UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
75 Hawthorne Street
San Francisco, CA 94105

March 17, 2017

George ("Pat") Brooks
US Department of the Navy
33000 Nixie Way, Bldg 50
San Diego, CA 92147

Dear Pat:

As discussed in recent Hunters Point Naval Shipyard technical calls concerning the Navy's Radiological Data Evaluation Plan, EPA's statistician, Anita Singh, has been reviewing the Navy's approaches and recommends additional approaches to consider for efficiently identifying potential signs of falsification. Based on data the Navy provided from the North Pier area, attached please find her analysis and recommendations. Please consider applying these recommendations to promote an effective and efficient evaluation process.

If you would like to discuss these comments, please contact me or Lily Lee on my staff, and we can also arrange a call with Ms. Singh. I can be reached at 415-972-3005 or chesnutt.john@epa.gov. Lily can be reached at 415-947-4187 or lee.lily@epa.gov.

Sincerely,

John Chesnutt, Manager
Pacific Islands and Federal Facilities Section
Superfund Division

Attachment

cc. Nina Bacey, State Department of Toxic Substances Control
Tina Low, Regional Water Quality Control Board
Amy Brownell, San Francisco Department of Public Health

Recommended Statistical and Graphical Methods to Identify Potential Patterns of Anomalies Representing Suspicious Activities in Data Sets Collected from the Hunters Point Naval Shipyard Site
March 17, 2017

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 Site (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.

EPA recommends that Navy considers using effective univariate and multivariate/multidimensional statistical and graphical methods to identify potential suspicious/anomalous patterns present in data sets collected from the various parcels of the Site. Graphical displays generated using multivariate methods to identify potential patterns present in a data set are extremely valuable. Effective pattern recognition graphical methods provide added insight into the patterns present in a data set which is not possible to identify and comprehend based upon the information provided by test statistics (e.g., K-S test statistic, ANOVA test etc.). Once anomalous patterns have been identified using graphical displays, one may want to use statistical methods (e.g., hypothesis tests) to verify the existence of those patterns exhibited by the graphical displays.

For identified ROCs, EPA recommends the use of multivariate methods which are better suited to effectively identify/recognize patterns present in a data set. Several ROCs are correlated (e.g., parent and daughter products), therefore multivariate methods which take correlations into consideration should be used. The use of such methods may improve the likelihood of finding patterns and signs of falsification in a straight forward manner. The principal component analysis (PCA), factor analysis and classification analysis are commonly used to identify patterns in multidimensional data sets. These methods are meant to effectively identify patterns simultaneously for multiple variables (ROCs) included in the data set. PCA and classification analysis are around for many decades and are routinely used to identify patterns present in complex data sets. These methods will reduce the likelihood of both false positives and false negatives.

Availability of Statistical Tools to Perform Multivariate Methods: Most commercial statistical software packages (e.g., SAS, SPSS) have these multivariate pattern recognition and data mining methods. Multivariate PCA methods are also available in freely available programs written in R script. In evaluations summarized in Sections 1 and 2 below, EPA software packages: Scout 2008 v 1.00.01 (2009) and ProUCL 5.1 (2016) have been used.

NERL-EPA Las Vegas started using and researching multivariate methods during early nineties. NERL-EPA Las Vegas developed a multivariate software package: Scout 2008, V 1.00.01 (2009). This software can be downloaded freely from the following website:

https://archive.epa.gov/esd/archive-scout/web/html/#Scout2008v101

All principle component graphs generated in this write up are generated using the Scout software package. Multiple Q-Q plots and side-by-side boxplots can be generated by using another EPA Software package, ProUCL 5.1 which can be downloaded from the following site:

https://www.epa.gov/land-research/proucl-software

Advantages of using Multivariate Methods: Multivariate methods perform evaluations for multiple ROCs simultaneously in comparison with univariate methods which perform evaluations one-variable (ROC) at a time – which can become tedious and cumbersome to perform when evaluations need to be performed for many parcels, survey units, sampling phases and sampling dates. The use of univariate methods does not take correlations between the various ROCs into considerations, and there is no guarantee that univariate test statistics (K-S test statistic) will identify suspicious activities correctly. Note that univariate methods used by the Navy in the January 31, 2107, presentation (stated in Figure on page 13 of this presentation) failed to identify June 4, 2012, as the date when suspicious activity took place during Sys-2 sampling phase (e.g., in SU-7).

The recommended multivariate approaches described above were used on the North Pier data sets. The effectiveness of the recommended multivariate methods has been illustrated using PCA on survey unit 1 (U1) and survey unit 7 (U7) multidimensional data sets. PCA has been performed on multivariate data set based upon ROCs: Cs-137, Bi-212, Pb-212, Bi-214, Pb-214, Ra-226, and Th-232/AC-228. For Survey Unit 1, PCA evaluations summarized in Figures 1 and 2 alone identified that potential suspicious activities (manipulated data) occurred during Sys-2 sampling phase on May 31, 2012; and for Survey Unit 7, PCA evaluations summarized in Figures 3 and 4 identified that potential suspicious activities occurred during Sys-2 sampling on June 4, 2012.

For verification, one may want to perform additional evaluations. For illustration purposes, some evaluations are summarized in Appendix A.

Comments on the Methods used in the Navy's North Pier Evaluations Presented on January 31, 2017: We know that the Navy did analyses beyond the examples that were presented in this particular conference call. These comments are based on the information received thus far. Note that univariate evaluations presented were performed only for two ROCs: Cs-137 and Ra-226. Those evaluations did not identify survey units and sampling phases (e.g., Sys-2) during which anomalies might have occurred and did not provide any information for other ROCs. Moreover, as stated in the figure displayed on page 13 (of 14), the K-S test (the main test used by the Navy) did not identify June 4, 2012, as being different from all other dates. However, PC graph shown in Figure 4 (supplemented with Figures A9-A11 of Appendix A) clearly identified June 4, 2012 to be the date when suspicious activity might have taken place (for all ROCs included in evaluations) during Sys-2 sampling phase.

- *The evaluations based upon multivariate methods presented in Section 1.0 below lead to the conclusion that suspicious activities occurred during Sys-2 sampling phase for all ROCs included in the PCA evaluation. These anomalies occurred in Survey Unit 1 on May 31, 2012, and in Survey Unit 7 on June 4, 2012.*

1.0 Evaluation of the North Pier Parcel Data Using Multivariate PCA Method for U1 and U7

At the North Pier parcel, only two rounds of systematic sampling: Sys-1 and Sys-2 were performed. Typically, observed values of a ROC are the highest during the first round of sampling Sys-1. Overall, values of ROCs should be the lowest during the final status survey, FSS-Sys and the highest during Sys-1. ROC values observed during Sys-2 phase should also be higher than FSS-Sys (after two rounds of sampling and remediation). If this "desired" pattern is not followed by observed values of ROCs during sampling phases, it may be inferred that data have been manipulated/falsified.

Using the recommended methods, suspicious patterns have been identified for all ROCs (included in the evaluation) during sampling phase(s) and collection dates. At the North Pier site, there are two other sampling phases: Biased FSS and RAS. Statistical methods have been used on all 5 sampling phases: Sys-

1, Sys-2, FSS-Sys, Bias-Sys, and RAS but comments have been provided based upon the comparison of Sys-1, Sys-2, and FSS-Sys data.

Scatter Plots of the First Two Principal Components (PCs)-U1: The first two PCs account for the majority of information (on all ROCs) present in a multivariate data set. For U1, the first two PCs explain about 88% of information (Figures 1 and 2) present in the multidimensional data set. Based upon data from U1, Figure 1 has graphical display of the first two principal components: PC1 and PC2 by sampling phases and Figure 2 has graphical displays of the first two PCs by collection dates.

