LOCKHEED MARTIN

DATE: April 4, 2017

TO: Felicia Barnett, Director SCMTSC, EPA, WAM

FROM: Anita Singh, Ph.D., SERAS Statistician

THROUGH: Richard Leuser, SERAS Deputy Program Manager

SUBJECT: Evaluations for Survey Units 8, 10, and 11 to Identify Potential Patterns of Anomalies Representing Suspicious Activities in the North Pier, Hunters Point Naval Shipyard Site, SERAS-106, WO-83

The identification of anomalous observations potentially representing falsification and suspicious activities in huge data sets collected from the various parcels of the Hunters Point Naval Shipyard (HPNS) Site over the past decade for many radionuclides of concern (ROCs) is a complex task. The use of advanced statistical and graphical methods especially designed to identify patterns present in complex multidimensional (for many variable [ROCs]) data sets is required for efficient and successful identification of anomalies and patterns potentially present in such data sets.

As described in the EPA letter report of March 17, 2017 to the United States Navy (Navy), EPA recommends that Navy considers using effective univariate and multivariate/multidimensional statistical and graphical methods to successfully identify potential suspicious/anomalous patterns present in data sets collected from the various parcels of the HPNS Site. As demonstrated in the March 17, 2017 EPA Report, graphical displays based upon multivariate methods are extremely valuable in identifying patterns present in complex multidimensional data sets. Effective pattern recognition graphical methods provide added insight into the patterns present in a data set which may not be possible to identify and interpret from the information provided by test statistics (e.g., Kolmogorov-Smirnov [K-S] test statistic, Peacock test, Kruskal and Wallis (K-W) test etc.). Once anomalous patterns have been identified, for confirmation purposes, one may want to use statistical methods (e.g., hypothesis tests) to verify the existence of those exhibited patterns. The use of principal component analysis (PCA) is recommended to identify patterns of anomalous activities present in data sets collected from the various parcels of the HPNS Site.

There are about 11 survey units (SUs) in North Pier. As demonstrated in the EPA report of March 17, 2017, multivariate approaches successfully identified all anomalous activities (Sys-2 phase sampling performed on dates 5-31-2012 and 6-4-2012) in Survey Unit 1 (SU1, U1, SU-1) and SU7 (U7, SU-7). In the present Technical Memorandum ™, those multivariate methods have been used on: 1) the combined data from all SUs of North Pier; 2) data from SU-8 (SU8, U8); 3) data from SU-10 (SU10, U10); and 4) data from SU-11 (SU11, U11)). PCA evaluations have been performed on multivariate data sets based upon ROCs: Cs-137, Bi-212, Pb-212, Bi-214, Pb-214, K-40, Ra-226, Th-232/AC-228, and U-238. For residential soils, release criteria (in pCi/g) for ROCs: Cs-137, Ra-226, Th-232 and U-235+D, respectively are 0.113, 1.0, 1.69, and 0.195. It is noted that SU2 through SU6 and SU9 do not have data collected during Sys-2 phase.

## 1.0 Evaluations for the Combined Data from All Survey Units of North Pier



ED_004747_00028873-00001

The color-coded graphs of the first two principal components (PCs) displayed in Figures 1 and 2 are sufficient to conclude that something very different happened during the Sys-2 sampling phase (Figure 1) and on May 31, 2012 and June 4, 2012 (Figure 2). It is noted that all Sys-2 sampling data were collected only on these two dates – May 31, 2012 and June 4, 2012.

To determine/verify if similar anomalous patterns are present in other SUs, statistical evaluations were performed on data sets collected from SU8, SU10 and SU11, which are described in Sections 2, 3 and 4, respectively. Evaluations for SU1 and SU7 are described in the EPA Report of March 17, 2017.

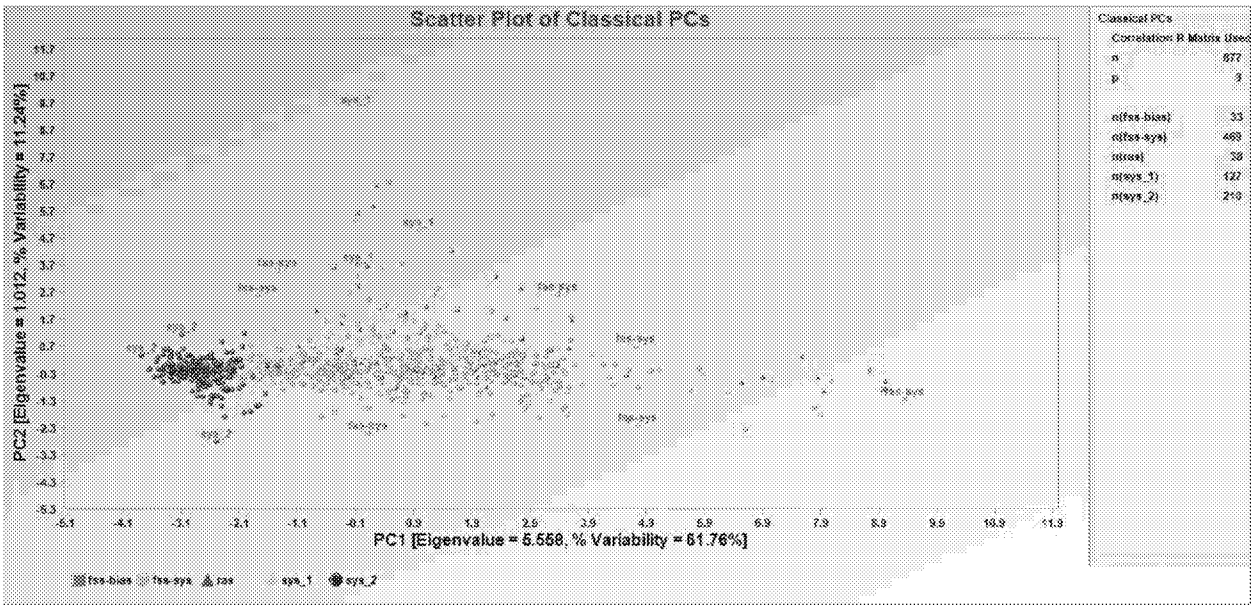


Figure 1. Scatter Plot of PC1 versus PC2 by Sampling Phases – Combined Data from All Survey Units

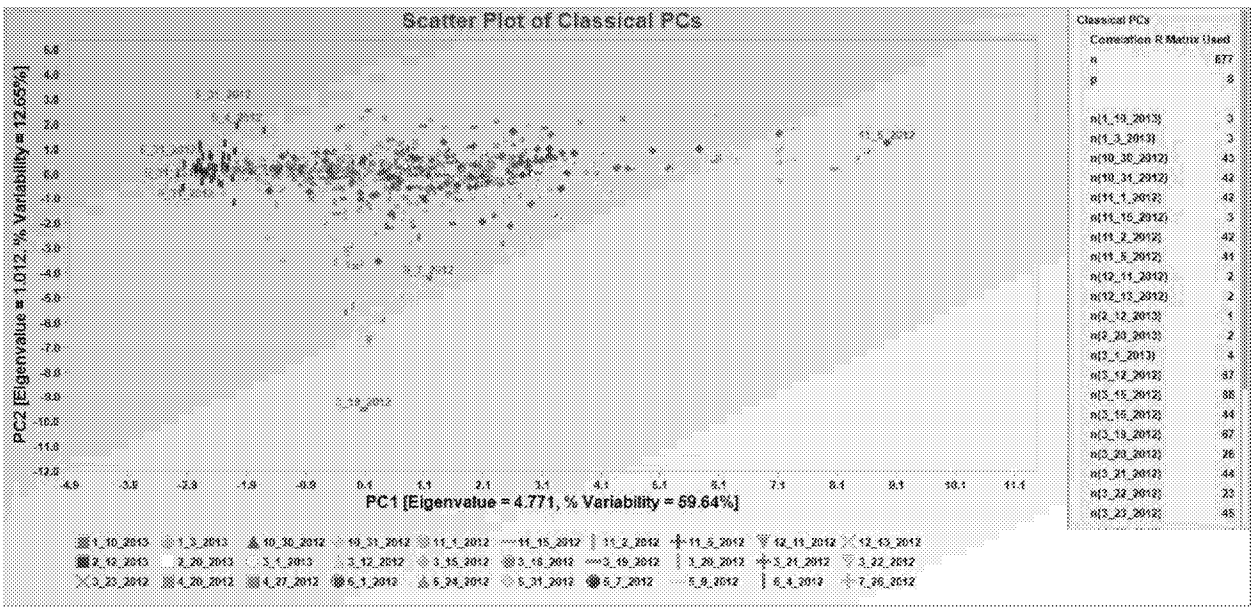


Figure 2. Scatter Plot of PC1 versus PC2 by Sampling Dates – Combined Data from All Survey Units

Pattern Identified for all Survey Units of North Pier: From Figures 1 and 2, it is concluded that anomalous activities perhaps are isolated to the Sys-2 sampling phase which was performed on the two dates listed

above. From Figure 1, it is noted that Sys-2 data (shown in magenta color) is tightly clustered with reduced variability and from Figure 2, it is noted data collected on May 31, 2013 (shown in light green) and on June 4, 2012 (shown in magenta) are tightly clustered together with reduced variability.

- These two graphs lead to the conclusion that Sys-2 data collected on 5-31-2012 and 6-4-2012 might have been manipulated. Since the PCs were computed using multivariate data sets for ROCs: K-40, Cs-137, Bi-212, Bi-214, Pb-212, Pb-214, Ra-226/Bi-214, U-235, and Th-232/Ac-228, this conclusion is applicable to all ROCs included in PC evaluations which are crucial (e.g., K-40, Ra-226/Bi-214, Th-232/Ac-228, Cs-137) in the identification of anomalous activities/patterns.

- For confirmation, scatter plots of the first PC (the most important PC) versus some selected ROCs (determined to be crucial in the identification of anomalous activities) by sampling phases and sampling dates are presented below in Figures 3 through 9 substantiating the conclusions derived and described above. For additional information, summary statistics for ROCs considered important (e.g., K-40, Ra-226/Bi-214, Th-232/AC-228, Pb-214, Bi-214, and Cs-137) to identify anomalous activities are presented in Appendix A.

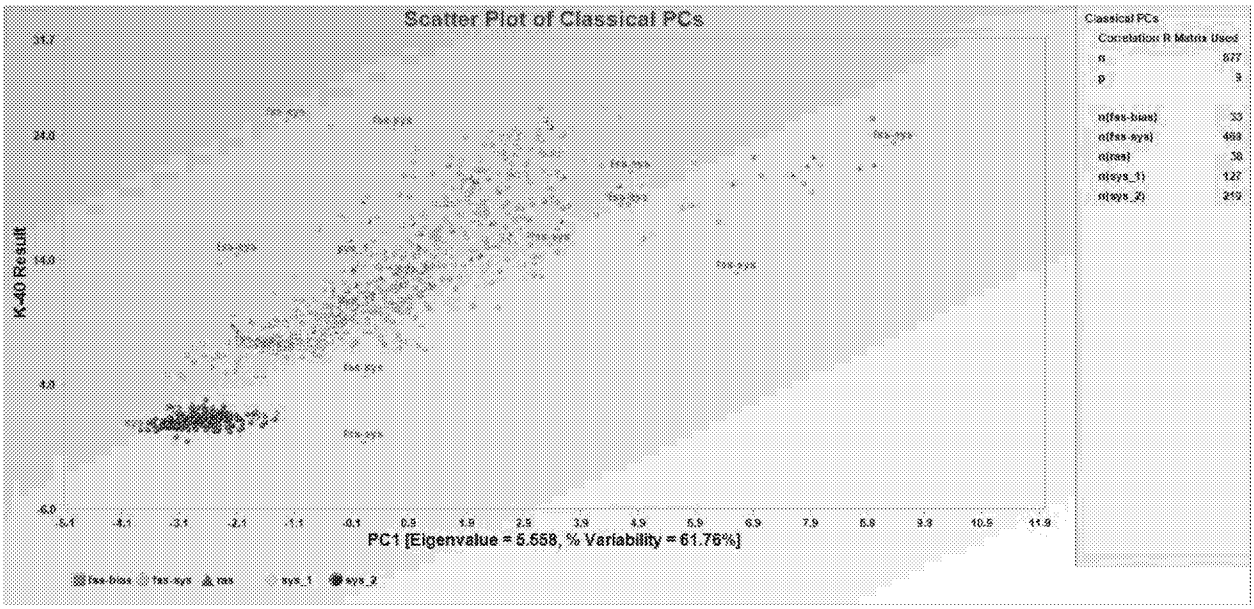


Figure 3. Scatter Plot of PC1 versus K-40 by Sampling Phases – Combined Data from All Survey Units

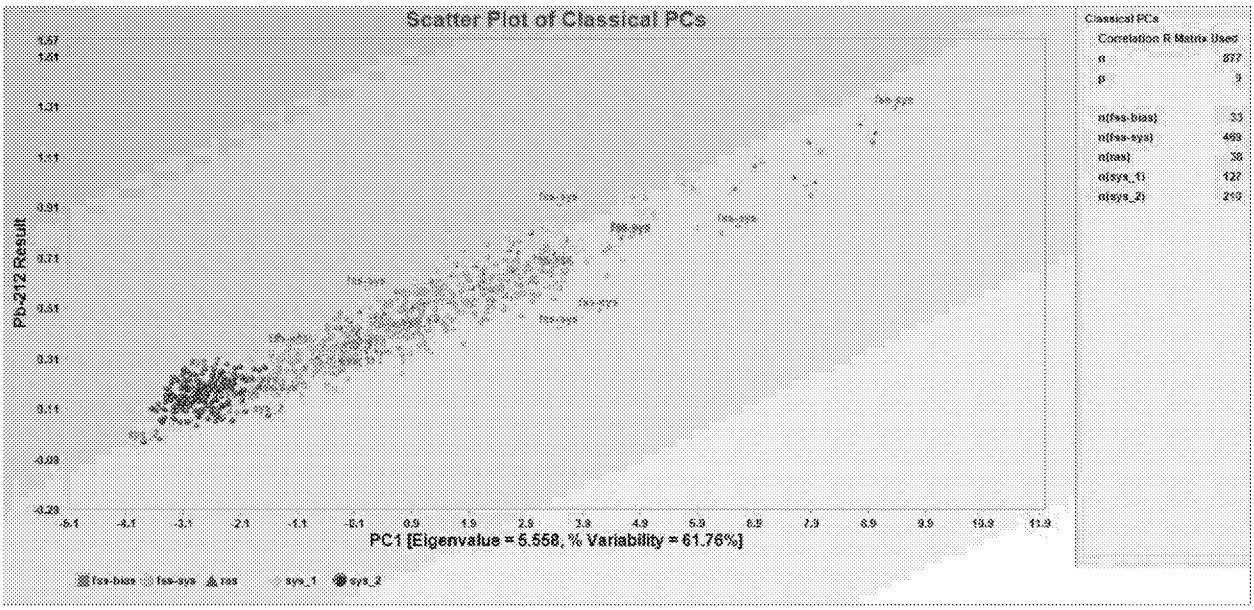


Figure 4. Scatter Plot of PC1 versus Pb-212 by Sampling Phases – Combined Data from All Survey Units

