .00391$$

Without Replacement:

$$P(All\ 4\ U-238\ samples\ \leq 0.50\ pCi/g) = \left(\frac{10}{40}\right)\left(\frac{9}{39}\right)\left(\frac{8}{38}\right)\left(\frac{7}{37}\right)$$
$$= 0.00230$$

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: $P(All\ 4\ samples\ < 0.50\ pCi/g) = \left(\frac{8}{40}\right)\left(\frac{8}{40}\right)\left(\frac{8}{40}\right)\left(\frac{8}{40}\right)$

$$= \frac{1}{625}$$

$$= .0016$$

$$P(At\ least\ one\ has\ radiation > 0.50\ pCi/g) = 1 - P(none\ with\ > 0.50\ pCi/g\ radiation)$$
$$= 1 - P(All\ 4\ radiation\ levels\ \leq 0.50\ pCi/g)$$
$$= 1 - .0016$$
$$= 0.998$$

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.

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

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.

$$P(U - 238\ source|radiation\ level\ between\ 0.00 - 0.50\ pCi/g) = \frac{\#\ of\ U{-}238\ values\ between\ 0{-}0.50\ pCi/g}{total\ number\ of\ values\ between\ 0{-}0.50\ pCi/g}$$
$$= \frac{10}{58}$$
$$= 0.172$$

$$P\left(U - 233/234\ source|radiation\ level\ between\ 0.00 - \ 0.50\frac{pCi}{g}\right) = \frac{\#\ of\ \ U{-}233/234\ values\ between\ 0{-}0.50\ pCi/g}{total\ number\ of\ values\ between\ 0{-}0.50\ pCi/g}$$
$$= \frac{8}{58}$$
$$= 0.138$$

$$P(U-235\,source \mid radiation\ level\ between\ 0-0.50\,pCi/g = \frac{\#\,of\ U-235\,values\ between\ 0-0.50\,pCi/g}{total\ number\ of\ values\ between\ 0-0.50\ pCi/g}$$

$$=\frac{40}{58}$$

$$=0.690$$

According to the above calculations, the most likely source of radiation appears to be Uranium 235.

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.

Completed Probability Distribution of 40 Usable Samples

x	P(x)	xP(x)	$x^2P(x)$
40	0.021	0.84	33.6
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	3.64	127.4
34	0.023	0.782	26.588
33	0.015	0.495	16.335
32	0.011	0.352	11.264
Totals	**1.000**	**37.119**	**1380.165**

Distribution of Usable Samples, the expected number (mean) of usable samples out of 40 samples, would be $\mu = \sum X_i P(X_i)$, resulting in 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. Listed below are the minimum and maximum usual values representing 95% of the values that fall within two standard deviations of the mean.

Minimum and Maximum Standard Deviation Formula:

Minimum Usual Value: $\mu - 2\sigma$ = 37.1 – 2(1.5) = 34.1 samples

Maximum Usual Value: $\mu + 2\sigma$ = 37.1 + 2(1.5) = 40.1 samples

The minimum and maximum usual values from the previous page represent the minimum of at least 34.1 usable samples and the maximum of at most 40.1 usable samples. The test engineer can feel confident with his choice of collecting 40 samples. By using this approach he will have the correct number of usable data samples (at least 35) approximately 95% of the time.

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.

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

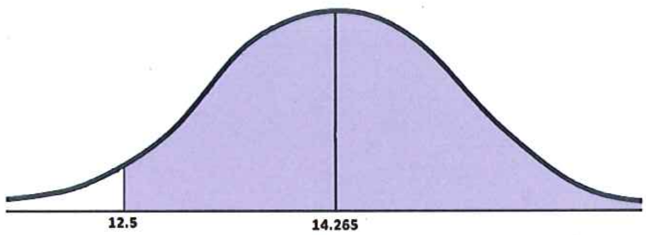
He then proceeded to calculate the probability of at least 13 usable tests out of 15 tests conducted using two different techniques. The first technique that he used involved the Binomial Probability Formula and the second technique that he used was the Normal Approximation to the Binomial Formula. These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

Binomial Probability Formula:

$$\begin{aligned} P(at\ least\ 13\ usable\ samples) &= {}_{15}C_{13}\,(0.951)^{13}(0.049)^{2} + {}_{15}C_{14}\,(0.951)^{14}(0.049)^{1} + {}_{15}C_{15}\,(0.951)^{15}(0.049)^{0} \\ &= 0.131198291 + 0.363759694 + .470660502 \\ &= 0.966 \end{aligned}$$

Normal Approximation to the Binomial Formula:

$$P(at\ least\ 13\ of\ 15\ usable\ samples) = P(x \geq 13)$$
$$= P(x > 12.5)$$
$$= 1 - P(x < 12.5)$$
$$= 1 - P\left(z < \frac{12.5 - 14.265}{0.836053228}\right)$$
$$= 1 - P(z < -2.11)$$
$$= 1 - 0.0174$$
$$= 0.9826$$
$$= 0.983$$



Normal Distribution of Duplicate Samples

The test 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 inappropriate 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.