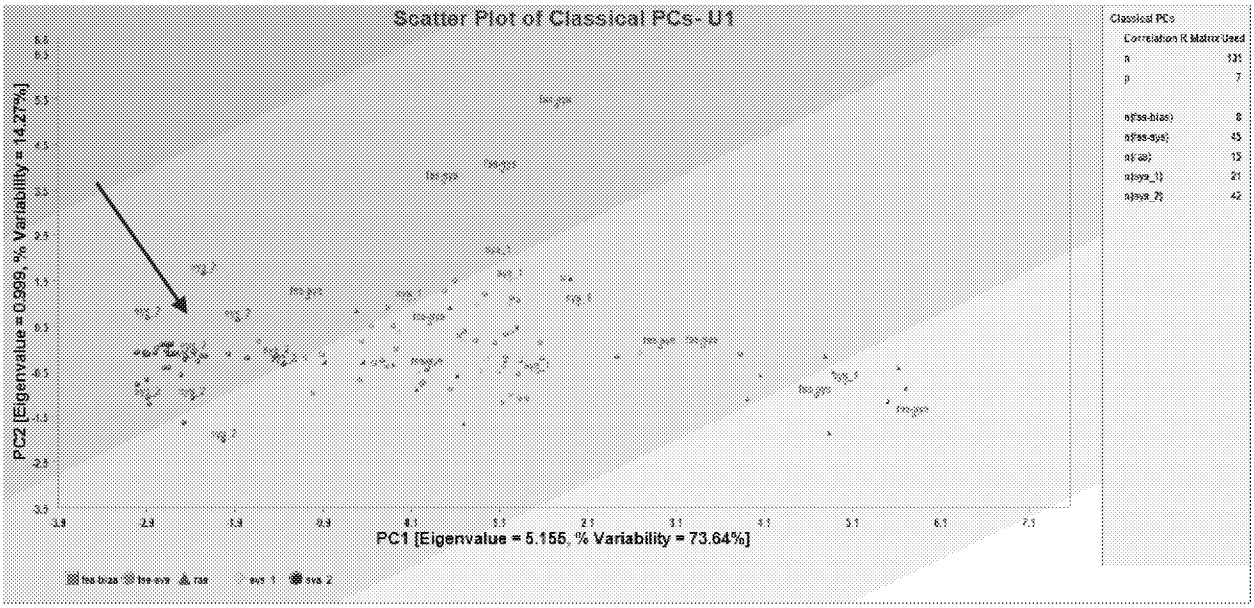

Figure 1. Scatter Plot of PC1 versus PC2 by Sampling Phases – Survey Unit 1

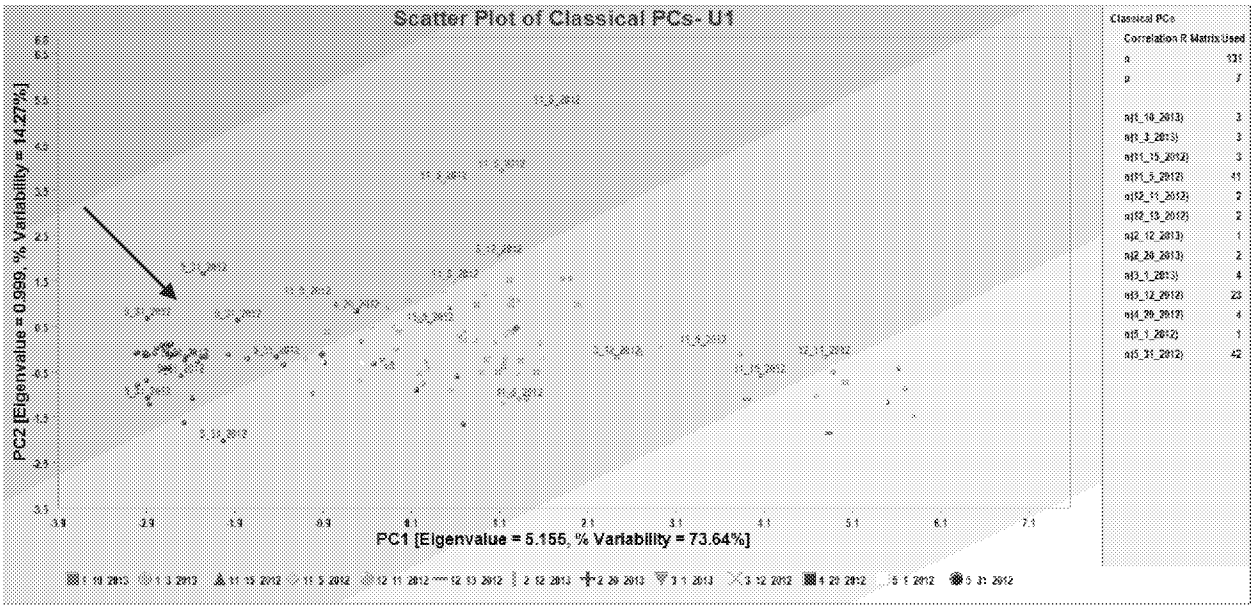

Figure 2. Scatter Plot of PC1 versus PC2 by Collection Dates – Survey Unit 1

<u>Survey Unit1:</u> From pattern displayed in Figure 1, it is noted that Sys-2 data set (42 observations) is tightly clustered (identified by a red arrow) with reduced variability and is well separated from the rest of the data.

This pattern leads to the conclusion that some anomalous activities might have taken place during Sys-2 phase. Similarly, from Figure 2 it is noted that data collected on May 31, 2012, (42 observations) is tightly clustered (identified by a red arrow) and is well separated from the rest of the data. This pattern leads to the conclusion that some anomalous activities might have taken place during the sample collection performed on May 31, 2012.

- *These two graphs alone identified anomalous data in U1 collected on May 31, 2012 during sampling phase Sys-2 for all ROCs considered in PCA evaluations.*

- *Similar pattern in observed in U8 as can be seen in graphs A12 and A13 presented in Appendix A.*

Scatter Plots of the First Two Principal Components (PCs)-U7: The first two PCs based upon U7 data set explain about 77% of the information (Figures 3 and 4) contained in the multidimensional (for all ROCs considered) data set. Based upon data from U7, Figure 3 has graphical display of the first two principal components: PC1 and PC2 by sampling phases and Figure 4 has graphical displays of the first two PCs by collection dates.