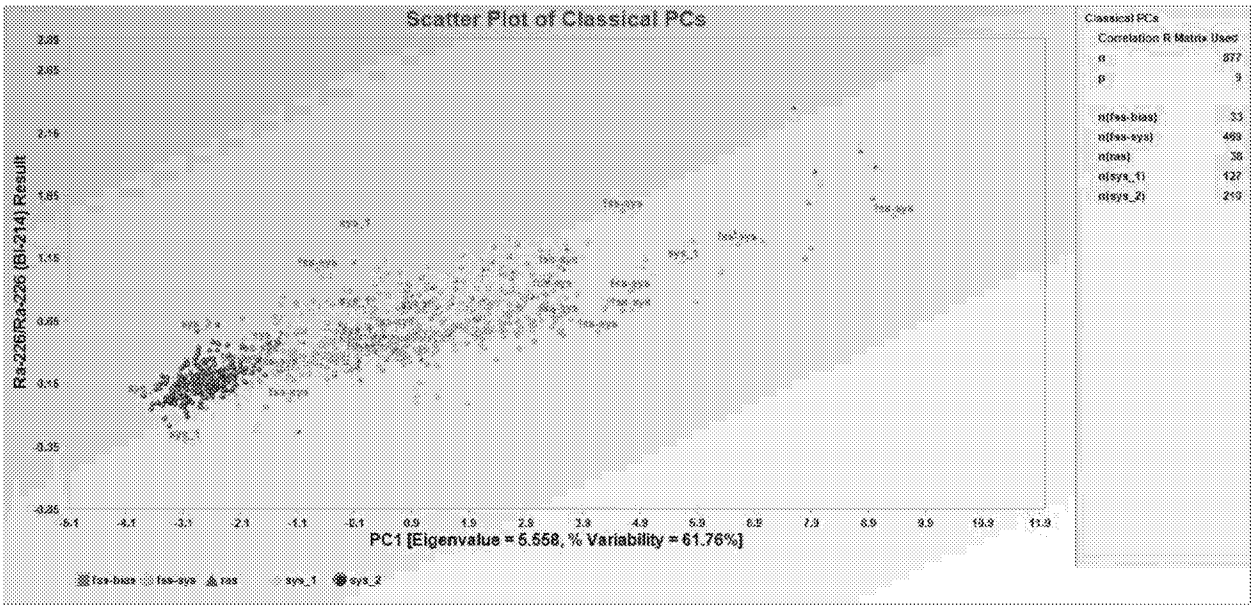


Figure 5. Scatter Plot of PC1 versus Ra-226/Bi-214 by Sampling Phases – Combined Data from All Survey Units

<u>Anomalous Patterns by Sampling Phases for K-40, Pb-212 and Ra-226/Bi-214) in All SUs of North Pier</u>: Figures 3 through 5 have scatter plots of K-40, Pb-212, and Ra-226/Bi-214, respectively, versus PC1 by sampling phases. A quick look at these graphs confirms that something very different happened during the Sys-2 (shown in magenta) sampling event. It is noted that Sys-2 data set is tightly clustered (with reduced mean and variance) and is well separated from the rest of data collected during other sampling phases.

<u>Anomalous Patterns by Collection Dates for K-40, Pb-212 and Ra-226/Bi-214) in All SUs of North Pier:</u> Figures 6 through 9 have scatter plots of K-40, Bi-214, Cs-137, and Ra-226/Bi-214, respectively versus PC1 by sampling dates. Again, a quick look at these graphs confirms that something very different

happened on 5-31-2012 and 6-4-2012 (Sys-2 sampling was conducted on these two days in North Pier). Graphs (not included here) for other ROCs also display similar patterns.

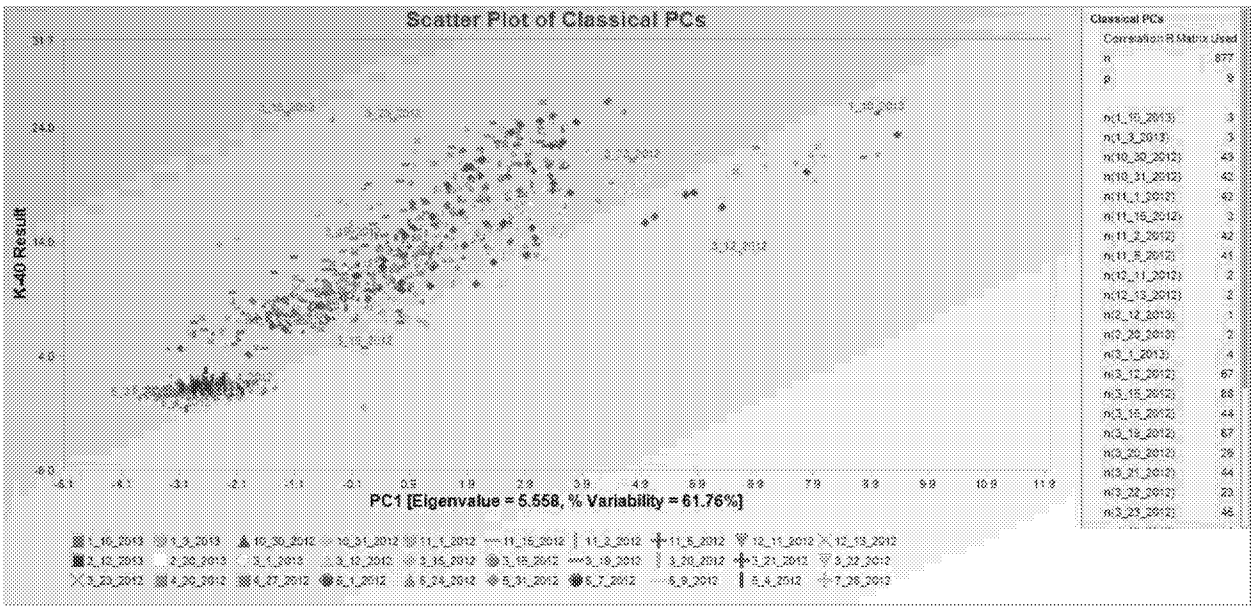


Figure 6. Scatter Plot of PC1 versus K-40 by Sampling Dates – Combined Data from All Survey Units

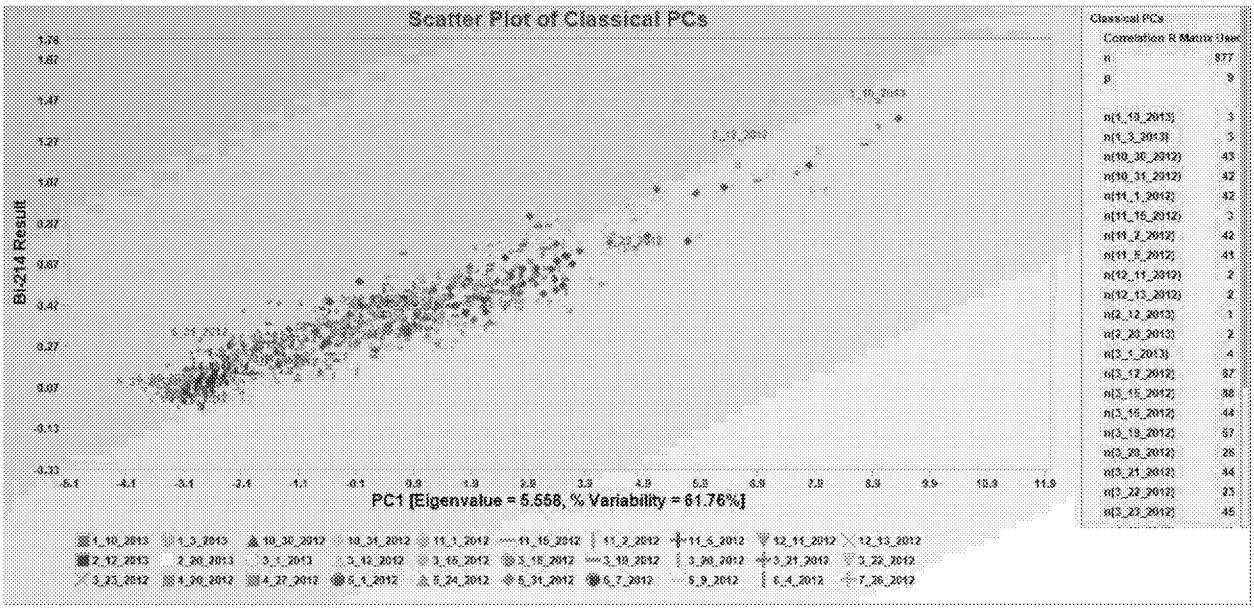


Figure 7. Scatter Plot of PC1 versus Bi-214 by Sampling Dates – Combined Data from All Survey Units

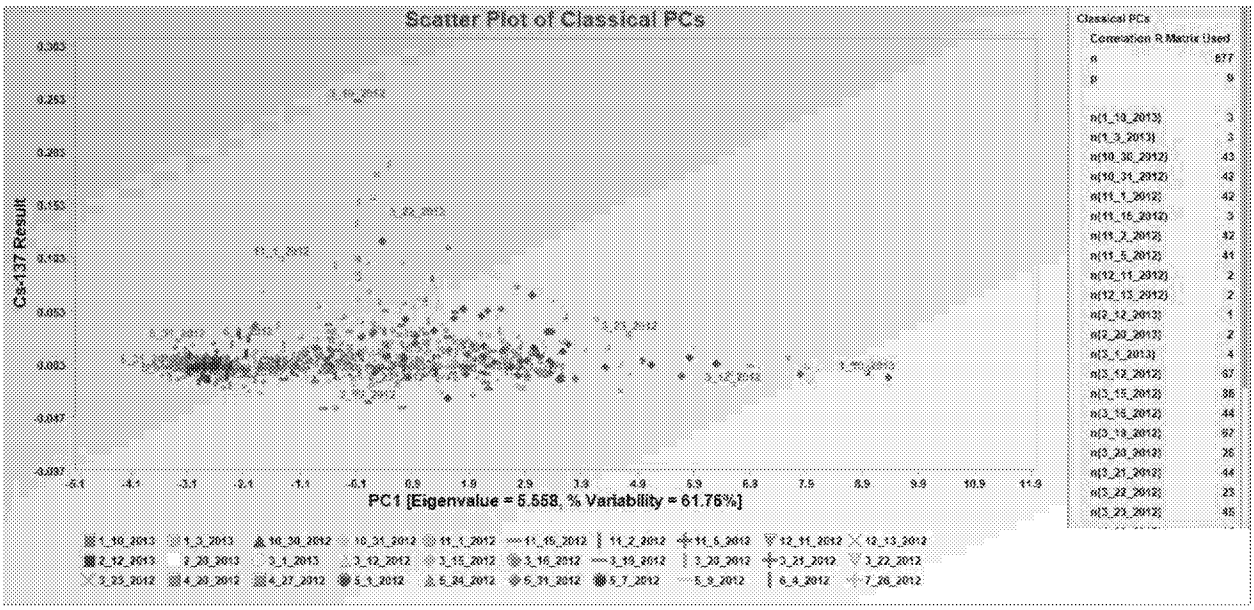


Figure 8. Scatter Plot of PC1 versus Cs-137 by Sampling Dates – Combined Data from All Survey Units

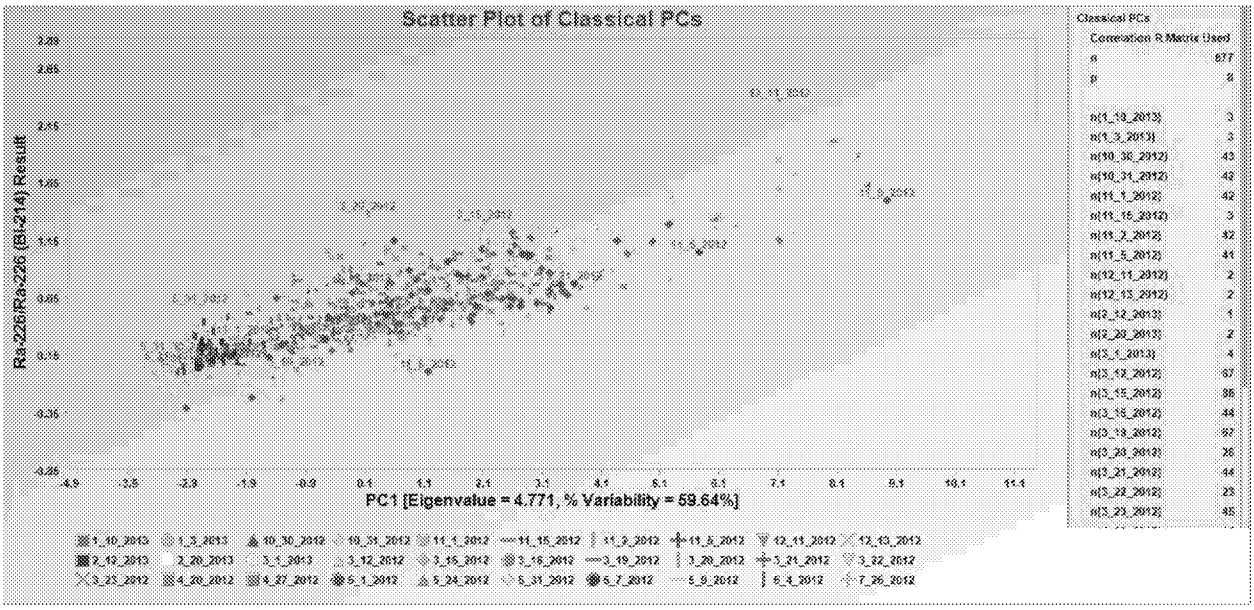


Figure 9. Scatter Plot of PC1 versus Ra-226/Bi-214 by Sampling Dates – Combined Data from All Survey Units

- For additional information, summary statistics for K-40 (Ra-226/Bi-214) based upon all North Pier data are presented in Tables A1 and A3 by sampling phases and in Tables A2 and A4 by collection dates of Appendix A. As noted in graphical displays shown in Figures 1 through 9, these tables also lead to the conclusion that Sys-2 data collected on May 31 and June 4 of 2012 exhibit anomalous activities with the lowest values of means, maxima and standard deviations.
    - The reduced values of means and standard deviations explain why data collected on May 31 and June 4, 2012 during Sys-2 sampling event are tightly clustered and well separated (potentially due to manipulation/falsification) from data collected on other dates and sampling phases.