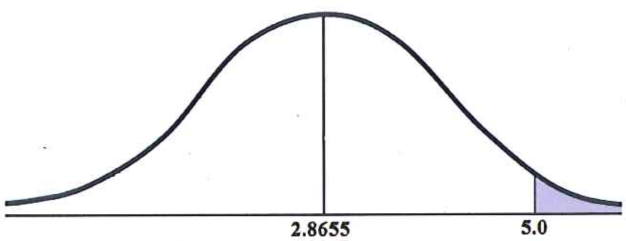
Samples with Soil Radiation Levels Exceeding 5 pCi/g

Uranium Levels from U1			Uranium Levels from U2	
May 8, 2010	**Aug 22, 2010**		**May 8, 2010**	**Aug 22, 2010**
None	B24208		None	B24260
	B24209			B24268
	B24210			
	B24226			

Since the soil samples collected on May 8, 2010 for both the U1 and U2 areas have radiation levels that are less than 5 pCi/g, there are no soil samples to be identified in the above chart. In contrast, the uranium levels that exceed the 5 pCi/g radiation level are isolated exclusively to the August 22, 2010 collection date for both the U1 and U2 areas as annotated by the soil sample identification numbers. Since approximately 11% of the U1 samples and 5% of the U2 samples from August U2 samples had radiation levels exceeding the CERCLA safe radiation level of 5 pCi/g, additional analysis and possible clean up 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.

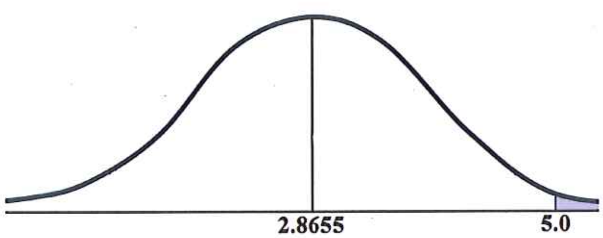
Single Sample:



U1 Radiation Level Single Sample from August 22, 2010

$$P(x > 5) = 1 - P(x < 5)$$
$$= 1 - P\left(z < \frac{5 - 2.8655}{1.7336}\right)$$
$$= 1 - P(z < 1.23)$$
$$= 1 - .8907$$
$$= 0.1093$$
$$= 0.109$$

Four Samples:

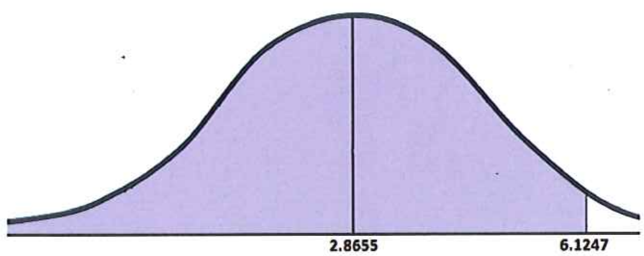


U2 Radiation Level Four Samples from August 22, 2010

$$P(\bar{x} > 5) = 1 - P(\bar{x} < 5)$$
$$= 1 - P\left(z < \left(\frac{5 - 2.8655}{1.7336/\sqrt{4}}\right)\right.$$
$$= 1 - P(z < 2.46)$$
$$= 1 - .9931$$
$$= 0.0069$$
$$= 0.007$$

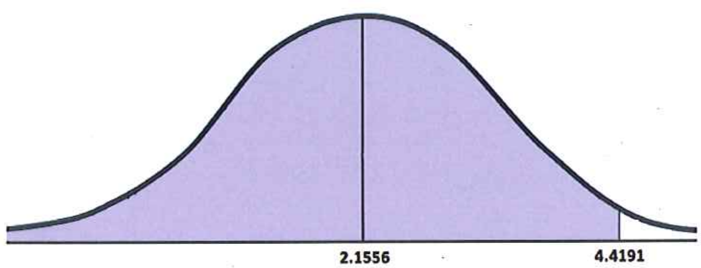
4. Percentiles Involving Uranium Radiation Levels

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.