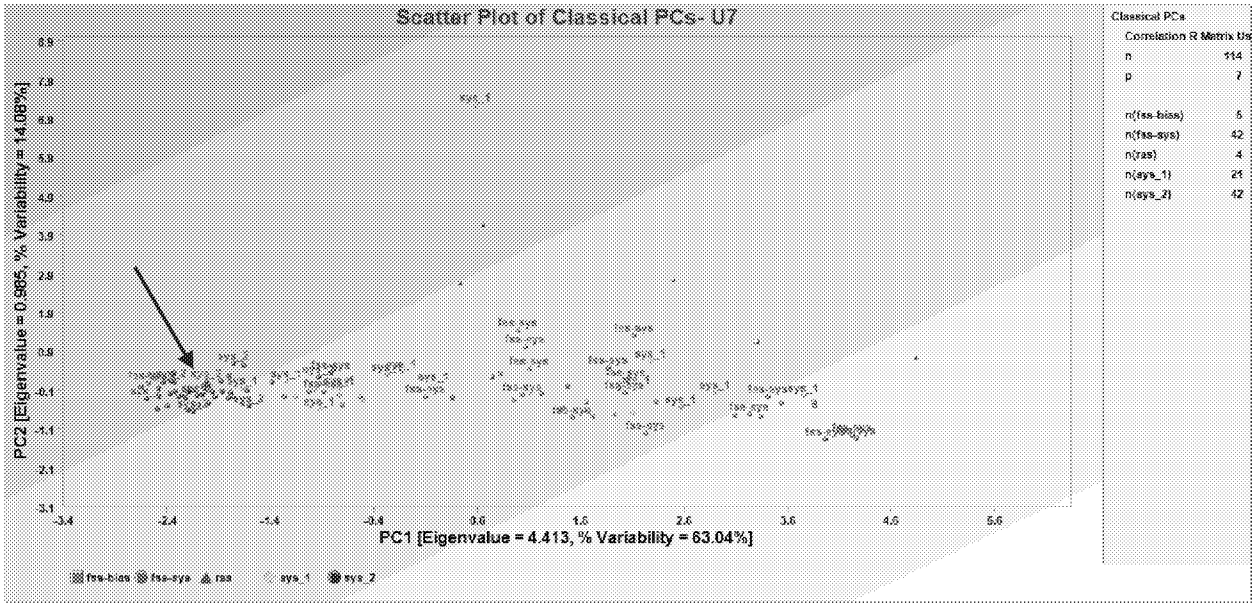

Figure 3. Scatter Plot of PC1 versus PC2 by Sampling Phases – Survey Unit 7

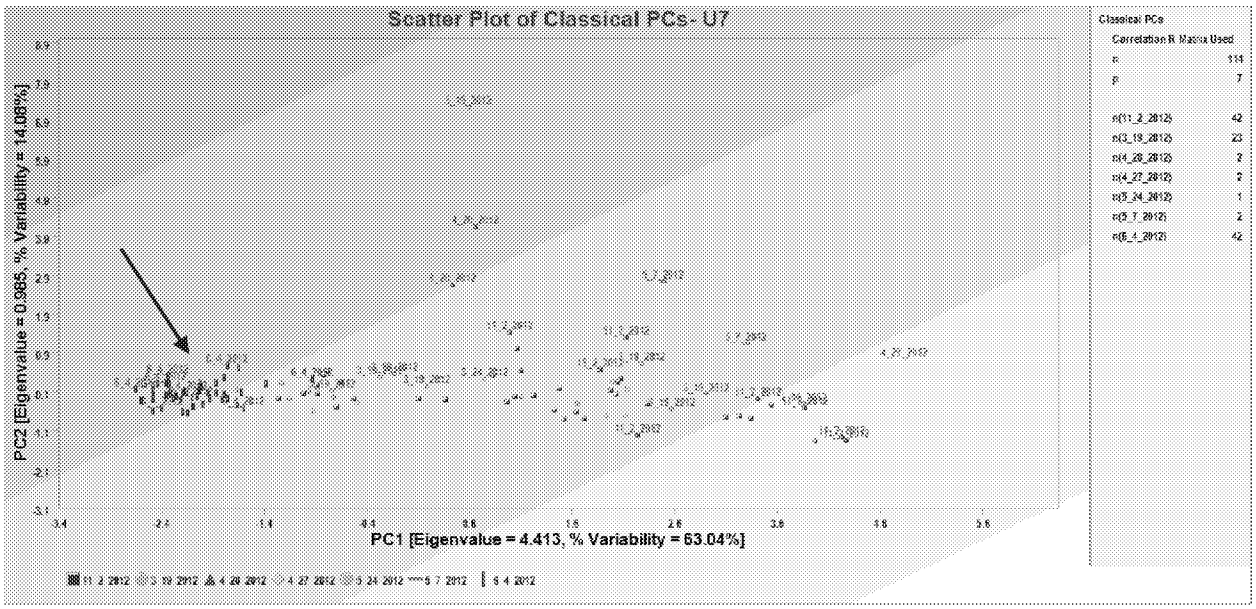

Figure 4. Scatter Plot of PC1 versus PC2 by Collection Dates – Survey Unit 7

Survey Unit 7: From pattern displayed in Figure 3, it is noted that Sys-2 data (42 observations) is tightly clustered (pointed by a red arrow) with reduced variability and is well separated from the rest of the data. This pattern leads to the conclusion that some different (suspicious) activities might have taken place during Sys-2 phase. Similarly, in Figure 12 it is noted that data collected on June 4, 2012, (42 observations) is tightly clustered (pointed by a red arrow) and is well separated from the rest of the data. This pattern leads to the conclusion that some different (suspicious) activities might have taken place during the sample collection performed on June 4, 2012.

- *These two graphs (Figures 3 and 4) alone identified potentially suspicious/altered data in U7 collected on June 4, 2012 during sampling phase Sys-2 for all ROCs simultaneously.*

2.0 In Depth Look at Survey Unit 1 and 7 Data Sets

One may want to look deeper into data sets collected from U1 and U7 to determine what happened on May 31, 2012, in U1 and on June 4, 2012, in U7. Summary Statistics were computed. Table 1 has summary statistics for Cs-137 by sampling phases in U1 and Table 2 has summary statistics for Cs-137 by sample collection dates for U1.

Table 1. Summary Statistics for Cs-137 in Survey Unit 1 by Sampling Phases

General Statistics for Uncensored Data Sets- Cs-137- Survey Unit 1

Variable	NumObs	# Missing	Minimum	Maximum	Mean	Geo-Mean	SD	SEM	MAD/0.675	Skewness	CV
Cs-137 Result (ss-bias)	8	0	-0.00575	0.0116	0.00124	N/A	0.00486	0.00172	0.00212	1.256	3.932
Cs-137 Result (ss-sys)	45	0	-0.0118	0.0673	0.00721	N/A	0.0161	0.0024	0.0102	1.976	2.233
Cs-137 Result (ras)	15	0	-0.0138	0.0229	0.00154	N/A	0.0101	0.00262	0.00906	0.503	6.579
Cs-137 Result (sys_1)	21	0	-0.00679	0.0304	0.0078	N/A	0.00966	0.00211	0.0107	0.653	1.239
Cs-137 Result (sys_2)	42	0	-0.0224	0.0218	-0.00101	N/A	0.0071	0.0011	0.0012	-0.191	-7.051

Table 2. Summary Statistics for Cs-137 in Survey Unit 1 by Collection Dates

General Statistics for Uncensored Data Sets

Variable	NumObs	# Missing	Minimum	Maximum	Mean	Geo-Mean	SD	SEM	MAD/0.675	Skewness	CV
Cs-137 Result (1_10_2013)	3	0	-0.00575	0	-0.00224	N/A	0.00308	0.00178	0.00145	-1.537	-1.371
Cs-137 Result (1_3_2013)	3	0	4.6830E-4	0.0229	0.00854	0.00288	0.0125	0.0072	0.00263	1.693	1.461
Cs-137 Result (11_15_2012)	3	0	2.6850E-4	0.0154	0.0062	0.00231	0.00805	0.00465	0.00402	1.514	1.297
Cs-137 Result (11_5_2012)	41	0	-0.0118	0.0573	0.00802	N/A	0.0166	0.00259	0.0151	1.867	2.067
Cs-137 Result (12_11_2012)	2	0	-0.00135	0.0077	0.00317	N/A	0.0064	0.00453	0.00671	N/A	2.017
Cs-137 Result (12_13_2012)	2	0	-0.0137	-0.00605	-0.00987	N/A	0.00541	0.00383	0.00567	N/A	-0.548
Cs-137 Result (2_12_2013)	1	0	0	0	0	0	N/A	N/A	0	N/A	N/A
Cs-137 Result (2_20_2013)	2	0	9.8530E-4	0.0116	0.00629	0.00338	0.00751	0.00531	0.00787	N/A	1.193
Cs-137 Result (3_1_2013)	4	0	-0.0077	0.00571	-0.00114	N/A	0.00551	0.00276	0.0053	0.152	-4.847
Cs-137 Result (3_12_2012)	23	0	-0.00675	0.0304	0.0073	N/A	0.00936	0.00195	0.00797	0.8	1.283
Cs-137 Result (4_20_2012)	4	0	-0.0138	0.0138	-0.00192	N/A	0.0116	0.00579	0.00889	0.911	-6.034
Cs-137 Result (5_1_2012)	1	0	0	0	0	0	N/A	N/A	0	N/A	N/A
Cs-137 Result (5_31_2012)	**42**	**0**	**-0.0224**	**0.0218**	**-0.00101**	**N/A**	**0.0071**	**0.0011**	**0.00122**	**-0.191**	**-7.051**

- Note that for survey unit 1, on May 31, 2012, 42 samples were evaluated during phase Sys-2.

- Table 1: Note data for Sys-2 (out of 3 phases) phase exhibits the lowest mean, lowest value of the maximum value, and the lowest standard deviation (sd). These values might have been manipulated during this phase to reduce mean and variability (explaining tight clustering for Sys-2 as shown in Figure 1).

- Table 2: Data for collection date May 31, 2012, exhibits the lowest mean, lowest value of the maximum value, and lowest standard deviation (sd) among all dates (including dates for FSS-Sys) with more than 4 samples. Cs-137 values on this date might have been manipulated to reduce mean and variability (explaining tight clustering for this date shown in Figure 2).

Table 3 has summary statistics for Cs-137 by sampling phases in U7 and Table 4 has summary statistics for Cs-137 by sample collection dates for U7.