For confirmation purposes, additional evaluations have been performed separately for SU8, SU10 and SU11. These evaluations are presented in Sections 2, 3, and 4.

## 2. Evaluations of SU-8 Data

Figures 10 and 11 have scatter plots of the first two PCs based upon data collected from SU8. As already noted in Figures 1 and 2 above, these figures further confirm that something very different happened during the Sys-2 sampling phase (shown in magenta on Figure 10) performed on May 31, 2012 (Figure 11). No sampling was performed in this SU8 on June 4, 2012. These two figures alone quickly suggest that anomalous activities are isolated to the Sys-2 (magenta) phase performed on 5-31-12 (magenta). Since PCs were computed using multivariate data set for ROCs: K-40, Cs-137, Bi-212, Bi-214, Pb-212, Pb-214, Ra-226/Bi-214, U-235, and Th-232/Ac-228, this conclusion is applicable to all crucial ROCs (in the identification of anomalous activities such as K-40, Ra-226/Bi-214, Cs-137) included in PC evaluations.

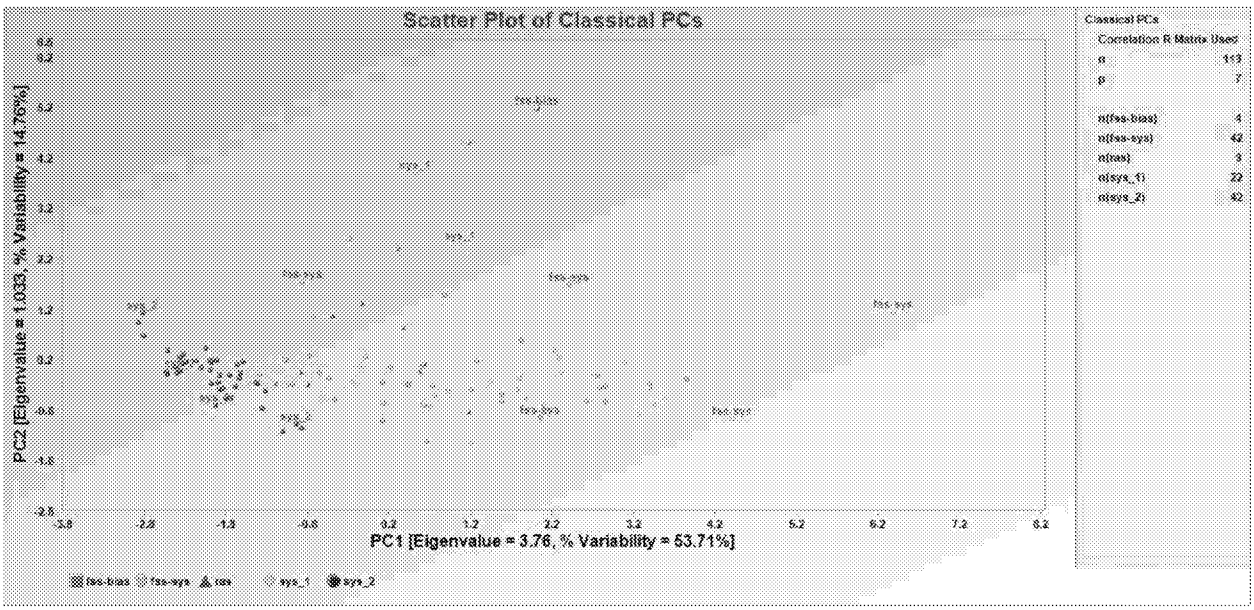


Figure 10. Scatter Plot of PC1 versus PC2 by Sampling Phases –Data from Survey Unit 8

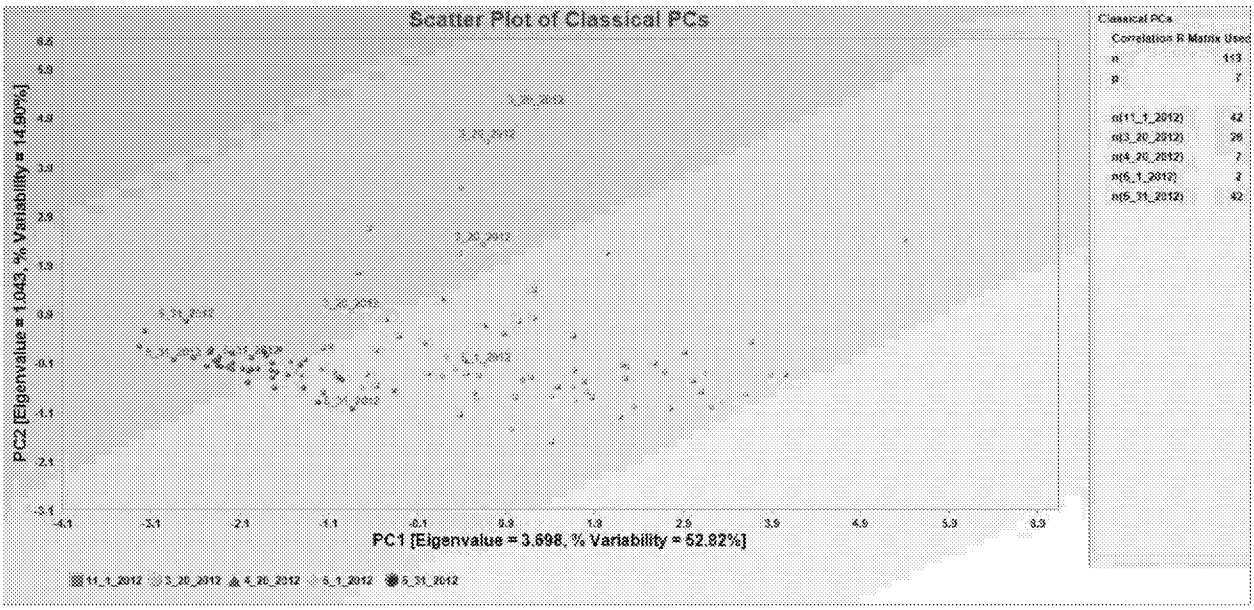

Figure 11. Scatter Plot of PC1 versus PC2 by Sampling Dates –Data from Survey Unit 8

- These two PC graphs shown in Figures 10 and 11 identified all anomalous activities that potentially took place in SU8.

For further verification, scatter plots of PC1 versus some of the ROCs (K-40, Cs-137, Ra-226/Bi-214, Th-232/Ac-228) by sampling phases and sampling dates are presented in Figures 12 through 15. Again, a quick look at these graphs confirms that something very different happened during the Sys-2 (shown in magenta) sampling phase on 5-31-2012. Other graphs (not included here) for other ROCs also display similar patterns.

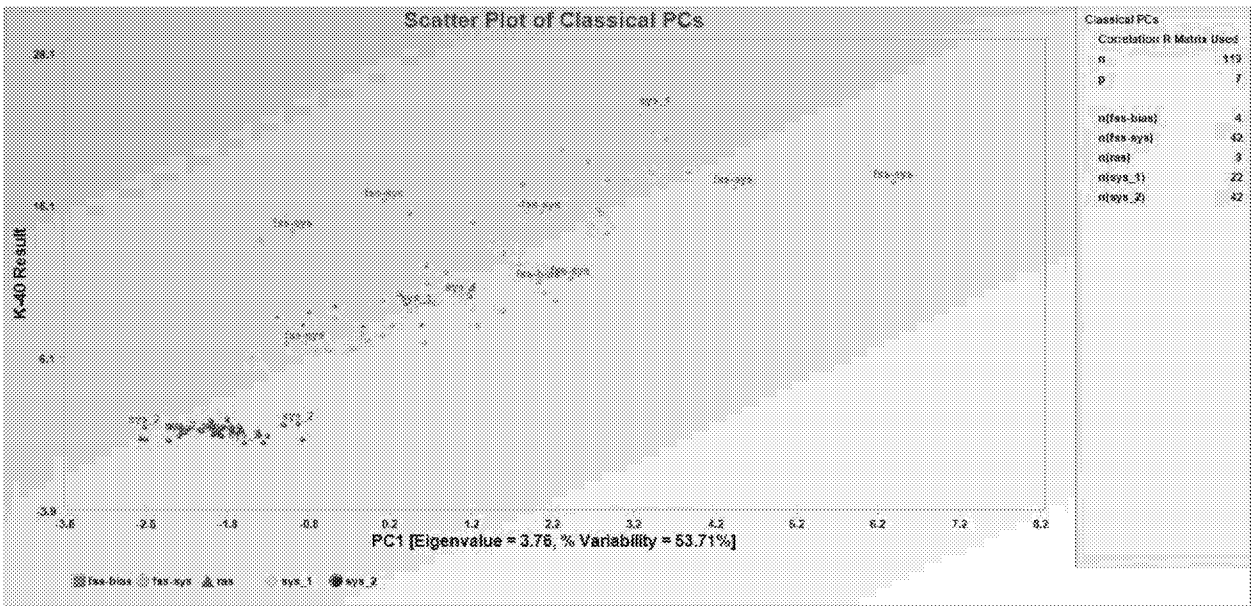

Figure 12. Scatter Plot of PC1 versus K-40 by Sampling Phases –Data from Survey Unit 8



ED_004747_00028873-00008

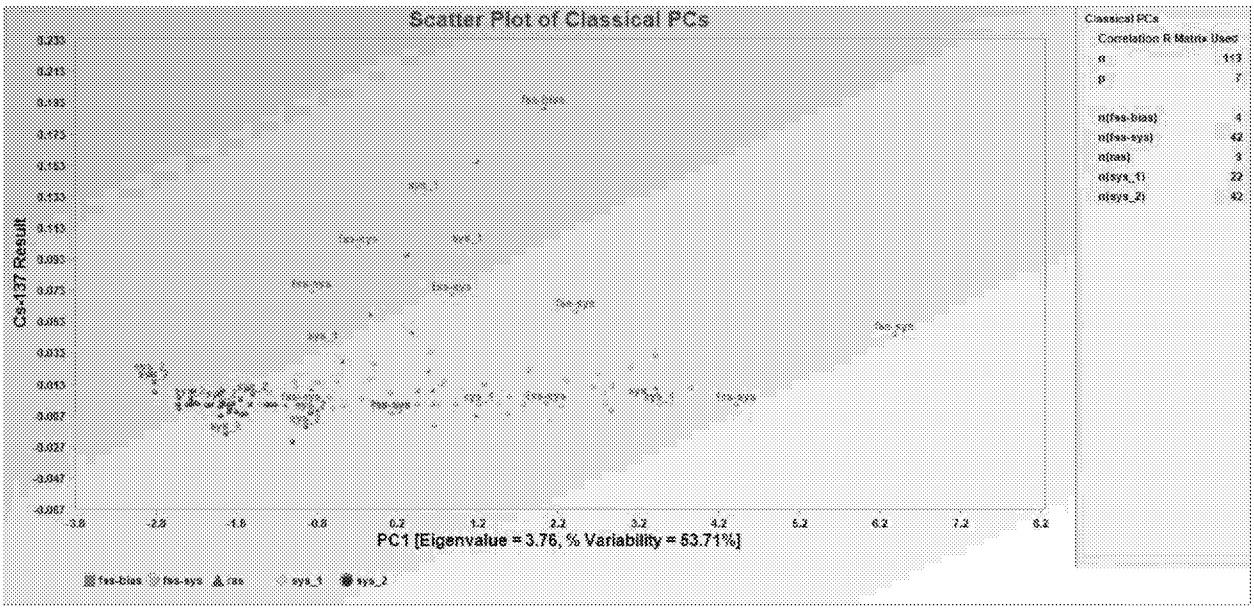


Figure 13. Scatter Plot of PC1 versus Cs-137 by Sampling Phases –Data from Survey Unit 8

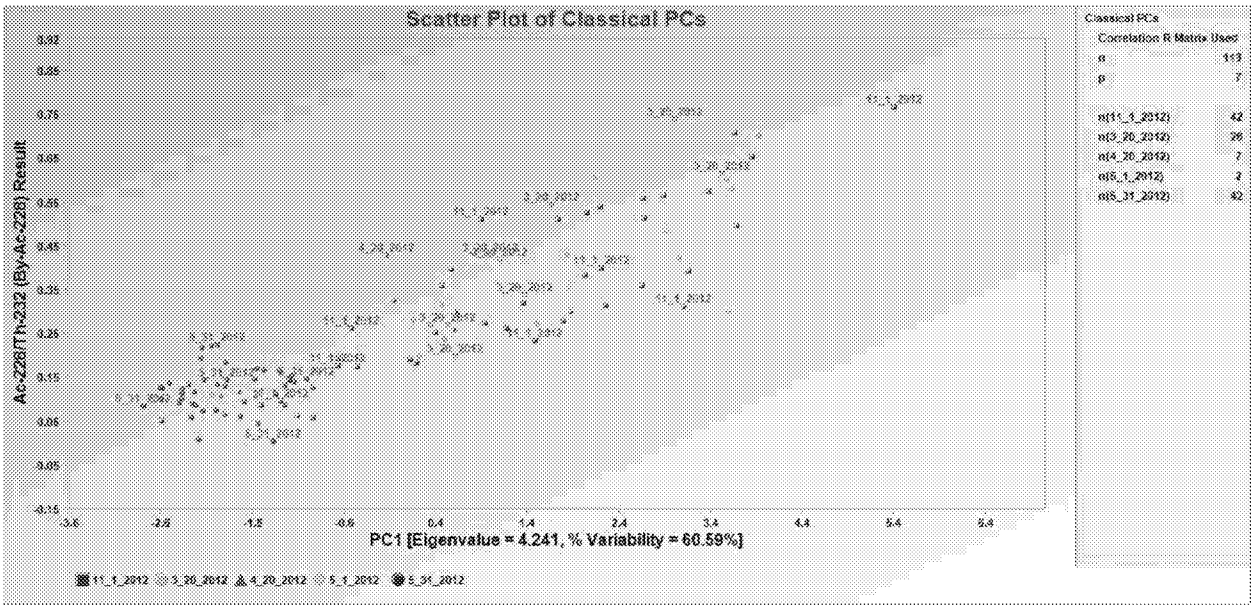


Figure 13a. Scatter plot of AC-228/Th-232 versus PC1 by Sample Collection Dates –Survey Unit 8