97th Percentile for U1 - August 22, 2010

$$\begin{aligned} x &= \bar{x} + 1.88s \\ &= 2.8655 + 1.88\,(1.7336) \\ &= 6.124668 \\ &= 6.1247\ pCi/g \end{aligned}$$



97th Percentile for U2 - August 22, 2010

$$\begin{aligned} x &= \bar{x} + 1.88s \\ &= 2.1556 + 1.88\,(1.204) \\ &= 4.41912 \\ &= 4.4191\ pCi/g \end{aligned}$$

The z score for the Standard Normal Distribution of 1.88 was used in order to separate the bottom 97% of radiation levels from the top 3%. In reviewing the two bell curves above, the Uranium in the U2 area would be considered clean since the maximum level of contamination only shows 4.4191 pCi/g. However, the uranium level in the U1 area show a contamination level of 6.1247 pCi/g which is considered to be dirty because it exceeds the radiation contamination level of 5 pCi/g.

For area U1 the value 6.1247 pCi/g represents the 97^{th} percentile. Since the value is larger than the 5 pCi/g level, it marks this area for further study and possible clean up. Whereas for the area U2 the value 4.4191 pCi/g represents the 97^{th} percentile which is below the 5 pCi/g level; therefore, this area can now be declared clean and no further study 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.

U1 Systematic Data for August 22, 2010

Best point estimate for proportion of the 216-S-19 pond with a uranium radiation level greater than 5 pCi/g:

$$\begin{aligned}\hat{p} &= \frac{\#\,of\ uranium\ samples > 5\,pCi/g}{total\ \#\,of\ uranium\ samples} \\ &= \frac{4}{36} \\ &= \frac{1}{9}\ or \approx 0.111\,samples\end{aligned}$$

Margin of error constructed for a 90% confidence interval using α = 0.010 significance level.

$$E = z_{\frac{\sigma}{2}}\sqrt{\frac{\hat{p}\hat{q}}{n}} \quad where \quad z_{\frac{\sigma}{2}} = z_{\frac{.05}{2}} = 1.645 \;\; n = 36 \;\; \hat{q} = 1 - \hat{p} = \frac{8}{9}$$

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

$$E = 0.086162271$$

$$E = 0.086$$

Confidence interval of 90% for this data set:

$$\hat{p} - E < p < \hat{p} + E$$

$$0.111 - 0.086 < p < 0.111 + 0.086$$

$$0.025 < p < 0.197$$

<u>**U2 Systematic Data for August 22, 2010**</u>

Best point estimate for proportion of the 216-S-19 pond with a uranium radiation level greater than 5 pCi/g:

$$\hat{p} = \frac{\#\, of\ uranium\ samples > 5pCi/g}{total\ \#\, of\ uranium\ samples}$$

$$= \frac{2}{39} or \approx 0.0513\, samples$$

Margin of error constructed for a 90% confidence interval using α = 0.010 significance level.

$$E = z_{\frac{\sigma}{2}}\sqrt{\frac{\hat{p}\hat{q}}{n}} \quad where \quad z_{\frac{\sigma}{2}} = z_{\frac{0.10}{2}} = 1.645 \;\; n = 39 \;\; \hat{q} = 1 - \hat{p} = \frac{37}{39}$$

$$E = 1.645\sqrt{\frac{\left(\frac{2}{39}\right)\left(\frac{37}{39}\right)}{36}}$$

$$E = 0.058101166$$

$$E = 0.058$$

Confidence interval of 90% for this data set:

$$\hat{p} - E < p < \hat{p} + E$$
$$0.0513 - 0.058 < p < 0.0513 + 0.058$$
$$-0.0067 < p < 0.1093$$
$$0.007 < p < 0.109$$

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. The Systematic sample data used was collected on August 22, 2010 from both areas U1 and U2. For U1, we are 95% confident that the proportion of this area that contains uranium radiation levels greater than 5 pCi/g is less than 0.197. For U2, we are 95% confident that the proportion of this area that contains uranium radiation levels greater than 5 pCi/g is less than 0.109.

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.