Table 3. Summary Statistics for Cs-137 in Survey Unit 7 by Sampling Phases

General Statistics for Uncensored Data Sets

Variable	NumObs	# Missing	Minimum	Maximum	Mean	Geo-Mean	SD	SEM	MAD/0.675	Skewness	CV
Cs-137 Result (fss-bias)	5	0	9.669E-4	0.112	0.033	N/A	0.0501	0.0224	0.00143	1.293	1.519
Cs-137 Result (fss-sys)	42	0	-0.0171	0.0826	0.00979	N/A	0.0191	0.00294	0.00881	2.032	1.948
Cs-137 Result (ras)	4	0	0	0.159	0.0761	0	0.0684	0.0342	0.0732	0.242	0.9
Cs-137 Result (sys_1)	21	0	-0.012	0.25	0.016	N/A	0.0545	0.0119	0.0089	4.344	3.408
Cs-137 Result (sys_2)	**42**	**0**	**-0.0176**	**0.0298**	**0.0010**	**N/A**	**0.00976**	**0.0015**	**0.00685**	**0.872**	**9.67**

Table 4. Summary Statistics for Cs-137 in Survey Unit 7 by Sampling Phases

General Statistics for Uncensored Data Sets

Variable	NumObs	# Missing	Minimum	Maximum	Mean	Geo-Mean	SD	SEM	MAD/0.67!	Skewness	CV
Cs-137 Result (11_2_2012)	42	0	-0.0171	0.0826	0.00979	N/A	0.0191	0.00294	0.00881	2.032	1.948
Cs-137 Result (3_19_2012)	23	0	-0.012	0.25	0.0145	N/A	0.0522	0.0109	0.00717	4.546	3.588
Cs-137 Result (4_20_2012)	2	0	0.0997	0.159	0.129	0.125	0.0427	0.0302	0.0447	N/A	0.331
Cs-137 Result (4_27_2012)	2	0	0	0.0466	0.0233	0	0.0329	0.0233	0.0345	N/A	1.414
Cs-137 Result (5_24_2012)	1	0	0	0	0	0	N/A	N/A	0	N/A	N/A
Cs-137 Result (5_7_2012)	2	0	0.0543	0.112	0.0831	0.078	0.0408	0.0289	0.0428	N/A	0.491
Cs-137 Result (6_4_2012)	42	0	-0.0176	0.0298	0.0010	N/A	0.00976	0.00151	0.0068	0.872	9.67

- Note that for survey unit 7, on June 4, 2012, 42 samples were evaluated during phase Sys-2.

- Table 3: Data for Sys-2 (out of 3 phases) phase exhibits the lowest mean, lowest value of the maximum value, and lowest sd. Values might have been manipulated during this phase to lower the mean and variability (explaining tight clustering for Sys-2 as shown in Figure 3).

- Table 4: Data for collection date June 4, 2012, exhibits the lowest mean, lowest value of the maximum value, and lowest sd among all dates (including sampling dates for FSS-Sys) with more than 4 samples. Values might have been manipulated on this date to reduce mean and variability (explaining tight clustering for June 4, 2012, as shown in Figure 4).

Summary: As demonstrated by patterns displayed in Figures 1 through 4, suspicious activities in U1 and U7 for ROCs included in the evaluations have been identified using only four PC graphs (Figures 1 through 4). These graphs identified that suspicious activities/ falsification for all ROCs included in the evaluations took place mainly during Sys-2 sampling phase. In U1, suspicious activity took place on May 31, 2012, and in U7, suspicious activity took place on June 4, 2012.

For Cs-137, these conclusions are supplemented with statistics displayed in Tables 1 through 4 for Cs-137. If deemed necessary, one may want to generate these statistics tables for all other ROCs. However, multivariate methods identified suspicious activities simultaneously for all ROCs included in the evaluations. Also, if deemed necessary, one can verify the conclusions derived based upon PC evaluations described above by using scatter plots of the first PC1 against ROCs considered in PC evaluations. Additionally, one can also use univariate graphical and statistical methods. For illustration purposes, some of these evaluations are summarized in Appendix A.

Appendix A

Additional Evaluations Verifying the Conclusions Derived Based Upon PCs Graphs Shown in Figures 1 through 4

As seen in the evaluations described earlier, the use of univariate statistical methods (e.g., used in the Navy presentation for North Pier) alone cannot effectively identify potential patterns present in a data set. Moreover, test statistics based upon classical statistical methods tend to get distorted by anomalies/outliers present in the data set. During the process of identifying anomalies/patterns in the Site data sets, there is no need to: generate histograms, perform goodness-of-fit (GOF) tests, use lognormal distribution, or logged statistics (e.g., taking logarithm of K-S distances).

In Section A1 of this appendix, additional graphs using PCA have been generated to confirm identified anomalies individually for some of the ROCs. Some effective univariate graphical displays have also been presented in Section A2.

A1. Scatter Plots of PC1 versus ROCs

As described in the main document, graphs of the first few PCs (PC1 versus PC2) by sampling phases and collection dates effectively identified anomalies for all ROCs used in the evaluations. However, one may want to verify these conclusions; scatter plots of the first PC1 against selected radionuclides of interest can be used to verify suspicious activities identified in the main document. In this section scatter plots using the first PC, PC1 have been used for Cs-137, Ra-226/Bi-214, and AC-228/Th-232.

Survey Unit 1

For U1, Figure A1 has graphical display of Cs-137 versus principal component 1 (PC1) by sampling phases, and Figure A2 has graphical display of AC-228/Th-232 versus PC1 by sampling phases. Figures A3, A4, and A5 respectively have scatter plots of Cs-137, Ra-226/Bi-214, and AC-228/Th-232 versus PC1 by sample collection dates. All these graphs identified the same anomalous data set of size 42 collected during Sys-2 sampling phase on May 31, 2012.