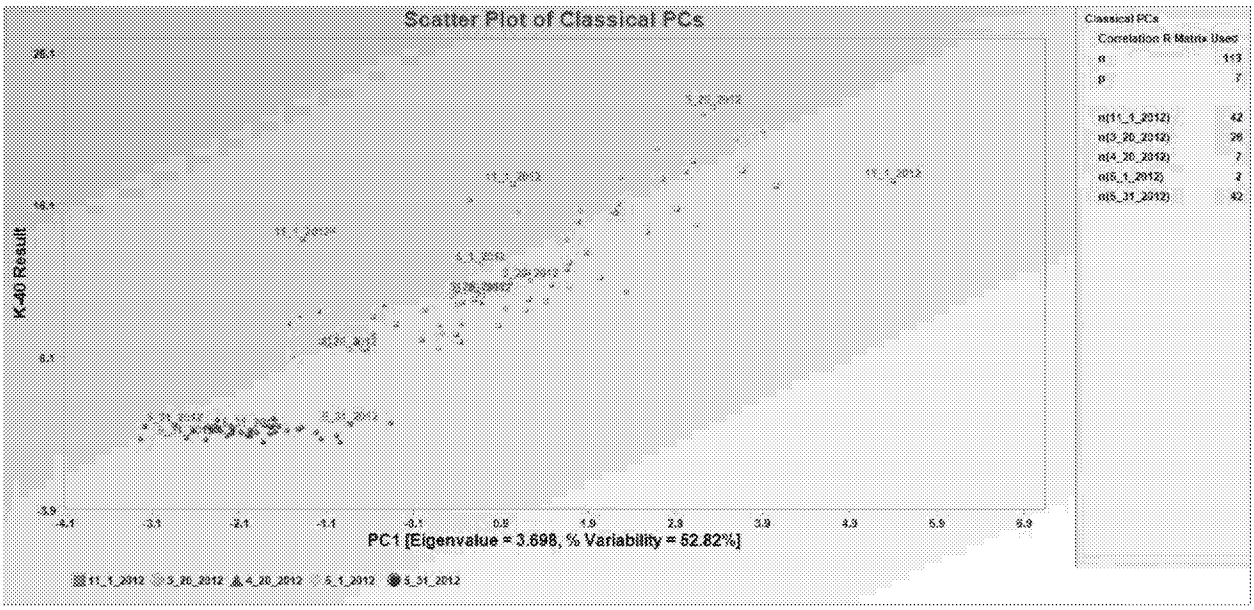


Figure 14. Scatter Plot of PC1 versus K-40 by Sampling Dates –Data from Survey Unit 8

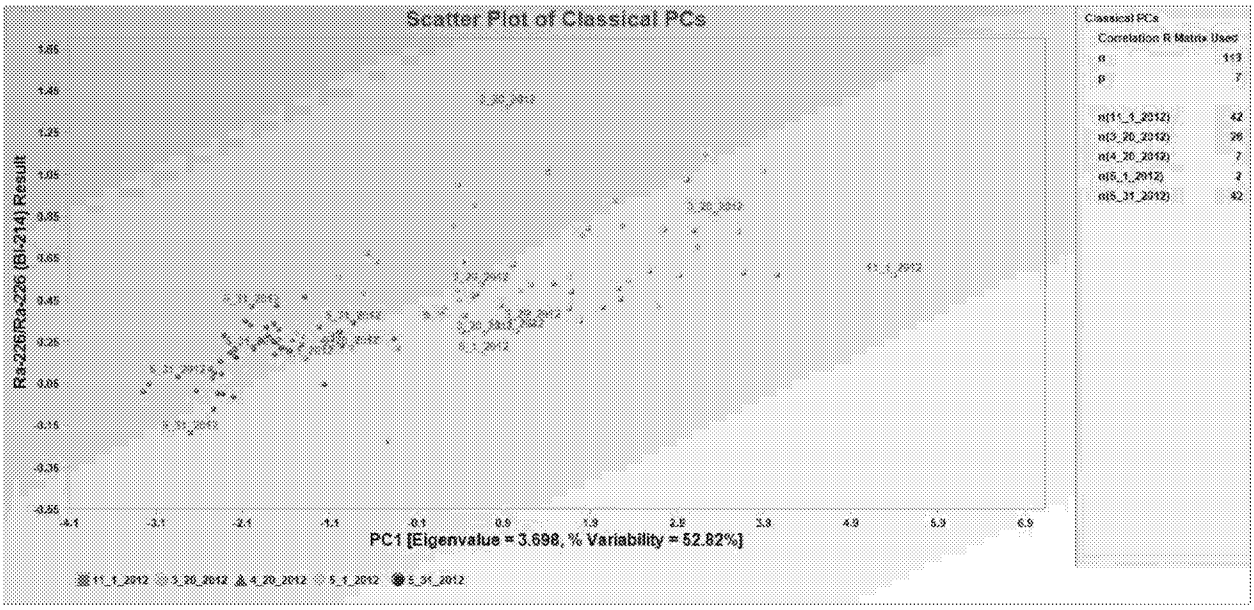


Figure 15. Scatter Plot of PC1 versus Ra-226/Bi-214 by Sampling Dates –Data from Survey Unit 8

- For additional information confirming the above findings, summary statistics for K-40 by sampling phases and sample collection dates are provided in Tables A5 and A6. Summary statistics for Ra-226/Bi-214 by sampling phases and dates are summarized in Tables A7 and A8. From these tables, it is noted that data collected on 5-31-2012 during the Sys-2 phase exhibit anomalous behavior with the lowest values of means and standard deviations.
    - The reduced values of means and standard deviations explain why data collected on May 31, 2012 during Sys-2 sampling event are tightly clustered and well separated (potentially due to manipulation/falsification) from data collected on other dates and sampling phases.

## 3. Evaluation of SU-10 Data

As concluded in Section 1 for North Pier, Sys-2 phase sampling performed on 5-31-2012 and 6-4-2012 exhibits anomalous activities. Therefore, evaluations for other survey units such as SU-10 and SU-11 may not be needed. However, for confirmatory purposes, PC evaluations for SU10 and SU11 data are summarized in Sections 3 and 4.

Just like in Sections 1 and 2, Figures 16 through 20 have scatter plots of PCs and PCs versus some of the crucial ROCs (e.g., K-40, Pb-214, Ra-226/Bi-214) using data collected from SU10. These graphs confirm that something very different happened during Sys-2 (Figures 16, 17, and 18 shown in magenta) sampling phase and on May 31, 2012 (Figures 19 and 20, magenta). Since PCs were computed using multivariate data for ROCs: K-40, Cs-137, Bi-212, Bi-214, Pb-212, Pb-214, Ra-226/Bi-214, U-235, and Th-232/Ac-228, these conclusions are applicable to all crucial ROCs included in PC evaluations. These graphical displays identified all anomalous activity that potentially took place in SU10.

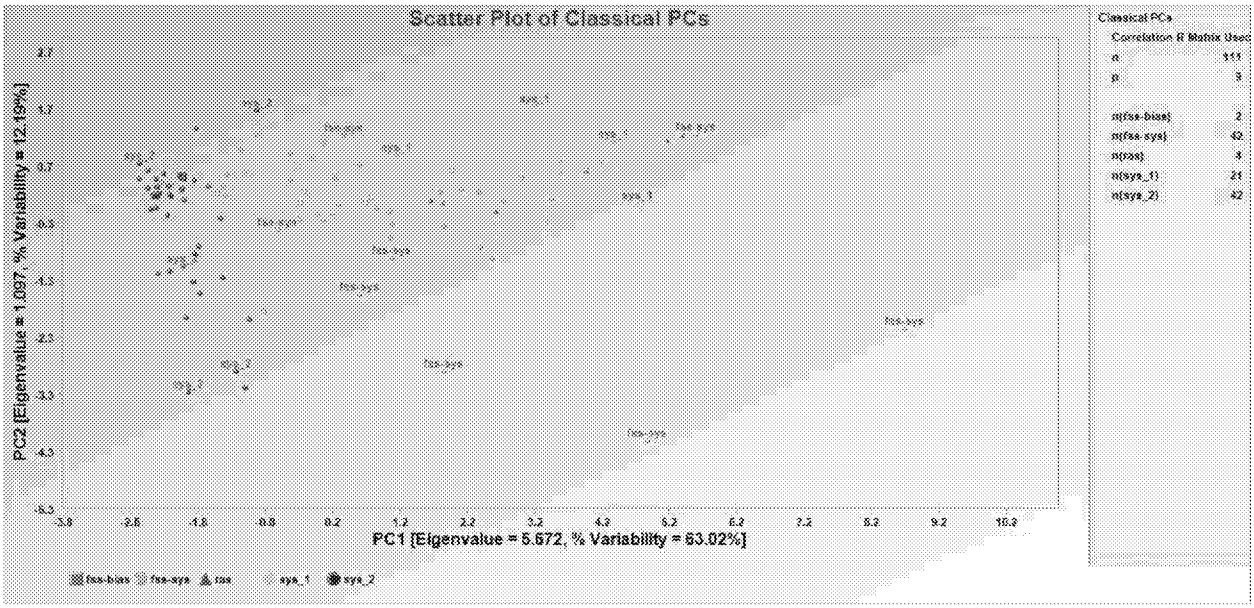


Figure 16. Scatter Plot of PC1 versus PC2 by Sampling Phases –Data from Survey Unit 10

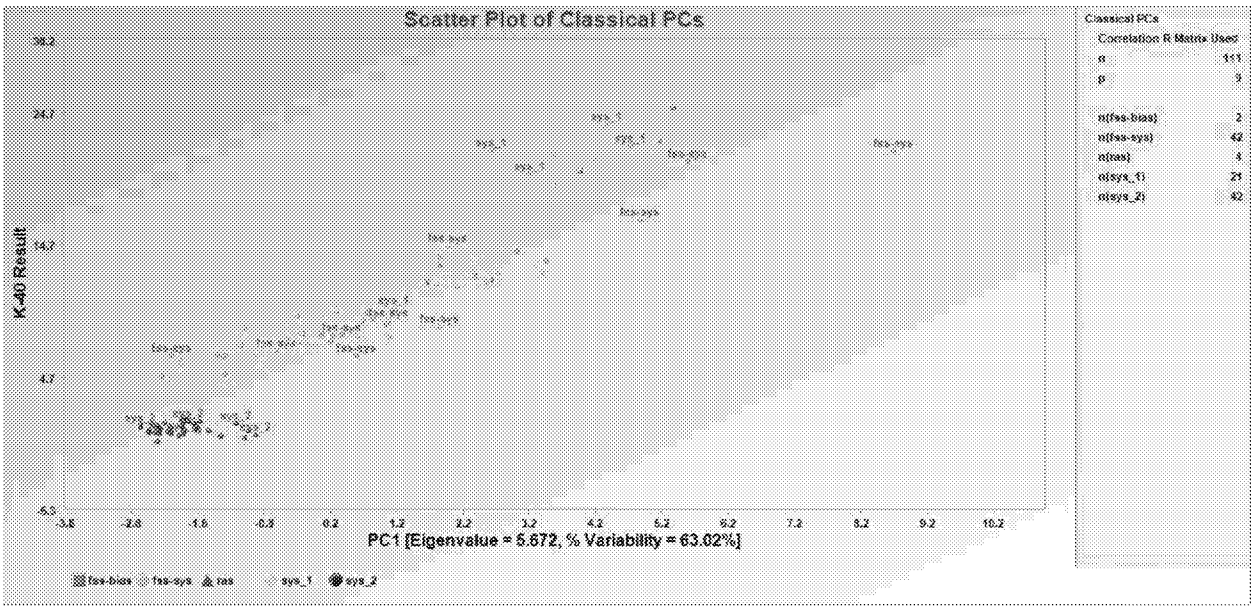


Figure 17. Scatter Plot of PC1 versus K-40 by Sampling Phases –Data from Survey Unit 10

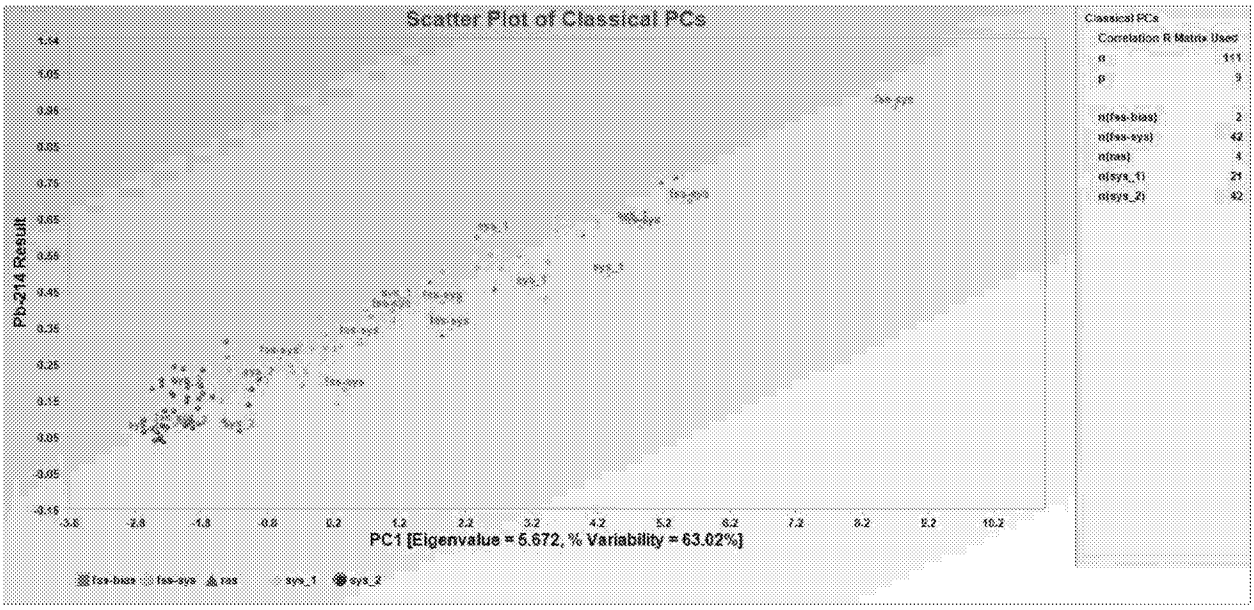


Figure 18. Scatter Plot of PC1 versus Pb-214 by Sampling Phases –Data from Survey Unit 10