__U1 Systematic Data for May 8, 2010__

Best point estimate for the mean nitrate level:

$$\bar{x} = \frac{\sum x}{n}$$
$$= 21.255\, mg / kg$$

Margin of error constructed for a 90% confidence interval using α = 0.010 significance level.

$$E = t_{\frac{\alpha}{2}}(n-1)\frac{s}{\sqrt{n}} \quad t \quad where \quad t_{\frac{\alpha}{2}}(n-1) = t_{\frac{0.10}{2}}(39) = 1.685 \;\; n = 40 \;\; s = 17.399 mg/kg$$

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

Confidence interval of 90% for this data set:

$$\overline{x} - E < \mu < \overline{x} + E$$
$$21.255 - 4.635 < \mu < 21.255 + 4.635$$
$$16.62 mg/kg < \mu < 25.89 mg/kg$$

U1 MIS Data for May 8, 2010

Best Point Estimate for the mean nitrate level:

$$\overline{x} = \frac{\sum x}{n}$$
$$= 10.1 mg/kg$$

Margin of error constructed for a 90% confidence interval using α = 0.010 significance level.

$$E = t_{\frac{\alpha}{2}}(n-1)\frac{s}{\sqrt{n}} \quad t \quad where \quad t_{\frac{\alpha}{2}}(n-1) = t_{\frac{0.10}{2}}(4) = 2.132 \;\; n = 5 \;\; s = 0.857 mg/kg$$

$$E = 2.132\left(\frac{.85732141}{\sqrt{5}}\right)$$
$$E = 0.817114693$$
$$E = 0.817 mg/kg$$

Confidence Interval of 90% for this data set:

$$\bar{x} - E < \mu < \bar{x} + E$$
$$10.1 - .817 < \mu < 10.1 + .817$$
$$9.283\,mg/kg < \mu < 10.917\,mg/kg$$

U2 Systematic Data for May 8, 2010

Best point estimate for the mean nitrate level:

$$\bar{x} = \frac{\sum x}{n}$$
$$= 13.315\,mg/kg$$

Margin of error constructed for a 90% confidence interval using α = 0.010 significance level.

$$E = t_{\frac{\alpha}{2}}(n-1)\frac{s}{\sqrt{n}} \quad t \quad where \quad t_{\frac{\alpha}{2}}(n-1) = t_{\frac{0.10}{2}}(39) = 1.685 \;\; n = 40 \;\; s = 13.173\,mg/kg$$
$$E = 1.685\left(\frac{13.173}{\sqrt{40}}\right)$$
$$E = 3.509575595$$
$$E = 3.510\,mg/kg$$

Confidence interval of 90% for this data set:

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

U2 MIS Data for May 8, 2010

Best point estimate for the mean nitrate level:

$$\bar{x} = \frac{\sum x}{n}$$
$$= 11.82\,mg/kg$$

Margin of error constructed for a 90% confidence interval using α = 0.010 significance level.

$$E = t_{\frac{\alpha}{2}}(n-1)\frac{s}{\sqrt{n}} \quad t \quad where \quad t_{\frac{\alpha}{2}}(n-1) = t_{\frac{0.10}{2}}(4) = 2.132 \;\; n = 5 \;\; s = 3.076 mg / kg$$

$$E = 2.132\left(\frac{3.076036411}{\sqrt{5}}\right)$$

$$E = 2.932875787$$

$$E = 2.933 mg / kg$$

Confidence Interval of 90% for this data set:

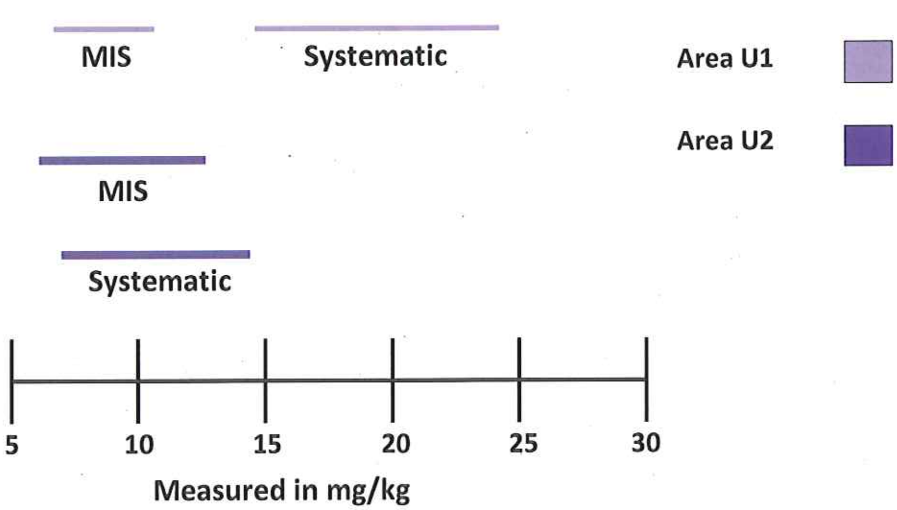
$$\overline{x} - E < \mu < \overline{x} + E$$