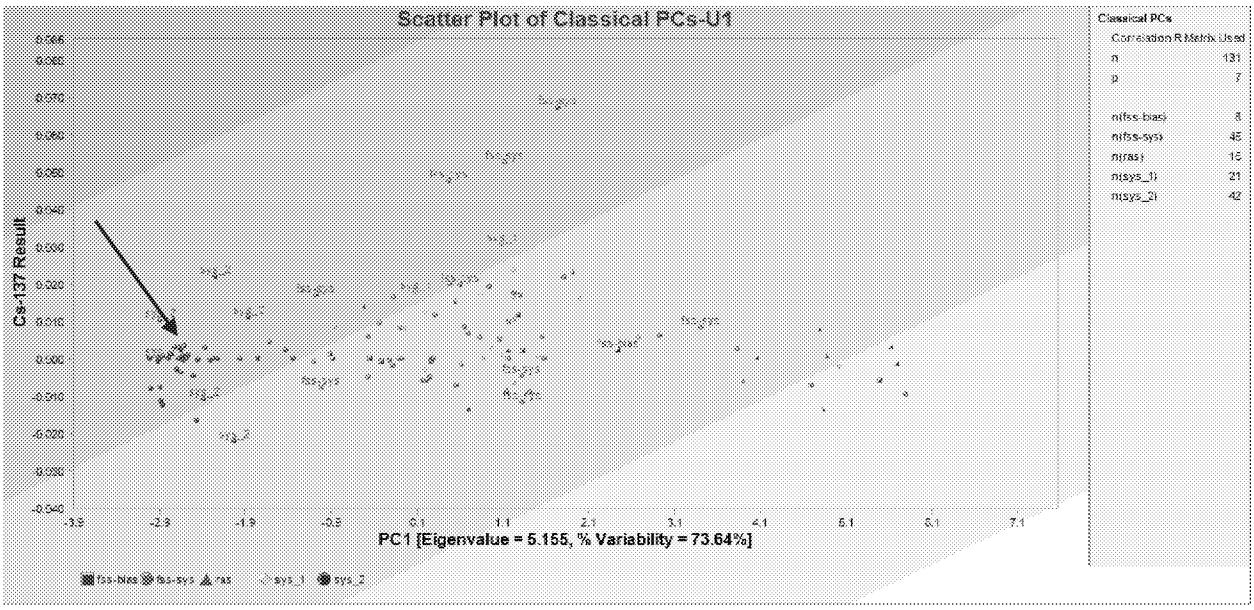

Figure A1. Scatter plot of Cs-137 versus PC1 by Sampling Phases –Survey Unit 1

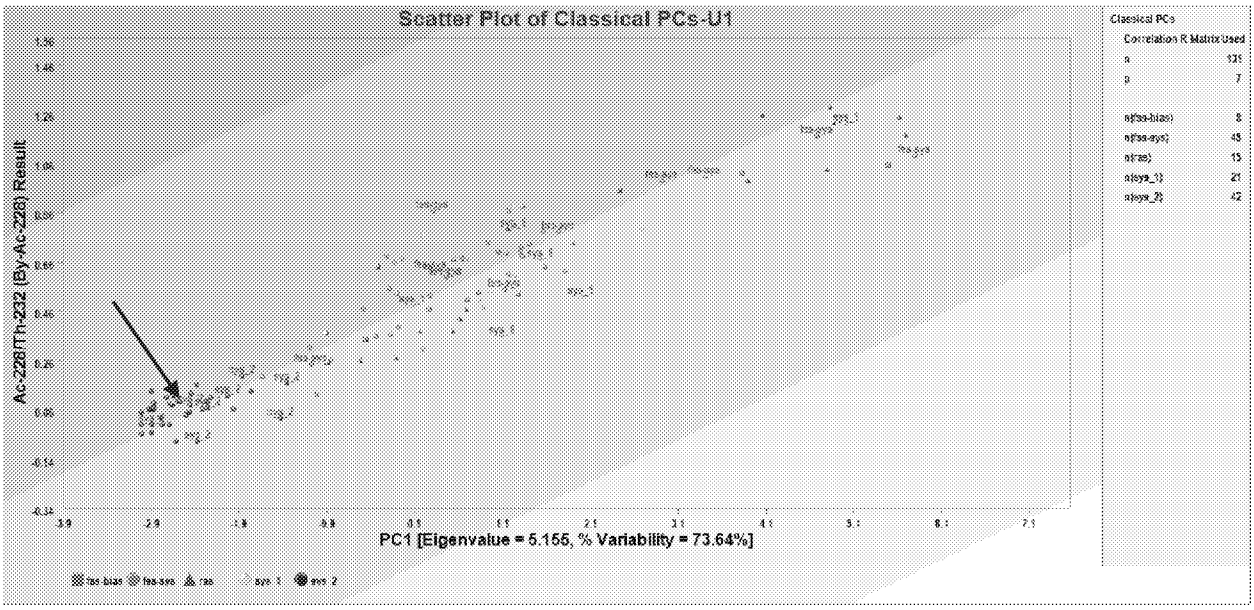

Figure A2. Scatter plot of AC-228/Th-232 versus PC1 by Sampling Phases –Survey Unit 1

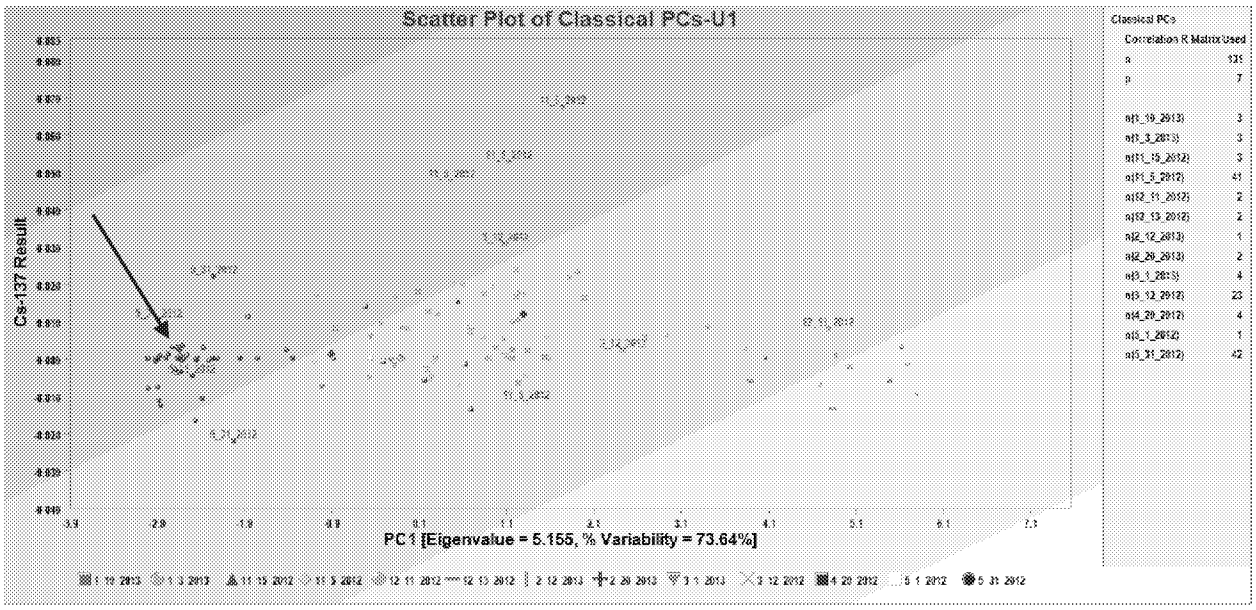

Figure A3. Scatter plot of Cs-137 versus PC1 by Sample Collection Dates –Survey Unit 1

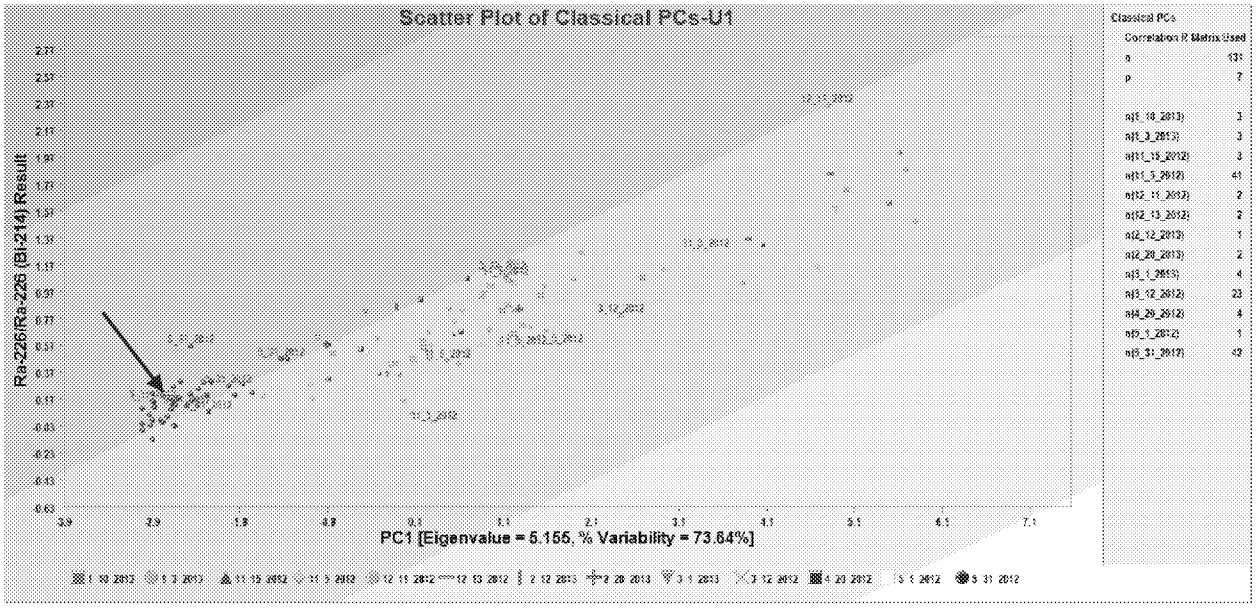

Figure A4. Scatter plot of Ra-226/Bi-214 versus PC1 by Sample Collection Dates –Survey Unit 1