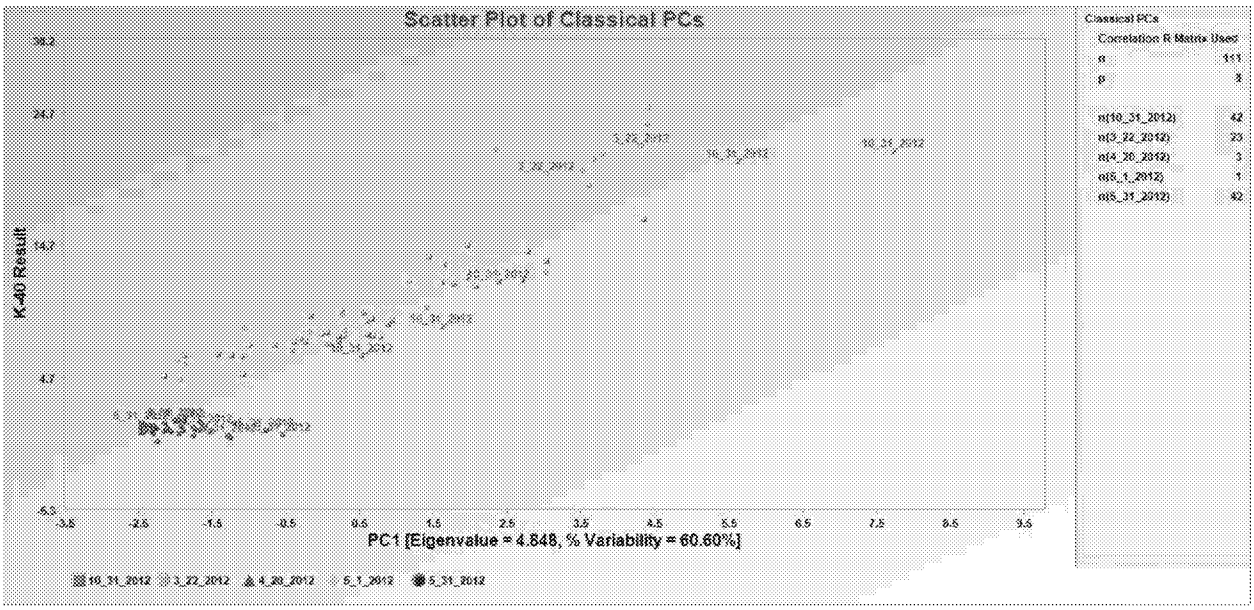


Figure 19. Scatter Plot of PC1 versus K-40 by Sampling Dates –Data from Survey Unit 10

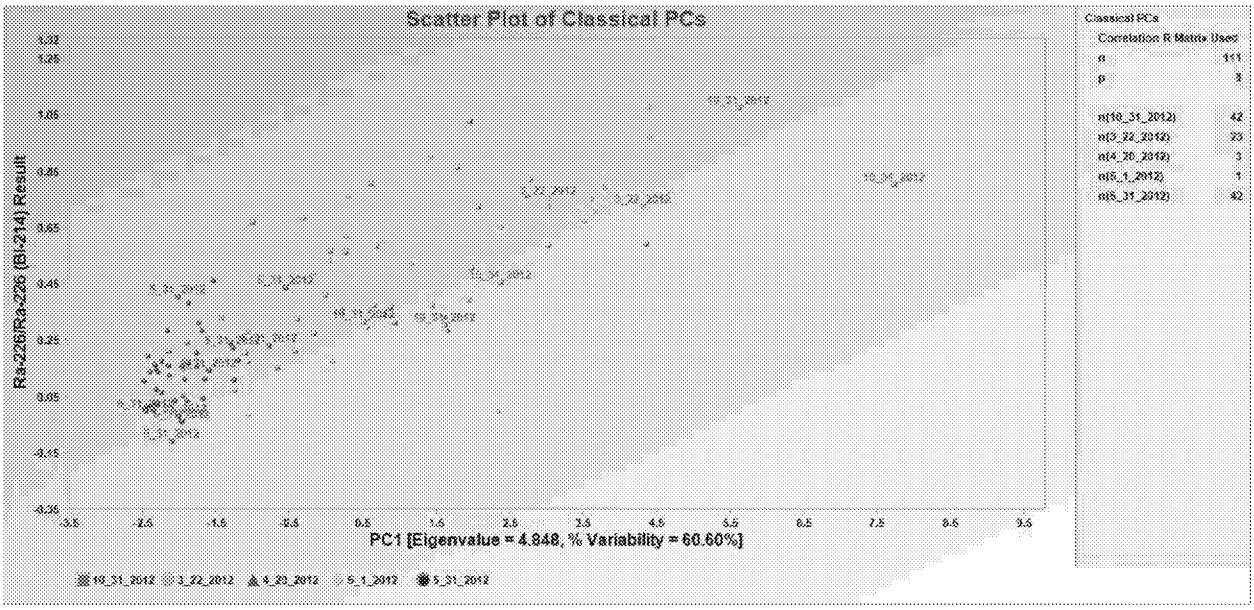


Figure 20. Scatter Plot of PC1 versus Ra-226/Bi-214 by Sampling Dates –Data from Survey Unit 10

- For additional information confirming the above findings, For SU-10, summary statistics for K-40 by sampling phases and sample collection dates are provided in Tables A9 and A10. Summary statistics for Bi-214 by sampling phases and dates are summarized in Tables A11 and A12. From these tables, it is noted that data collected on 5-31-2012 during Sys-2 phase exhibits anomalous behavior exhibiting the lowest values of means and standard deviations.
    - The reduced values of means and standard deviations explain why data collected on May 31, 2012 during Sys-2 sampling event are tightly clustered and well separated (potentially due to manipulation/falsification) from data collected on other dates and sampling phases.

## 4.0 Evaluation of SU-11 Data

Figures 21 through 26 have scatter plots of PCs and PCs versus some of the ROCs (e.g., K-40, Th-232/Ac-228, Ra-226/Bi-214) using data collected from SU11. These graphs further confirm that something very different happened during the Sys-2 (Figures 21, 23, and 24 shown in magenta) sampling phase and on May 31, 2012 (Figures 22, 25 and 26, magenta). Since the PCs were computed using data for ROCs: K-40, Cs-137, Bi-212, Bi-214, Pb-212, Pb-214, Ra-226/Bi-214, U-235, and Th-232/Ac-228, this conclusion is applicable to all ROCs included in the PC evaluations.

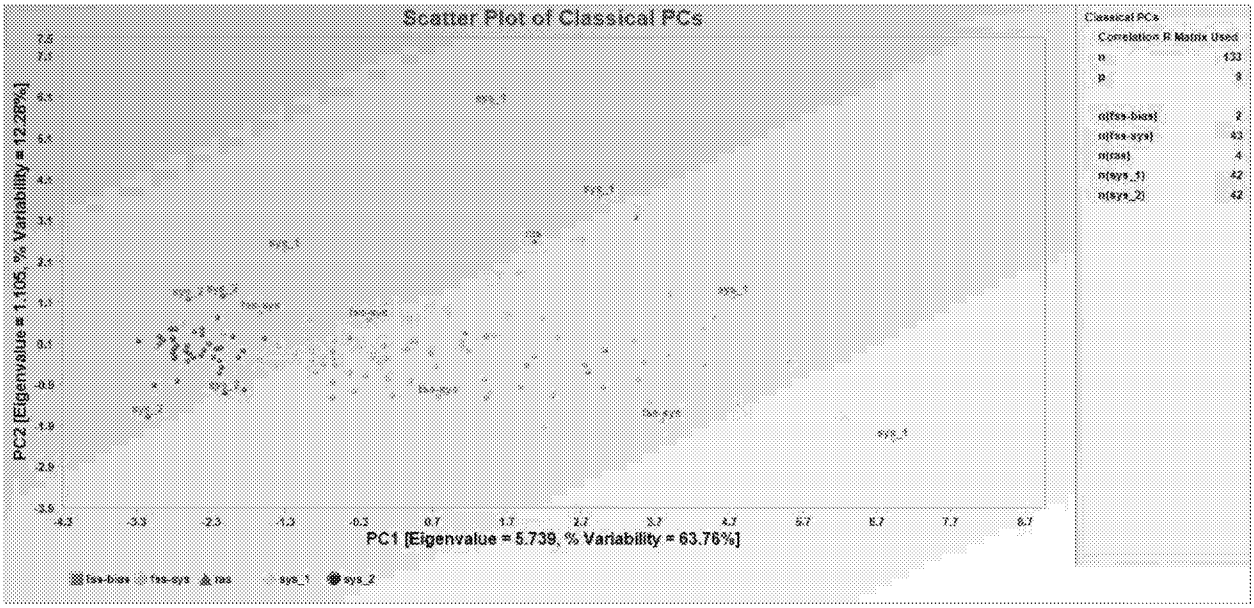


Figure 21. Scatter Plot of PC1 versus PC2 by Sampling Phases –Data from Survey Unit 11

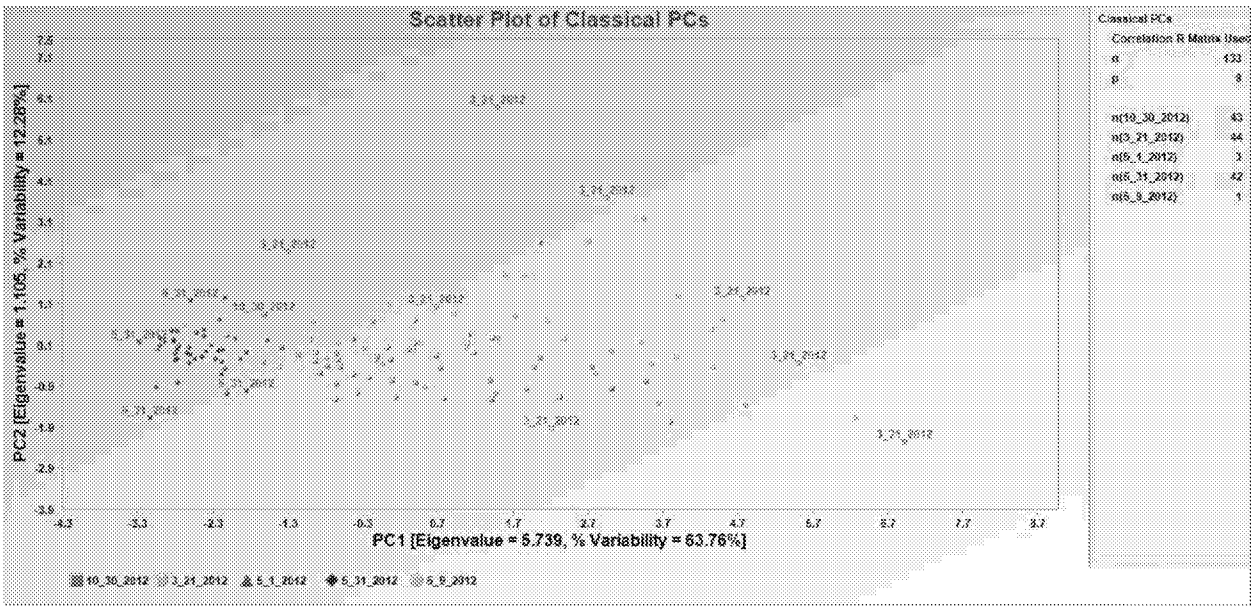


Figure 22. Scatter Plot of PC1 versus PC2 by Sampling Dates –Data from Survey Unit 11



ED_004747_00028873-00014

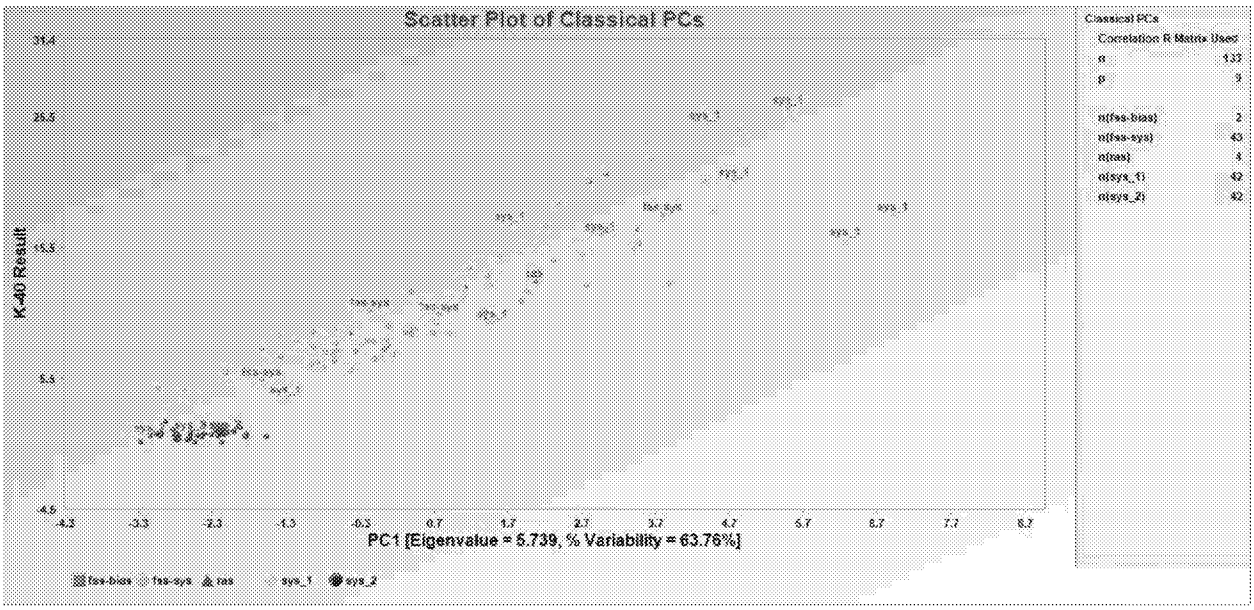


Figure 23. Scatter Plot of PC1 versus K-40 by Sampling Phases –Data from Survey Unit 11