$$11.82 - 2.933 < \mu < 11.82 + 2.933$$

$$8.887 mg / kg < \mu < 14.753 mg / kg$$

Below is a graphic comparison of areas U1 and U2 from May 2010 for nitrate levels of systematic and MIS data.

Confidence Intervals for Systematic and MIS Data for U1 and U2



Since the U1 MIS and Systematic data do not overlap, there does not appear to be a difference in the mean for Nitrate levels for U1 with respect to the sampling technique. However, because the U2 MIS and Systematic do overlap, there doesn't appear to be any difference in the mean for Nitrate levels for U2 with respect to sampling techniques.

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. The sample data was collected on May 8, 2010 for both U1 and U2 Systematic and MIS data. For U1 Systematic data, we are 95% confident that the mean nitrate level for U1 is less than 25.89 mg/kg. For U1 MIS data, we are 95% confident that the mean nitrate level for U1 is less than 10.917 mg/kg. For U2 Systematic data, we are 95% confident that the mean nitrate level for U2 is less than 16.825 mg/kg. For U2 MIS data, we are 95% confident that the mean nitrate level for U2 is 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.

Systematic Nitrate Levels for May 8, 2010

U1 Systematic		U2 Systematic	
ID Number	**Nitrate Level**	**ID Number**	**Nitrate Level**
B241K4	44	B241R3	49
B241K8	42	B241R4	61
B241L0	47	B241W1	43
B241L9	71		
B241M0	60		
B241P0	48		
B241P2	48		

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.

U1 Systematic Nitrate Data for May 8, 2010

$$Given: \bar{x} = 21.255 mg/kg; \mu = 40 mg/kg; s = 17.399 mg/kg; n = 40 \ and \ \alpha = 0.01 \ signficance \ level$$

$H_0 = 40mg/kg$

$H_1 = 40mg/kg\,(claim)$

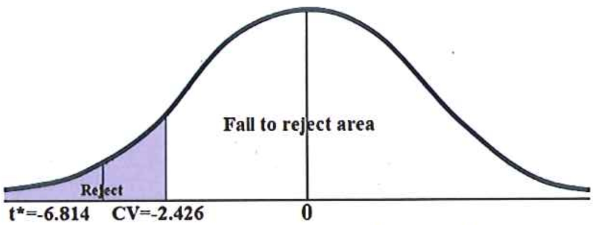
$t_{0.01}(39) = -2.426$

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

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

$$t^* = -6.813827776$$

$$t^* = -6.814$$



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

Since the test statistic of -6.814 is less than the critical value of -2.426, reject H_0. There is sufficient evidence to support the claim that the mean nitrate level for the U1 area on May 8, 2010 is less than the action level of 40 mg/kg.

U2 Systematic Nitrate Data for May 8, 2010

$$Given: \bar{x} = 13.315; \mu = 40mg/kg; s = 13.173; n = 40 \text{ and } \alpha = 0.01\, signficance\, level$$

$H_0 = 40mg/kg$

$H_1 = 40mg/kg\,(claim)$

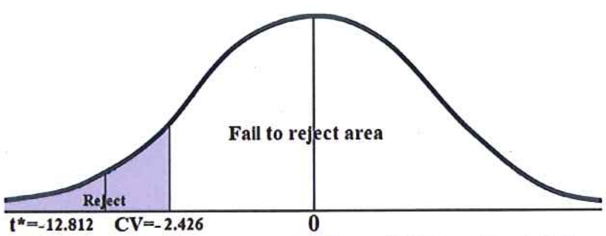
$t_{0.01}(39) = -2.426$

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

$$t^* = \frac{13.315 - 40}{13.173/\sqrt{40}}$$

$$t^* = -12.81186964$$

$$t^* = -12.812$$



Student's-t Distribution for Nitrate Levels Area U2 Collected May 8, 2010

Since the test statistic of -12.811 is less than the critical value of -2.426, reject H_0. There is sufficient evidence to support the claim that the mean nitrate level for the U2 area on May 8, 2010 is less than the 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.

$$Given: \sigma = 15 mg/kg; E = 5 mg/kg; and\ \alpha = 0.05\ z_{\frac{.05}{2}} = 1.96$$

$$n = \left[\frac{(z_{\frac{\alpha}{2}})(\sigma)}{E}\right]^2$$

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

$$n = [5.88]^2$$

$$n = 34.5744$$

$$n = 35\, samples$$

As a result of these calculations, the number of usable samples calculated using a 95% confidence level for both U1 and U2 is 35 samples.