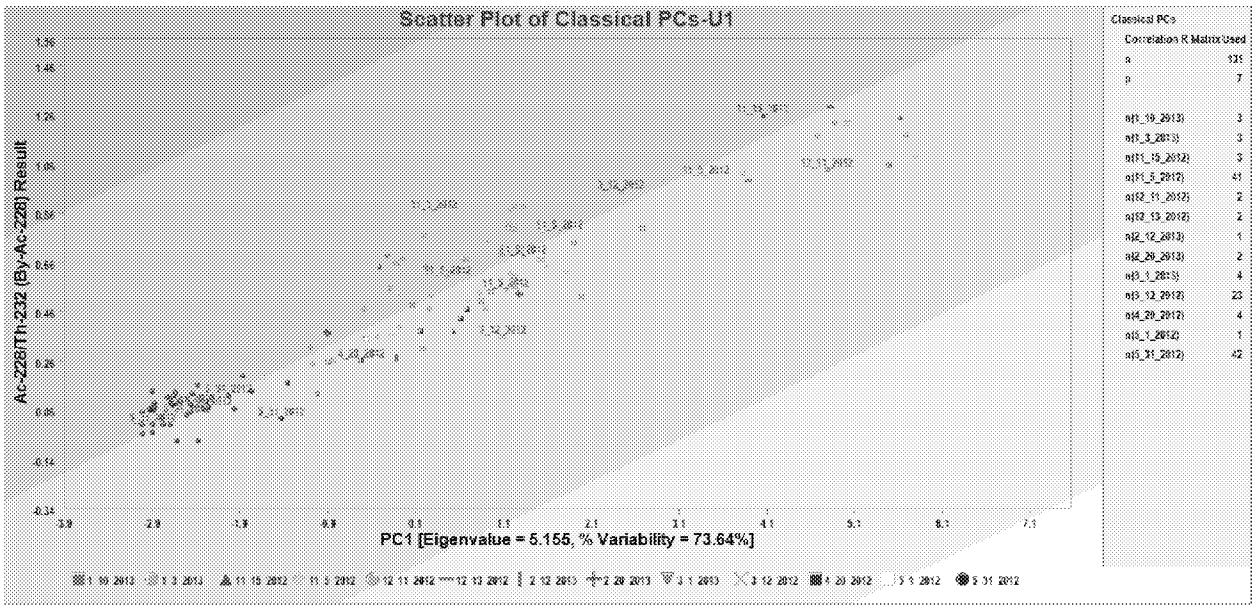

Figure A5. Scatter plot of Ac-228/Th-232 versus PC1 by Sample Collection Dates –Survey Unit 1

Survey Unit 7

For U7, Figure A6 has graphical display of Cs-137 versus principal component 1 (PC1) by sampling phases, Figure 7 has the graphical display of Ra226/Bi-214 versus PC1 by sampling phases and Figure A8 has graphical display of AC-228/Th-232 versus PC1 by sampling phases. Figures A9, A10, and A11 respectively have scatter plots of Cs-137, Ra-226/Bi-214, and AC-228/Th-232 versus PC1 by sample collection dates. All these graphs confirmed the same anomalous data set of size 42 collected during Sys-2 sampling phase on June 4, 2012.

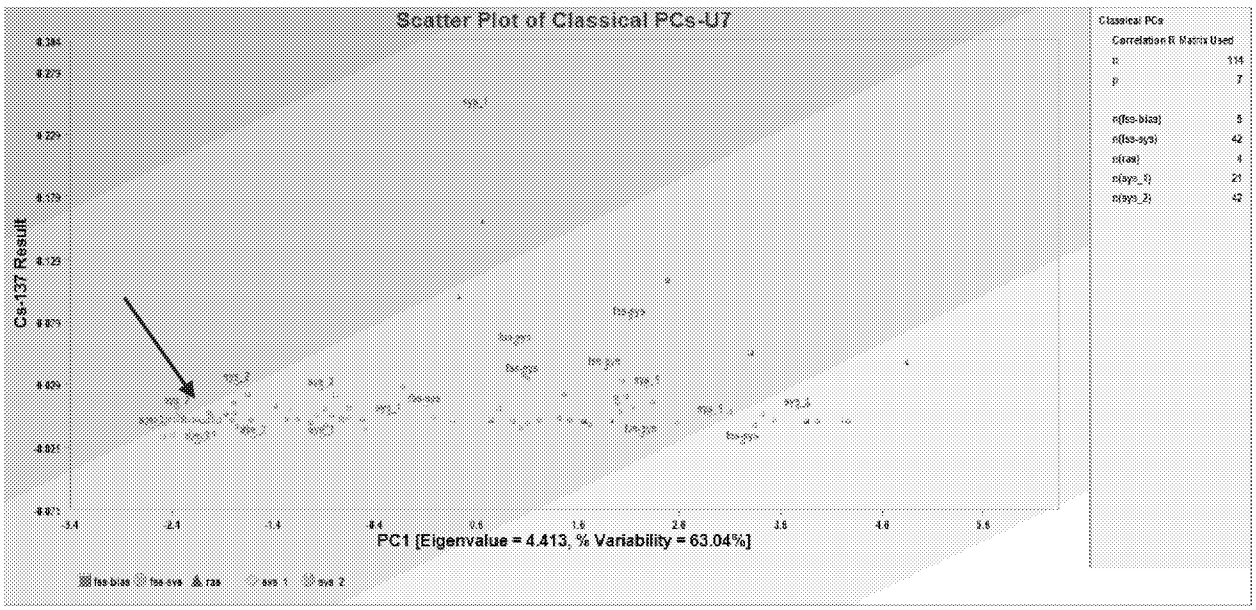

Figure A6. Scatter plot of Cs-137 versus PC1 by Sampling Phases –Survey Unit 7

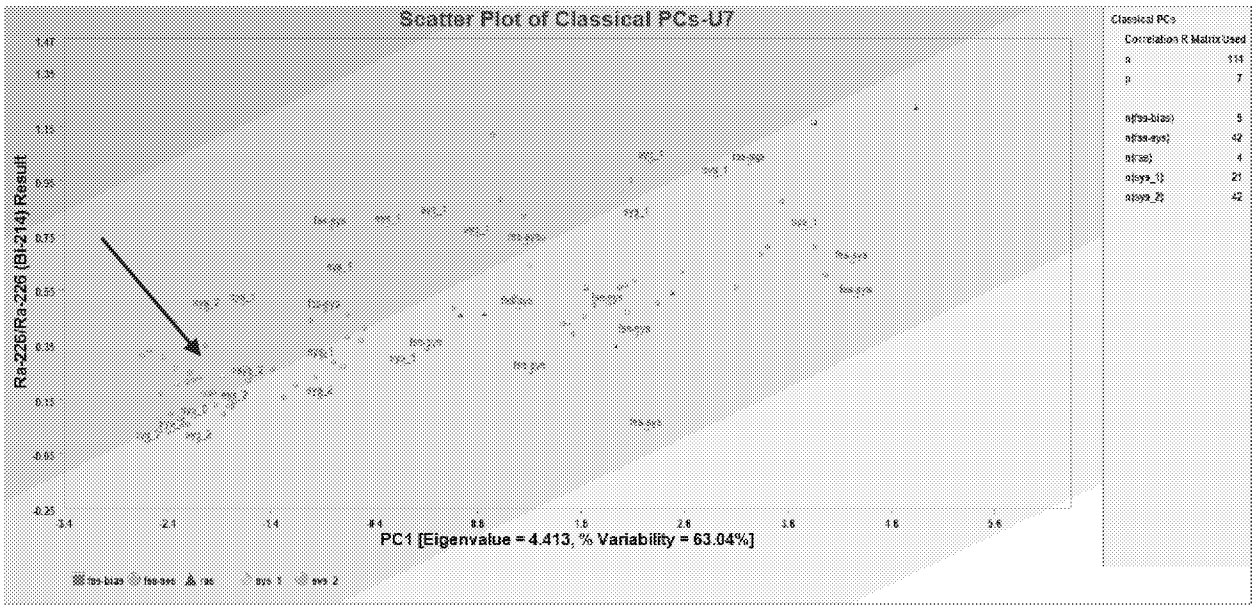

Figure A7. Scatter plot of Ra-226/Bi-214 versus PC1 by Sampling Phases –Survey Unit 7