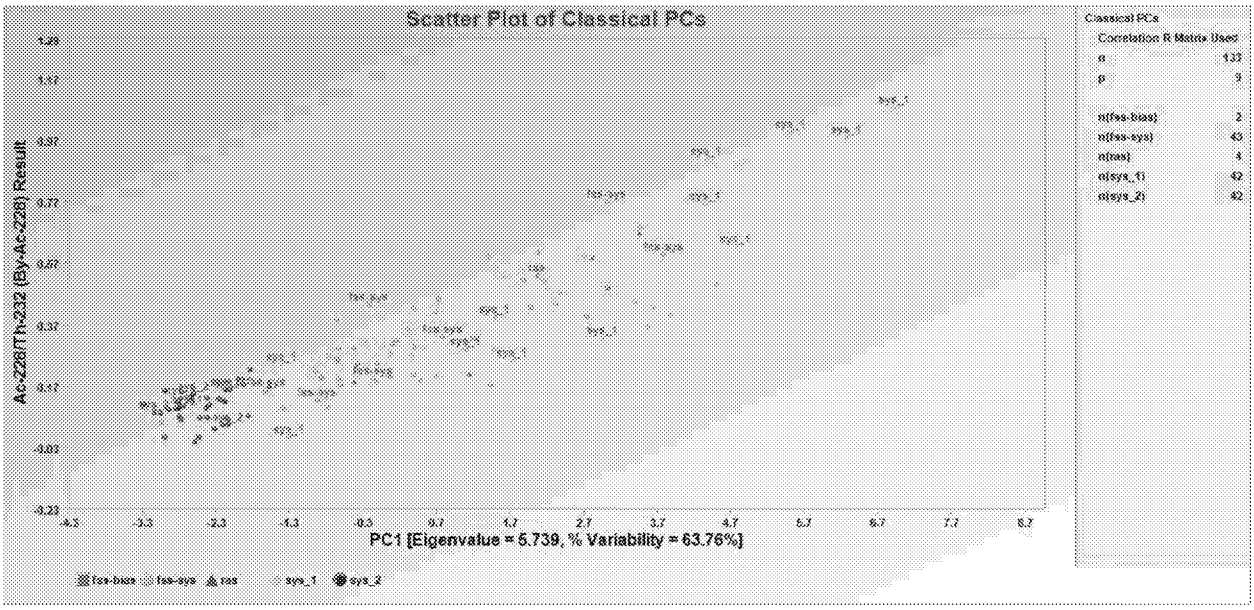


Figure 24. Scatter Plot of PC1 versus Th-232/AC-228 by Sampling Phases –Data from Survey Unit 11

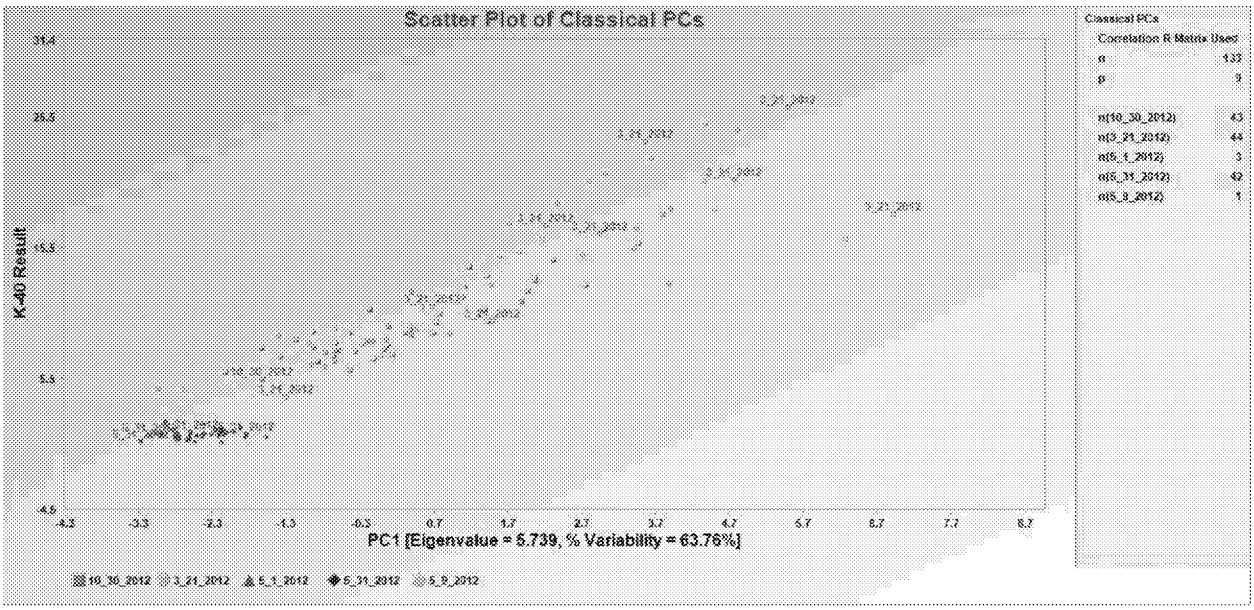


Figure 25. Scatter Plot of PC1 versus K-40 by Sampling Dates –Data from Survey Unit 11

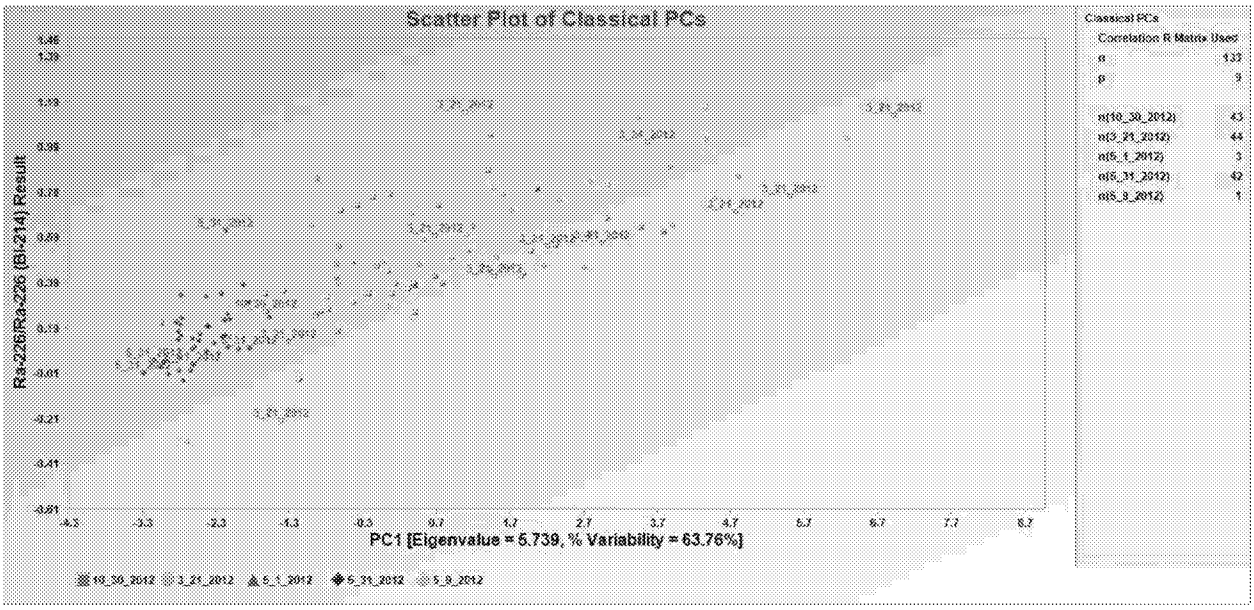


Figure 26. Scatter Plot of PC1 versus Ra-226/Bi-214 by Sampling Dates –Data from Survey Unit 11

- For additional information confirming the above findings, summary statistics for K-40 by sampling phases and sample collection dates are provided in Tables A13 and A14. Summary statistics for Ra-226/Bi-214 by sampling phases and dates are summarized in Tables A15 and A16. From these tables, it is noted that data collected on 5-31-2012 during the Sys-2 phase exhibits anomalous behavior with the lowest values of means and standard deviations.
    - The reduced values of means and standard deviations explain why data collected on May 31, 2012 during Sys-2 sampling event are tightly clustered and well separated (potentially due to manipulation/falsification) from data collected on other dates and sampling phases.

# Appendix A

## Table A1. Summary Statistics for K-40 by Collection Dates – Combined North Pier Data

| Variable | NumObs | # Missing | Minimum | Maximum | Mean | Geo-Mean | SD | SEM | MAD/0.675 | Skewness | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K-40 Result (1_10_2013) | 3 | 0 | 9.208 | 25.34 | 15.83 | 14.46 | 8.443 | 4.875 | 5.548 | 1.357 | 0.533 |
| K-40 Result (1_3_2013) | 3 | 0 | 16.08 | 21.58 | 18.26 | 18.11 | 2.924 | 1.688 | 1.527 | 1.493 | 0.16 |
| K-40 Result (10_30_2012) | 43 | 0 | 4.761 | 18.1 | 9.624 | 9.187 | 3.1 | 0.473 | 2.372 | 1.012 | 0.322 |
| K-40 Result (10_31_2012) | 42 | 0 | 4.76 | 21.8 | 9.632 | 9.039 | 3.826 | 0.59 | 1.898 | 1.607 | 0.397 |
| K-40 Result (11_1_2012) | 42 | 0 | 6.541 | 18.91 | 11.85 | 11.17 | 4.037 | 0.623 | 5.428 | 0.285 | 0.341 |
| K-40 Result (11_15_2012) | 3 | 0 | 20.35 | 22.26 | 21.33 | 21.32 | 0.956 | 0.552 | 1.305 | -0.235 | 0.0448 |
| K-40 Result (11_2_2012) | 42 | 0 | 5.76 | 23.9 | 12.97 | 11.87 | 5.577 | 0.861 | 7.176 | 0.671 | 0.43 |
| K-40 Result (11_5_2012) | 41 | 0 | 8.925 | 24.59 | 16.65 | 15.91 | 4.857 | 0.759 | 6.079 | -0.134 | 0.292 |
| K-40 Result (12_11_2012) | 2 | 0 | 20.85 | 21.59 | 21.22 | 21.22 | 0.523 | 0.37 | 0.549 | N/A | 0.0247 |
| K-40 Result (12_13_2012) | 2 | 0 | 20.08 | 22.29 | 21.19 | 21.16 | 1.563 | 1.105 | 1.638 | N/A | 0.0738 |
| K-40 Result (2_12_2013) | 1 | 0 | 13.62 | 13.62 | 13.62 | 13.62 | N/A | N/A | 0 | N/A | N/A |
| K-40 Result (2_20_2013) | 2 | 0 | 11.53 | 17.28 | 14.41 | 14.12 | 4.066 | 2.875 | 4.262 | N/A | 0.282 |
| K-40 Result (3_1_2013) | 4 | 0 | 9.994 | 10.62 | 10.33 | 10.32 | 0.328 | 0.164 | 0.385 | -0.0864 | 0.0318 |
| K-40 Result (3_12_2012) | 67 | 0 | 8.662 | 24.65 | 17.1 | 16.64 | 3.941 | 0.481 | 4.759 | 0.115 | 0.23 |
| K-40 Result (3_15_2012) | 88 | 0 | 7.19 | 23.18 | 14.06 | 13.52 | 3.893 | 0.415 | 4.655 | 0.277 | 0.277 |
| K-40 Result (3_16_2012) | 44 | 0 | 4.7 | 25.4 | 15.54 | 14.44 | 5.735 | 0.865 | 6.761 | 0.211 | 0.369 |
| K-40 Result (3_19_2012) | 67 | 0 | 4.65 | 24.41 | 13.58 | 12.37 | 5.607 | 0.685 | 6.538 | 0.233 | 0.413 |
| K-40 Result (3_20_2012) | 26 | 0 | 6.148 | 22.48 | 12.51 | 11.54 | 5.224 | 1.024 | 5.183 | 0.686 | 0.417 |
| K-40 Result (3_21_2012) | 44 | 0 | 4.11 | 26.3 | 14.16 | 12.87 | 5.912 | 0.891 | 6.901 | 0.292 | 0.418 |
| K-40 Result (3_22_2012) | 23 | 0 | 4.539 | 25.15 | 13.64 | 11.89 | 7.002 | 1.46 | 8.882 | 0.322 | 0.513 |
| K-40 Result (3_23_2012) | 45 | 0 | 5.31 | 26.18 | 12.97 | 11.83 | 5.833 | 0.87 | 4.329 | 0.852 | 0.45 |
| K-40 Result (4_20_2012) | 16 | 0 | 8.243 | 18.72 | 11.68 | 11.3 | 3.201 | 0.8 | 3.738 | 0.851 | 0.274 |
| K-40 Result (4_27_2012) | 2 | 0 | 15.18 | 20.68 | 17.93 | 17.72 | 3.889 | 2.75 | 4.077 | N/A | 0.217 |
| K-40 Result (5_1_2012) | 7 | 0 | 9.044 | 22.62 | 12.86 | 12.33 | 4.542 | 1.717 | 2.298 | 2.087 | 0.353 |
| K-40 Result (5_24_2012) | 1 | 0 | 9.287 | 9.287 | 9.287 | 9.287 | N/A | N/A | 0 | N/A | N/A |
| K-40 Result (5_31_2012) | 168 | 0 | -0.219 | 2.274 | 1.038 | N/A | 0.425 | 0.0328 | 0.477 | -0.0292 | 0.41 |
| K-40 Result (5_7_2012) | 2 | 0 | 18.46 | 19.45 | 18.96 | 18.95 | 0.7 | 0.495 | 0.734 | N/A | 0.0369 |
| K-40 Result (5_9_2012) | 1 | 0 | 16.94 | 16.94 | 16.94 | 16.94 | N/A | N/A | 0 | N/A | N/A |
| K-40 Result (6_4_2012) | 42 | 0 | -0.611 | 2.73 | 1.42 | N/A | 0.537 | 0.0829 | 0.431 | -0.868 | 0.378 |
| K-40 Result (7_26_2012) | 4 | 0 | -0.552 | 7.628 | 5.329 | N/A | 3.934 | 1.967 | 0.584 | -1.958 | 0.738 |