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:

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

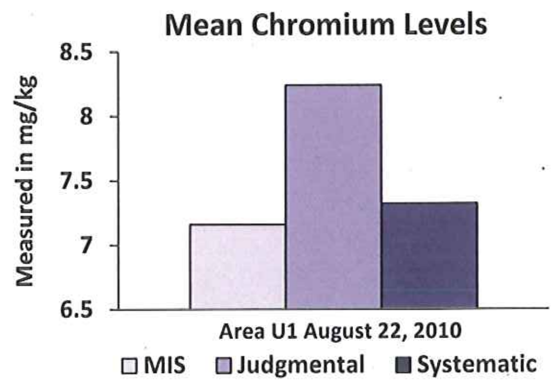
Significance Level: $\alpha = 0.05$ Critical Value: $t_{0.05/2} = \pm 2.776$ Degrees of Freedom: 4

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

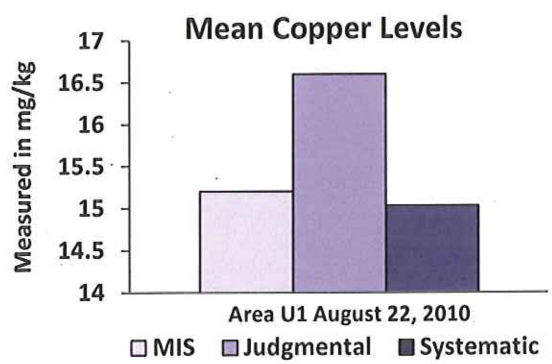
Hypothesis Test	Test Statistic	Outcome
MIS vs Systematic	-0.548	Fail to Reject H_0
MIS vs Judgmental	-3.557	Reject H_0
Systematic vs Judgmental	-2.683	Fail to Reject H_0

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	1.643168
Judgmental	16.6	2.607681
Systematic	15.0277	1.796602



Copper Hypothesis Test Results

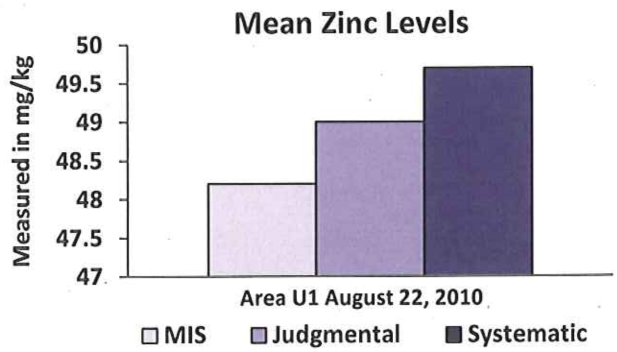
Hypothesis Test	Test Statistic	Outcome
MIS vs Systematic	0.217	Fail to Reject H_0
MIS vs Judgmental	-1.016	Fail to Reject H_0
Systematic vs Judgmental	-1.306	Fail to Reject H_0

Conclusion: Since the test statistic for all three comparisons (0.217, -1.016, -1.306) 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, Judgmental and Systematic sampling.

3. Comparison Tests Involving Zinc

Zinc Summary Statistics in mg/kg

Sampling Method	Mean	Standard Deviation
MIS	48.2	1.095445
Judgmental	49	2.345208
Systematic	49.694	2.955087



Zinc Hypothesis Test Results

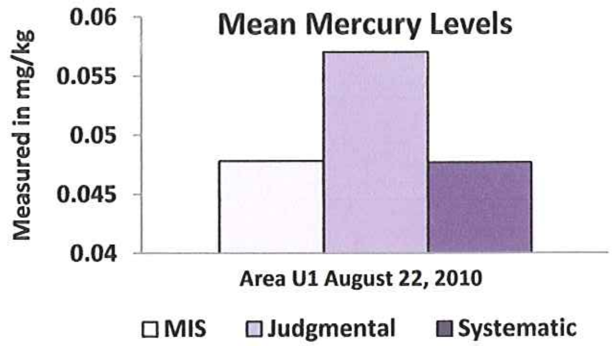
Hypothesis Test	Test Statistic	Outcome
MIS vs Systematic	-2.151	Fail to Reject H_0
MIS vs Judgmental	-0.691	Fail to Reject H_0
Systematic vs Judgmental	0.599	Fail to Reject H_0

Conclusion: Since the test statistic for all three comparisons (-2.151, -0.691, 0.599) 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, Judgmental and Systematic sampling.