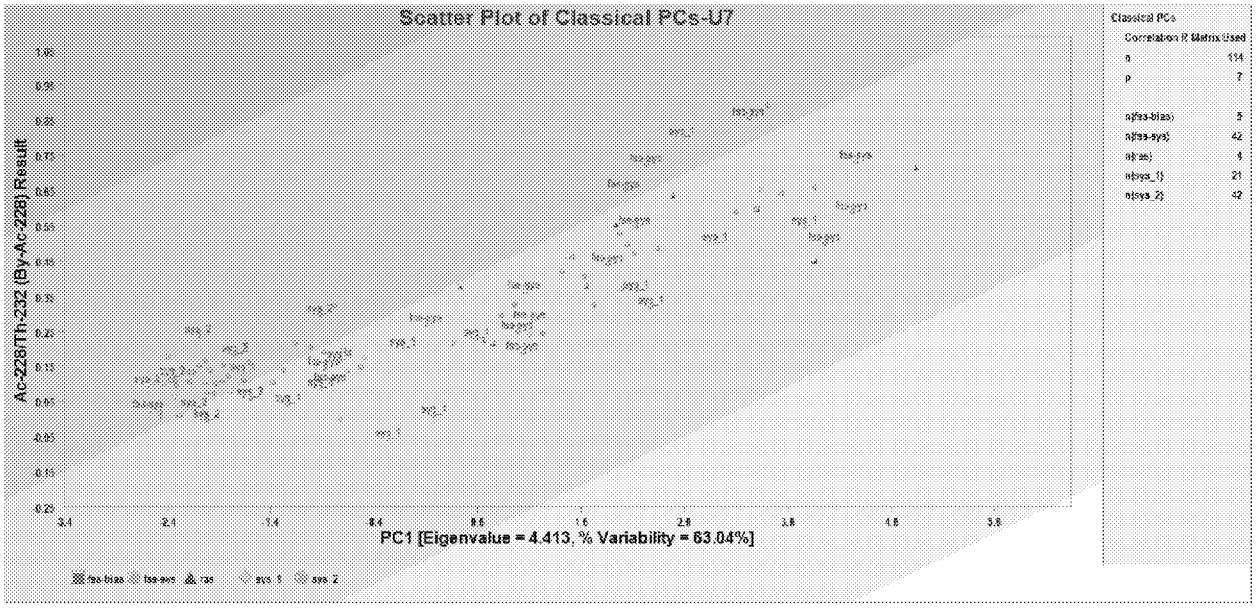

Figure A8. Scatter plot of Ac-228/Th-232 versus PC1 by Sampling Phases –Survey Unit 7

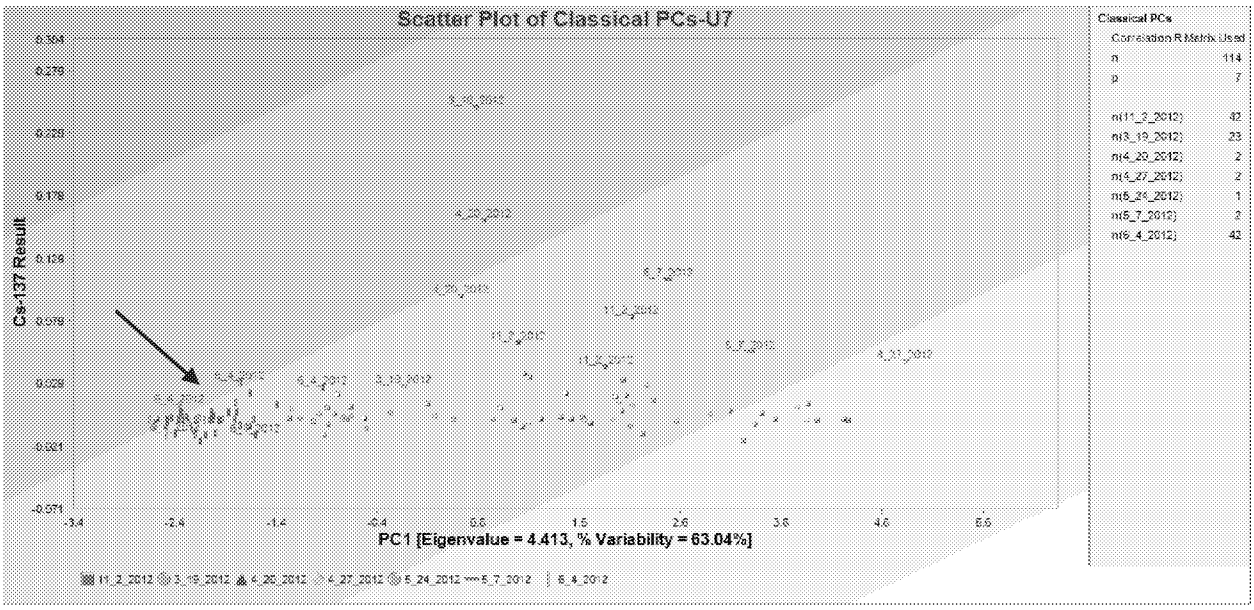

Figure A9. Scatter plot of Cs 137 versus PC1 by Sample Collection Dates –Survey Unit 7

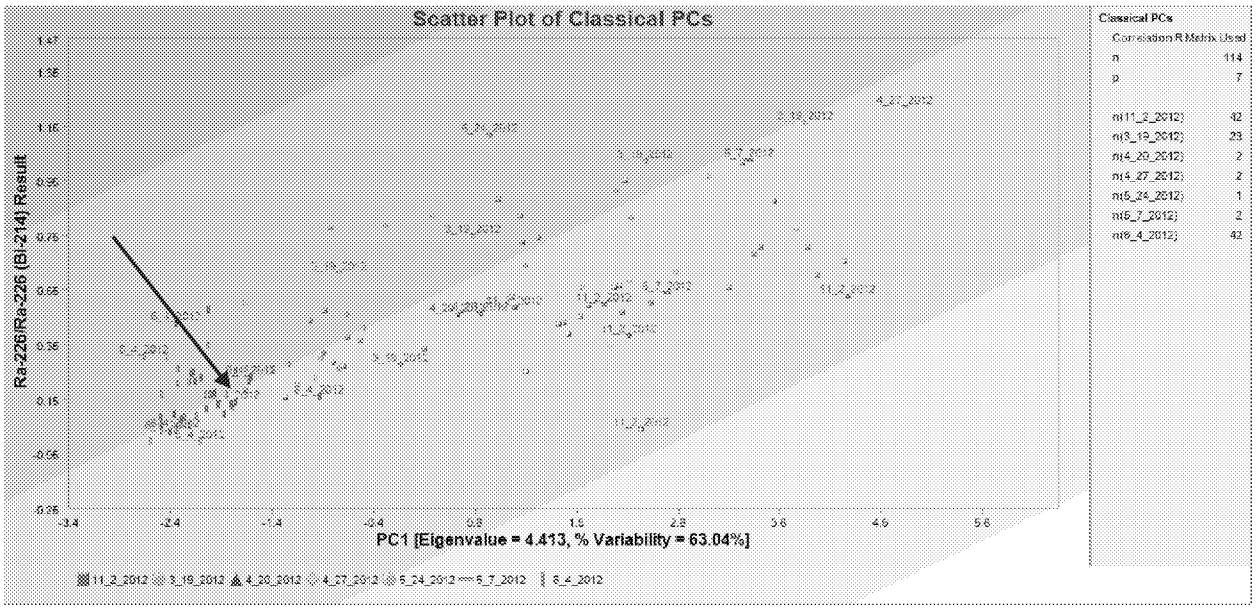

Figure A10. Scatter plot of Ra-226/Bi-214 versus PC1 by Sample Collection Dates –Survey Unit 7