## Table A2. Summary Statistics for K-40 by Sampling Phases – Combined North Pier Data

| Variable | NumObs | # Missing | Minimum | Maximum | Mean | Geo-Mean | SD | SEM | MAD/0.675 | Skewness | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K-40 Result (fss-bias) | 33 | 0 | 9.208 | 25.34 | 16.64 | 15.95 | 4.747 | 0.826 | 6.153 | 0.0643 | 0.285 |
| K-40 Result (fss-sys) | 469 | 0 | -0.552 | 26.18 | 13.28 | N/A | 5.213 | 0.241 | 5.723 | 0.455 | 0.392 |
| K-40 Result (ras) | 38 | 0 | 8.243 | 22.62 | 14.76 | 14.01 | 4.777 | 0.775 | 5.53 | 0.303 | 0.324 |
| K-40 Result (sys_1) | 127 | 0 | 4.11 | 26.3 | 13.85 | 12.59 | 5.802 | 0.515 | 7.026 | 0.273 | 0.419 |
| K-40 Result (sys_2) | 210 | 0 | -0.611 | 2.73 | 1.114 | N/A | 0.474 | 0.0327 | 0.473 | -0.0259 | 0.425 |



ED_004747_00028873-00017

## Table A3. Summary Statistics for Ra-226/Bi-215 by Collection Dates – Combined North Pier Data

| Variable | NumObs | # Missing | Minimum | Maximum | Mean | Geo-Mean | SD | SEM | MAD/0.675 | Skewness | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ra-226/Ra-226 (Bi-214) Result (1_10_2013) | 3 | 0 | 0.323 | 1.628 | 0.772 | 0.576 | 0.742 | 0.428 | 0.0606 | 1.726 | 0.962 |
| Ra-226/Ra-226 (Bi-214) Result (1_3_2013) | 3 | 0 | 1.05 | 1.594 | 1.236 | 1.212 | 0.31 | 0.179 | 0.0222 | 1.727 | 0.251 |
| Ra-226/Ra-226 (Bi-214) Result (10_30_2012) | 43 | 0 | -0.0382 | 1.043 | 0.478 | N/A | 0.226 | 0.0345 | 0.251 | 0.34 | 0.473 |
| Ra-226/Ra-226 (Bi-214) Result (10_31_2012) | 42 | 0 | 0.074 | 1.078 | 0.467 | 0.409 | 0.237 | 0.0365 | 0.217 | 0.837 | 0.507 |
| Ra-226/Ra-226 (Bi-214) Result (11_1_2012) | 42 | 0 | 0.167 | 1.074 | 0.5 | 0.454 | 0.226 | 0.0349 | 0.188 | 0.972 | 0.453 |
| Ra-226/Ra-226 (Bi-214) Result (11_15_2012) | 3 | 0 | 0.66 | 2.008 | 1.33 | 1.205 | 0.674 | 0.389 | 0.98 | 0.0572 | 0.507 |
| Ra-226/Ra-226 (Bi-214) Result (11_2_2012) | 42 | 0 | 0.0488 | 1.021 | 0.522 | 0.466 | 0.218 | 0.0337 | 0.21 | 0.288 | 0.418 |
| Ra-226/Ra-226 (Bi-214) Result (11_5_2012) | 41 | 0 | 0 | 1.49 | 0.701 | 0 | 0.319 | 0.0499 | 0.272 | 0.301 | 0.455 |
| Ra-226/Ra-226 (Bi-214) Result (12_11_2012) | 2 | 0 | 1.882 | 2.36 | 2.121 | 2.107 | 0.338 | 0.239 | 0.354 | N/A | 0.159 |
| Ra-226/Ra-226 (Bi-214) Result (12_13_2012) | 2 | 0 | 1.361 | 1.844 | 1.603 | 1.584 | 0.342 | 0.242 | 0.358 | N/A | 0.213 |
| Ra-226/Ra-226 (Bi-214) Result (2_12_2013) | 1 | 0 | 0.86 | 0.86 | 0.86 | 0.86 | N/A | N/A | 0 | N/A | N/A |
| Ra-226/Ra-226 (Bi-214) Result (2_20_2013) | 2 | 0 | 0.575 | 0.845 | 0.71 | 0.697 | 0.191 | 0.135 | 0.2 | N/A | 0.269 |
| Ra-226/Ra-226 (Bi-214) Result (3_1_2013) | 4 | 0 | 0.356 | 0.821 | 0.558 | 0.529 | 0.21 | 0.105 | 0.202 | 0.575 | 0.375 |
| Ra-226/Ra-226 (Bi-214) Result (3_12_2012) | 67 | 0 | 0.157 | 1.733 | 0.807 | 0.749 | 0.294 | 0.0359 | 0.289 | 0.52 | 0.364 |
| Ra-226/Ra-226 (Bi-214) Result (3_15_2012) | 88 | 0 | 0.0554 | 1.307 | 0.627 | 0.584 | 0.221 | 0.0235 | 0.177 | 0.738 | 0.352 |
| Ra-226/Ra-226 (Bi-214) Result (3_16_2012) | 44 | 0 | 0.0232 | 1.015 | 0.586 | 0.525 | 0.2 | 0.0301 | 0.212 | -0.61 | 0.341 |
| Ra-226/Ra-226 (Bi-214) Result (3_19_2012) | 67 | 0 | 0.055 | 1.168 | 0.569 | 0.498 | 0.245 | 0.0299 | 0.275 | 0.0258 | 0.43 |
| Ra-226/Ra-226 (Bi-214) Result (3_20_2012) | 26 | 0 | 0.218 | 1.372 | 0.64 | 0.579 | 0.294 | 0.0576 | 0.303 | 0.772 | 0.459 |
| Ra-226/Ra-226 (Bi-214) Result (3_21_2012) | 44 | 0 | -0.313 | 1.168 | 0.625 | N/A | 0.326 | 0.0491 | 0.286 | -0.657 | 0.521 |
| Ra-226/Ra-226 (Bi-214) Result (3_22_2012) | 23 | 0 | -0.00836 | 1.084 | 0.542 | N/A | 0.326 | 0.068 | 0.208 | -0.446 | 0.601 |
| Ra-226/Ra-226 (Bi-214) Result (3_23_2012) | 45 | 0 | -0.0412 | 1.08 | 0.542 | N/A | 0.26 | 0.0388 | 0.163 | 0.43 | 0.48 |
| Ra-226/Ra-226 (Bi-214) Result (4_20_2012) | 16 | 0 | -0.231 | 1.067 | 0.477 | N/A | 0.305 | 0.0762 | 0.274 | -0.188 | 0.639 |
| Ra-226/Ra-226 (Bi-214) Result (4_27_2012) | 2 | 0 | 0.35 | 1.227 | 0.788 | 0.655 | 0.62 | 0.439 | 0.65 | N/A | 0.787 |
| Ra-226/Ra-226 (Bi-214) Result (5_1_2012) | 7 | 0 | 0.19 | 0.809 | 0.535 | 0.492 | 0.21 | 0.0794 | 0.127 | -0.193 | 0.393 |
| Ra-226/Ra-226 (Bi-214) Result (5_24_2012) | 1 | 0 | 1.121 | 1.121 | 1.121 | 1.121 | N/A | N/A | 0 | N/A | N/A |
| Ra-226/Ra-226 (Bi-214) Result (5_31_2012) | 168 | 0 | -0.187 | 0.62 | 0.162 | N/A | 0.136 | 0.0105 | 0.131 | 0.474 | 0.839 |
| Ra-226/Ra-226 (Bi-214) Result (5_7_2012) | 2 | 0 | 0.546 | 1.033 | 0.79 | 0.751 | 0.344 | 0.244 | 0.361 | N/A | 0.436 |
| Ra-226/Ra-226 (Bi-214) Result (5_9_2012) | 1 | 0 | 1.12 | 1.12 | 1.12 | 1.12 | N/A | N/A | 0 | N/A | N/A |
| Ra-226/Ra-226 (Bi-214) Result (6_4_2012) | 42 | 0 | 0 | 0.485 | 0.182 | 0 | 0.107 | 0.0166 | 0.112 | 0.621 | 0.592 |
| Ra-226/Ra-226 (Bi-214) Result (7_26_2012) | 4 | 0 | 0.301 | 0.589 | 0.41 | 0.398 | 0.125 | 0.0623 | 0.063 | 1.483 | 0.303 |

## Table A4. Summary Statistics for Ra-226/Bi-214 by Sampling Phases – Combined North Pier Data

| General Statistics for Uncensored Data Sets | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | NumObs | # Missing | Minimum | Maximum | Mean | Geo-Mean | SD | SEM | MAD/0.675 | Skewness | CV |
| Ra-226/Ra-226 (Bi-214) Result (fss-bias) | 33 | 0 | 0.221 | 1.628 | 0.748 | 0.68 | 0.314 | 0.0547 | 0.316 | 0.519 | 0.42 |
| Ra-226/Ra-226 (Bi-214) Result (fss-sys) | 469 | 0 | -0.0412 | 1.532 | 0.575 | N/A | 0.253 | 0.0117 | 0.253 | 0.546 | 0.44 |
| Ra-226/Ra-226 (Bi-214) Result (ras) | 38 | 0 | -0.231 | 2.36 | 0.801 | N/A | 0.57 | 0.0924 | 0.446 | 0.989 | 0.711 |
| Ra-226/Ra-226 (Bi-214) Result (sys_1) | 127 | 0 | -0.313 | 1.733 | 0.644 | N/A | 0.329 | 0.0292 | 0.291 | -0.00868 | 0.511 |
| Ra-226/Ra-226 (Bi-214) Result (sys_2) | 210 | 0 | -0.187 | 0.62 | 0.166 | N/A | 0.131 | 0.00905 | 0.118 | 0.461 | 0.788 |

## Table A5. Summary Statistics for K-40 in Survey Unit 8 by Sampling Phases

| Variable | NumObs | # Missing | Minimum | Maximum | Mean | Geo-Mean | SD | SEM | MAD/0.675 | Skewness | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K-40 Result (fss-bias) | 4 | 0 | 10.1 | 15.59 | 11.76 | 11.56 | 2.595 | 1.297 | 0.741 | 1.833 | 0.221 |
| K-40 Result (fss-sys) | 42 | 0 | 6.541 | 18.91 | 11.85 | 11.17 | 4.037 | 0.623 | 5.428 | 0.285 | 0.341 |
| K-40 Result (ras) | 9 | 0 | 8.243 | 12.13 | 9.395 | 9.323 | 1.282 | 0.427 | 1.152 | 1.349 | 0.136 |
| K-40 Result (sys_1) | 22 | 0 | 6.148 | 22.48 | 12.65 | 11.53 | 5.603 | 1.195 | 5.304 | 0.591 | 0.443 |
| K-40 Result (sys_2) | 42 | 0 | 0.48 | 2.004 | 1.247 | 1.187 | 0.36 | 0.0556 | 0.38 | -0.241 | 0.289 |

## Table A6. Summary Statistics for K-40 in Survey Unit 8 by Sampling Dates

| Variable | NumObs | # Missing | Minimum | Maximum | Mean | Geo-Mean | SD | SEM | MAD/0.675 | Skewness | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K-40 Result (11_1_2012) | 42 | 0 | 6.541 | 18.91 | 11.85 | 11.17 | 4.037 | 0.623 | 5.428 | 0.285 | 0.341 |
| K-40 Result (3_20_2012) | 26 | 0 | 6.148 | 22.48 | 12.51 | 11.54 | 5.224 | 1.024 | 5.183 | 0.686 | 0.417 |
| K-40 Result (4_20_2012) | 7 | 0 | 8.243 | 9.65 | 8.835 | 8.819 | 0.588 | 0.222 | 0.809 | 0.322 | 0.0665 |
| K-40 Result (5_1_2012) | 2 | 0 | 10.58 | 12.13 | 11.36 | 11.33 | 1.096 | 0.775 | 1.149 | N/A | 0.0965 |
| K-40 Result (5_31_2012) | 42 | 0 | 0.48 | 2.004 | 1.247 | 1.187 | 0.36 | 0.0556 | 0.38 | -0.241 | 0.289 |

## Table A7. Summary Statistics for Ra-226 by Bi-214 in Survey Unit 8 by Sampling Phases

General Statistics for Uncensored Data Sets

| Variable | NumObs | # Missing | Minimum | Maximum | Mean | Geo-Mean | SD | SEM | MAD/0.675 | Skewness | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ra-226/Ra-226 (Bi-214) Result (fss-bias) | 4 | 0 | 0.29 | 0.494 | 0.405 | 0.394 | 0.104 | 0.0519 | 0.111 | -0.229 | 0.256 |
| Ra-226/Ra-226 (Bi-214) Result (fss-sys) | 42 | 0 | 0.167 | 1.074 | 0.5 | 0.454 | 0.226 | 0.0349 | 0.188 | 0.972 | 0.453 |
| Ra-226/Ra-226 (Bi-214) Result (ras) | 9 | 0 | -0.231 | 0.629 | 0.304 | N/A | 0.246 | 0.0821 | 0.18 | -1.132 | 0.811 |
| Ra-226/Ra-226 (Bi-214) Result (sys_1) | 22 | 0 | 0.218 | 1.372 | 0.683 | 0.62 | 0.298 | 0.0635 | 0.29 | 0.567 | 0.436 |
| Ra-226/Ra-226 (Bi-214) Result (sys_2) | 42 | 0 | -0.187 | 0.461 | 0.188 | N/A | 0.143 | 0.022 | 0.155 | -0.413 | 0.757 |