4. Comparison Tests Involving Mercury

Mercury Summary Statistics in mg/kg

Sampling Method	Mean	Standard Deviation
MIS	0.0478	0.006017
Judgmental	0.057	0.017393
Systematic	0.047667	0.030792



Mercury Hypothesis Test Results

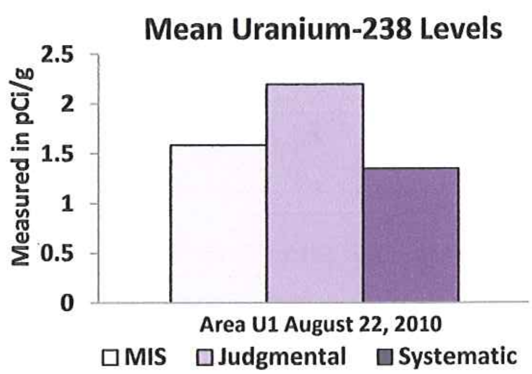
Hypothesis Test	Test Statistic	Outcome
MIS vs Systematic	0.0230	Fail to Reject H_0
MIS vs Judgmental	-1.118	Fail to Reject H_0
Systematic vs Judgmental	-1.002	Fail to Reject H_0

Conclusion: Since the test statistic for all three comparisons (0.0230, -1.118, -1.002) 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, Judgmental and Systematic sampling.

5. Comparison Tests Involving Uranium-238

U-238 Summary Statistics in pCi/g

Sampling Method	Mean	Standard Deviation
MIS	1.584	0.085323
Judgmental	2.196	1.526771
Systematic	1.346389	0.810996



Uranium-238 Hypothesis Test Results

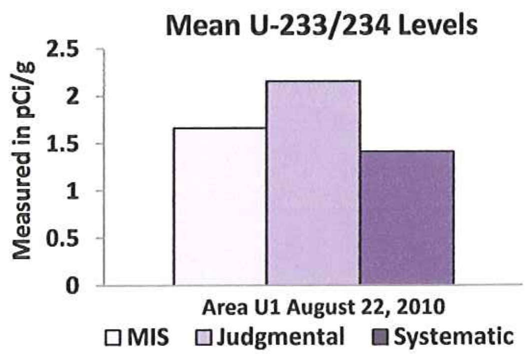
Hypothesis Test	Test Statistic	Outcome
MIS vs Systematic	1.692	Fail to Reject H_0
MIS vs Judgmental	-0.895	Fail to Reject H_0
Systematic vs Judgmental	-1.221	Fail to Reject H_0

Conclusion: Since the test statistic for all three comparisons (1.692, -0.895, -1.221) 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, Judgmental and Systematic sampling.

6. Comparison Tests Involving Uranium-233/234

U-233/234 Summary Statistics in pCi/g

Sampling Method	Mean	Standard Deviation
MIS	1.662	0.0947101
Judgmental	2.154	1.3202197
Systematic	1.4105556	0.8155347



Uranium-233/234 Hypothesis Test Results

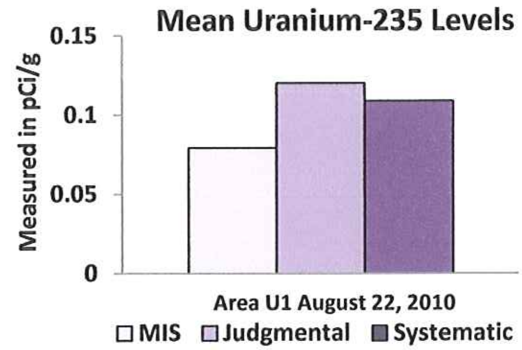
Hypothesis Test	Test Statistic	Outcome
MIS vs Systematic	1.766	Fail to Reject H_0
MIS vs Judgmental	-0.831	Fail to Reject H_0
Systematic vs Judgmental	-1.227	Fail to Reject H_0

Conclusion: Since the test statistic for all three comparisons (1.766, -0.831, -1.227) 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, Judgmental and Systematic sampling.