## Table A8. Summary Statistics for Ta-226 by Bi-214 in Survey Unit 8 by Sampling Dates

General Statistics for Uncensored Data Sets

| Variable | NumObs | # Missing | Minimum | Maximum | Mean | Geo-Mean | SD | SEM | MAD/0.675 | Skewness | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ra-226/Ra-226 (Bi-214) Result (11_1_2012) | 42 | 0 | 0.167 | 1.074 | 0.5 | 0.454 | 0.226 | 0.0349 | 0.188 | 0.972 | 0.453 |
| Ra-226/Ra-226 (Bi-214) Result (3_20_2012) | 26 | 0 | 0.218 | 1.372 | 0.64 | 0.579 | 0.294 | 0.0576 | 0.303 | 0.772 | 0.459 |
| Ra-226/Ra-226 (Bi-214) Result (4_20_2012) | 7 | 0 | -0.231 | 0.629 | 0.301 | N/A | 0.275 | 0.104 | 0.18 | -1.146 | 0.915 |
| Ra-226/Ra-226 (Bi-214) Result (5_1_2012) | 2 | 0 | 0.19 | 0.435 | 0.312 | 0.288 | 0.173 | 0.122 | 0.181 | N/A | 0.553 |
| Ra-226/Ra-226 (Bi-214) Result (5_31_2012) | 42 | 0 | -0.187 | 0.461 | 0.188 | N/A | 0.143 | 0.022 | 0.155 | -0.413 | 0.757 |



ED_004747_00028873-00019

## Table A9. Summary Statistics for K-40 in Survey Unit 10 by Sampling Phases

General Statistics for Uncensored Data Sets

| Variable | NumObs | # Missing | Minimum | Maximum | Mean | Geo-Mean | SD | SEM | MAD/0.675 | Skewness | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K-40 Result (fss-bias) | 2 | 0 | 20.29 | 25.15 | 22.72 | 22.59 | 3.437 | 2.43 | 3.603 | N/A | 0.151 |
| K-40 Result (fss-sys) | 42 | 0 | 4.76 | 21.8 | 9.632 | 9.039 | 3.826 | 0.59 | 1.898 | 1.607 | 0.397 |
| K-40 Result (ras) | 4 | 0 | 11.9 | 22.62 | 14.97 | 14.41 | 5.139 | 2.569 | 1.023 | 1.917 | 0.343 |
| K-40 Result (sys_1) | 21 | 0 | 4.539 | 23.88 | 12.78 | 11.19 | 6.657 | 1.453 | 5.361 | 0.509 | 0.521 |
| K-40 Result (sys_2) | 42 | 0 | -0.219 | 1.607 | 0.819 | N/A | 0.403 | 0.0621 | 0.427 | -0.181 | 0.492 |

## Table A10. Summary Statistics for K-40 in Survey Unit 10 by Sampling Dates

General Statistics for Uncensored Data Sets

| Variable | NumObs | # Missing | Minimum | Maximum | Mean | Geo-Mean | SD | SEM | MAD/0.675 | Skewness | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K-40 Result (10_31_2012) | 42 | 0 | 4.76 | 21.8 | 9.632 | 9.039 | 3.826 | 0.59 | 1.898 | 1.607 | 0.397 |
| K-40 Result (3_22_2012) | 23 | 0 | 4.539 | 25.15 | 13.64 | 11.89 | 7.002 | 1.46 | 8.882 | 0.322 | 0.513 |
| K-40 Result (4_20_2012) | 3 | 0 | 11.9 | 13.28 | 12.42 | 12.4 | 0.752 | 0.434 | 0.252 | 1.633 | 0.0606 |
| K-40 Result (5_1_2012) | 1 | 0 | 22.62 | 22.62 | 22.62 | 22.62 | N/A | N/A | 0 | N/A | N/A |
| K-40 Result (5_31_2012) | 42 | 0 | -0.219 | 1.607 | 0.819 | N/A | 0.403 | 0.0621 | 0.427 | -0.181 | 0.492 |

## Table A11. Summary Statistics for Bi-214 in Survey Unit 10 by Sampling Phases

General Statistics for Uncensored Data Sets

| Variable | NumObs | # Missing | Minimum | Maximum | Mean | Geo-Mean | SD | SEM | MAD/0.675 | Skewness | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bi-214 Result (fss-bias) | 2 | 0 | 0.477 | 0.541 | 0.509 | 0.508 | 0.0455 | 0.0322 | 0.0477 | N/A | 0.0894 |
| Bi-214 Result (fss-sys) | 42 | 0 | 0 | 0.806 | 0.311 | 0 | 0.172 | 0.0266 | 0.158 | 0.83 | 0.554 |
| Bi-214 Result (ras) | 4 | 0 | 0.375 | 0.563 | 0.447 | 0.442 | 0.0812 | 0.0406 | 0.0444 | 1.426 | 0.181 |
| Bi-214 Result (sys_1) | 21 | 0 | 0.0741 | 0.579 | 0.333 | 0.295 | 0.151 | 0.0329 | 0.117 | 0.222 | 0.453 |
| Bi-214 Result (sys_2) | 42 | 0 | -0.0351 | 0.44 | 0.1 | N/A | 0.0847 | 0.0131 | 0.0594 | 1.732 | 0.845 |

## Table A12. Summary Statistics for Bi-214 in Survey Unit 10 by Sampling Dates

General Statistics for Uncensored Data Sets

| Variable | NumObs | # Missing | Minimum | Maximum | Mean | Geo-Mean | SD | SEM | MAD/0.675 | Skewness | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bi-214 Result (10_31_2012) | 42 | 0 | 0 | 0.806 | 0.311 | 0 | 0.172 | 0.0266 | 0.158 | 0.83 | 0.554 |
| Bi-214 Result (3_22_2012) | 23 | 0 | 0.0741 | 0.579 | 0.348 | 0.309 | 0.153 | 0.0319 | 0.16 | 0.0293 | 0.439 |
| Bi-214 Result (4_20_2012) | 3 | 0 | 0.375 | 0.435 | 0.409 | 0.408 | 0.0306 | 0.0177 | 0.0279 | -1.028 | 0.075 |
| Bi-214 Result (5_1_2012) | 1 | 0 | 0.563 | 0.563 | 0.563 | 0.563 | N/A | N/A | 0 | N/A | N/A |
| Bi-214 Result (5_31_2012) | 42 | 0 | -0.0351 | 0.44 | 0.1 | N/A | 0.0847 | 0.0131 | 0.0594 | 1.732 | 0.845 |

## Table A13. Summary Statistics for Pb-214 in Survey Unit 10 by Sampling Dates

General Statistics for Uncensored Data Sets

| Variable | NumObs | # Missing | Minimum | Maximum | Mean | Geo-Mean | SD | SEM | MAD/0.675 | Skewness | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pb-214 Result (10_31_2012) | 42 | 0 | 0.0651 | 0.955 | 0.354 | 0.313 | 0.173 | 0.0267 | 0.138 | 1.114 | 0.489 |
| Pb-214 Result (3_22_2012) | 23 | 0 | 0.0963 | 0.76 | 0.409 | 0.351 | 0.199 | 0.0414 | 0.264 | -0.0386 | 0.486 |
| Pb-214 Result (4_20_2012) | 3 | 0 | 0.328 | 0.474 | 0.418 | 0.413 | 0.079 | 0.0456 | 0.031 | -1.597 | 0.189 |
| Pb-214 Result (5_1_2012) | 1 | 0 | 0.748 | 0.748 | 0.748 | 0.748 | N/A | N/A | 0 | N/A | N/A |
| Pb-214 Result (5_31_2012) | 42 | 0 | 0.0328 | 0.309 | 0.132 | 0.114 | 0.0663 | 0.0102 | 0.0793 | 0.432 | 0.503 |



ED_004747_00028873-00020

## Table A14. Summary Statistics for Pb-214 in Survey Unit 10 by Sampling Phases

General Statistics for Uncensored Data Sets

| Variable | NumObs | # Missing | Minimum | Maximum | Mean | Geo-Mean | SD | SEM | MAD/0.675 | Skewness | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pb-214 Result (fss-bias) | 2 | 0 | 0.602 | 0.76 | 0.681 | 0.676 | 0.112 | 0.0791 | 0.117 | N/A | 0.164 |
| Pb-214 Result (fss-sys) | 42 | 0 | 0.0651 | 0.955 | 0.354 | 0.313 | 0.173 | 0.0267 | 0.138 | 1.114 | 0.489 |
| Pb-214 Result (ras) | 4 | 0 | 0.328 | 0.748 | 0.501 | 0.479 | 0.177 | 0.0886 | 0.108 | 1.182 | 0.354 |
| Pb-214 Result (sys_1) | 21 | 0 | 0.0963 | 0.652 | 0.383 | 0.33 | 0.186 | 0.0406 | 0.182 | -0.0202 | 0.486 |
| Pb-214 Result (sys_2) | 42 | 0 | 0.0328 | 0.309 | 0.132 | 0.114 | 0.0663 | 0.0102 | 0.0793 | 0.432 | 0.503 |

## Table A15. Summary Statistics for K-40 in Survey Unit 11 by Sampling Phases

General Statistics for Uncensored Data Sets

| Variable | NumObs | # Missing | Minimum | Maximum | Mean | Geo-Mean | SD | SEM | MAD/0.675 | Skewness | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K-40 Result (fss-bias) | 2 | 0 | 20.62 | 21.17 | 20.9 | 20.89 | 0.389 | 0.275 | 0.408 | N/A | 0.0186 |
| K-40 Result (fss-sys) | 43 | 0 | 4.761 | 18.1 | 9.624 | 9.187 | 3.1 | 0.473 | 2.372 | 1.012 | 0.322 |
| K-40 Result (ras) | 4 | 0 | 9.044 | 16.94 | 12.91 | 12.6 | 3.229 | 1.615 | 2.955 | 0.154 | 0.25 |
| K-40 Result (sys_1) | 42 | 0 | 4.11 | 26.3 | 13.83 | 12.58 | 5.859 | 0.904 | 6.434 | 0.409 | 0.424 |
| K-40 Result (sys_2) | 42 | 0 | 0.674 | 2.274 | 1.272 | 1.229 | 0.336 | 0.0518 | 0.245 | 0.747 | 0.264 |

## Table A16. Summary Statistics for K-40 in Survey Unit 11 by Sampling Dates

General Statistics for Uncensored Data Sets

| Variable | NumObs | # Missing | Minimum | Maximum | Mean | Geo-Mean | SD | SEM | MAD/0.675 | Skewness | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K-40 Result (10_30_2012) | 43 | 0 | 4.761 | 18.1 | 9.624 | 9.187 | 3.1 | 0.473 | 2.372 | 1.012 | 0.322 |
| K-40 Result (3_21_2012) | 44 | 0 | 4.11 | 26.3 | 14.16 | 12.87 | 5.912 | 0.891 | 6.901 | 0.292 | 0.418 |
| K-40 Result (5_1_2012) | 3 | 0 | 9.044 | 13.03 | 11.56 | 11.41 | 2.193 | 1.266 | 0.608 | -1.664 | 0.19 |
| K-40 Result (5_31_2012) | 42 | 0 | 0.674 | 2.274 | 1.272 | 1.229 | 0.336 | 0.0518 | 0.245 | 0.747 | 0.264 |
| K-40 Result (5_9_2012) | 1 | 0 | 16.94 | 16.94 | 16.94 | 16.94 | N/A | N/A | 0 | N/A | N/A |

## Table A17. Summary Statistics for Th-232/Ac-228 in Survey Unit 11 by Sampling Phases

General Statistics for Uncensored Data Sets

| Variable | NumObs | # Missing | Minimum | Maximum | Mean | Geo-Mean | SD | SEM | MAD/0.675 | Skewness | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ac-228/Th-232 (By-Ac-228) Result (fss-bias) | 2 | 0 | 0.486 | 0.585 | 0.536 | 0.533 | 0.0695 | 0.0492 | 0.0729 | N/A | 0.13 |
| Ac-228/Th-232 (By-Ac-228) Result (fss-sys) | 43 | 0 | 0.044 | 0.767 | 0.313 | 0.266 | 0.167 | 0.0255 | 0.173 | 0.749 | 0.533 |
| Ac-228/Th-232 (By-Ac-228) Result (ras) | 4 | 0 | 0.181 | 0.666 | 0.394 | 0.337 | 0.24 | 0.12 | 0.255 | 0.281 | 0.608 |
| Ac-228/Th-232 (By-Ac-228) Result (sys_1) | 42 | 0 | 0 | 1.075 | 0.422 | 0 | 0.26 | 0.04 | 0.222 | 0.959 | 0.615 |
| Ac-228/Th-232 (By-Ac-228) Result (sys_2) | 42 | 0 | -0.0164 | 0.217 | 0.0979 | N/A | 0.0509 | 0.00786 | 0.05 | -0.111 | 0.52 |

## Table A16. Summary Statistics for Th-232/Ac-228 in Survey Unit 11 by Sampling Dates

General Statistics for Uncensored Data Sets

| Variable | NumObs | # Missing | Minimum | Maximum | Mean | Geo-Mean | SD | SEM | MAD/0.675 | Skewness | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ac-228/Th-232 (By-Ac-228) Result (10_30_2012) | 43 | 0 | 0.044 | 0.767 | 0.313 | 0.266 | 0.167 | 0.0255 | 0.173 | 0.749 | 0.533 |
| Ac-228/Th-232 (By-Ac-228) Result (3_21_2012) | 44 | 0 | 0 | 1.075 | 0.427 | 0 | 0.255 | 0.0384 | 0.206 | 0.907 | 0.596 |
| Ac-228/Th-232 (By-Ac-228) Result (5_1_2012) | 3 | 0 | 0.181 | 0.526 | 0.304 | 0.269 | 0.192 | 0.111 | 0.0342 | 1.704 | 0.634 |
| Ac-228/Th-232 (By-Ac-228) Result (5_31_2012) | 42 | 0 | -0.0164 | 0.217 | 0.0979 | N/A | 0.0509 | 0.00786 | 0.05 | -0.111 | 0.52 |
| Ac-228/Th-232 (By-Ac-228) Result (5_9_2012) | 1 | 0 | 0.666 | 0.666 | 0.666 | 0.666 | N/A | N/A | 0 | N/A | N/A |



ED_004747_00028873-00021