7. Comparison Tests Involving Uranium-235

Uranium-235 Summary Statistics in pCi/g

Sampling Method	Mean	Standard Deviation
MIS	0.079	0.0157
Judgmental	0.1198	0.064228
Systematic	0.108556	0.21524



Uranium-235 Hypothesis Test Results

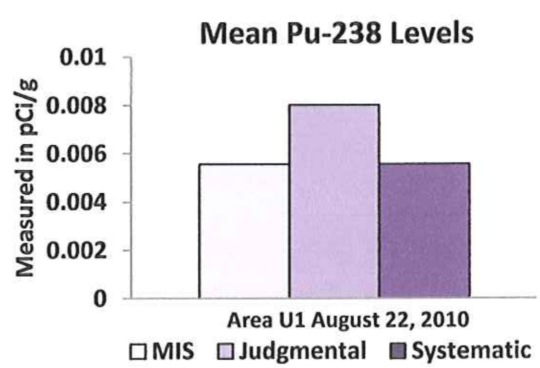
Hypothesis Test	Test Statistic	Outcome
MIS vs Systematic	-0.809	Fail to Reject H_0
MIS vs Judgmental	-1.380	Fail to Reject H_0
Systematic vs Judgmental	-0.245	Fail to Reject H_0

Conclusion: Since the test statistic for all three comparisons (-.809, -1.380, -0.245) 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, Judgmental and Systematic sampling.

8. Comparison Tests Involving Plutonium-238

Pu-238 Summary Statistics in pCi/g

Sampling Method	Mean	Standard Deviation
MIS	0.00556	0.004326
Judgmental	0.008	0.005099
Systematic	0.006794	0.004738



Plutonium-238 Hypothesis Test Results

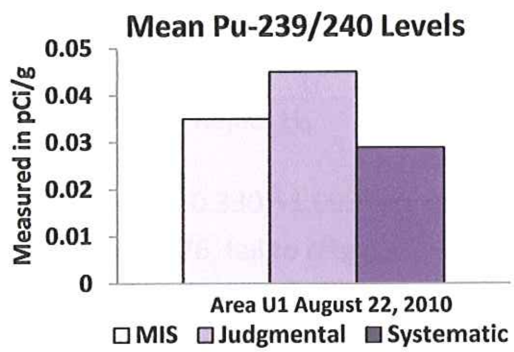
Hypothesis Test	Test Statistic	Outcome
MIS vs Systematic	-0.591	Fail to Reject H_0
MIS vs Judgmental	-0.816	Fail to Reject H_0
Systematic vs Judgmental	-0.500	Fail to Reject H_0

Conclusion: Since the test statistic for all three comparisons (-0.591, -0.816, -0.500) 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, Judgmental and Systematic sampling.

9. Comparison Tests Involving Plutonium-239/240

Pu-239/240 Summary Statistics in pCi/g

Sampling Method	Mean	Standard Deviation
MIS	0.035	0.0081548
Judgmental	0.045	0.0310242
Systematic	0.0288889	0.0330414



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 statistic for all three comparisons (0.925, -0.697, -1.079) 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, Judgmental and Systematic sampling.

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	0.077	Fail to Reject H_0

Conclusion: Since the test statistics for both the comparison of MIS and Judgmental sampling as well as Systematic and Judgmental sampling (1.376 and 0.077 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 from MIS and Judgmental sampling 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 Nitrate levels obtained from MIS and Systematic sampling.

Comparison Summary:

For the data collected from area U1 for August 22, 2010, there were only two cases where statistical differences were detected between sampling methods. One case involved Judgmental samples of Chromium. Due to the nature of Judgmental sampling and the uncertain assumption of normality for Judgmental sampling data, this result should be considered bias. The other statistical difference in sampling methods resulted in MIS and Systematic for the element Nitrate. A small number of multiple hypothesis tests reject H_0, but actually this is false since the significance level of 0.05 allows for this mistake. Eleven hypothesis tests were compared using MIS and Systematic sampling for a number of elements. Of these 11 tests, only one had a statistical difference. According to the significance level, this mistake will occur approximately 5% of the time meaning that this mistake will be found when one does not exist. Therefore, additional analysis should be performed to see if statistical differences really exist.