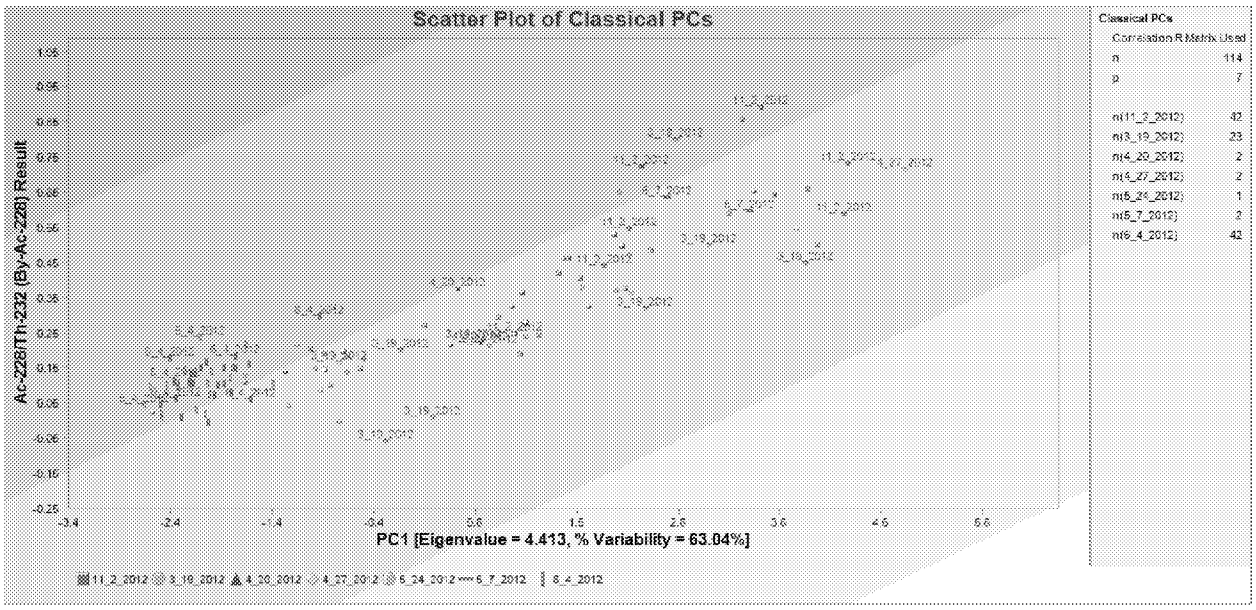

Figure A11. Scatter plot of AC-228/Th-232 versus PC1 by Sample Collection Dates –Survey Unit 7

Survey Unit 8

A couple of PC graphs for Survey Unit (U8) have also been generated. Figure A12 has graphical display of Cs-137 versus principal component 1 (PC1) by sampling phases and Figure 13 has the graphical display of Ac-228/Th-232 versus PC1 by sampling phases. These graphs also confirmed that anomalous activity occurred during Sys-2 sampling phase on May 31, 2012.

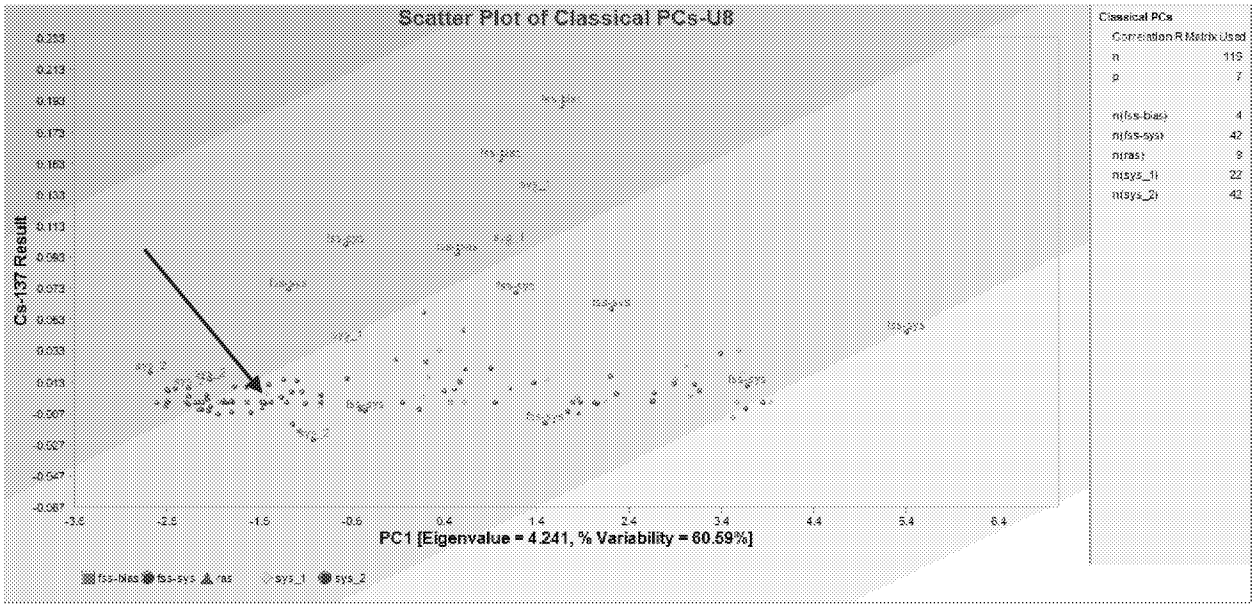

Figure A12. Scatter plot of Cs-137 versus PC1 by Sampling Phases –Survey Unit 8

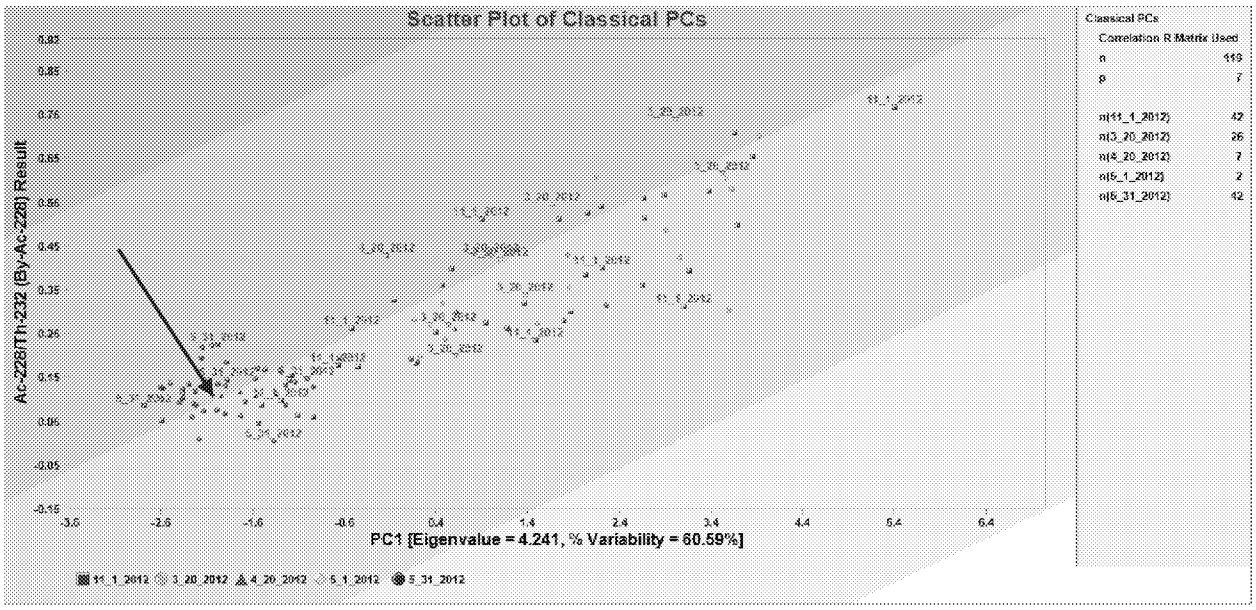

Figure A13. Scatter plot of AC-228/Th-232 versus PC1 by Sample Collection Dates –Survey Unit 8

From figures A1-A13 for U1, U7, and U8, it is easy to note that something abnormal happened on May 31, 2012 during sampling phase Sys-2 for U1 and U8 and on June 4 during sampling phase Sys-2 for U7. It seems like, data for phase Sys-2 processed on May 31, 2012, (for U1 and U8) and on June 4, 2012, (for U7) has been altered with low values to reduce mean and variance.

A2. Univariate Methods – One ROC at a Time

Evaluation of Cs-137

Figures A14 and A15 compare Cs-137 during 5 sampling phases using the combined data from all survey units. Graphical displays have been formalized by drawing a horizontal line at the $DCGL_w$ value of 0.13. From Figures A14 and A15, it is noted that Cs-137 values do not follow the "desired" ROC pattern described above; values of Cs-137 observed during Sys-2 are lower than the values observed during FSS-Sys phase suggesting that values during Sys-2 sampling might have been altered. To substantiate this observation further, evaluations can be performed separately for the various survey units in the North Pier parcel.

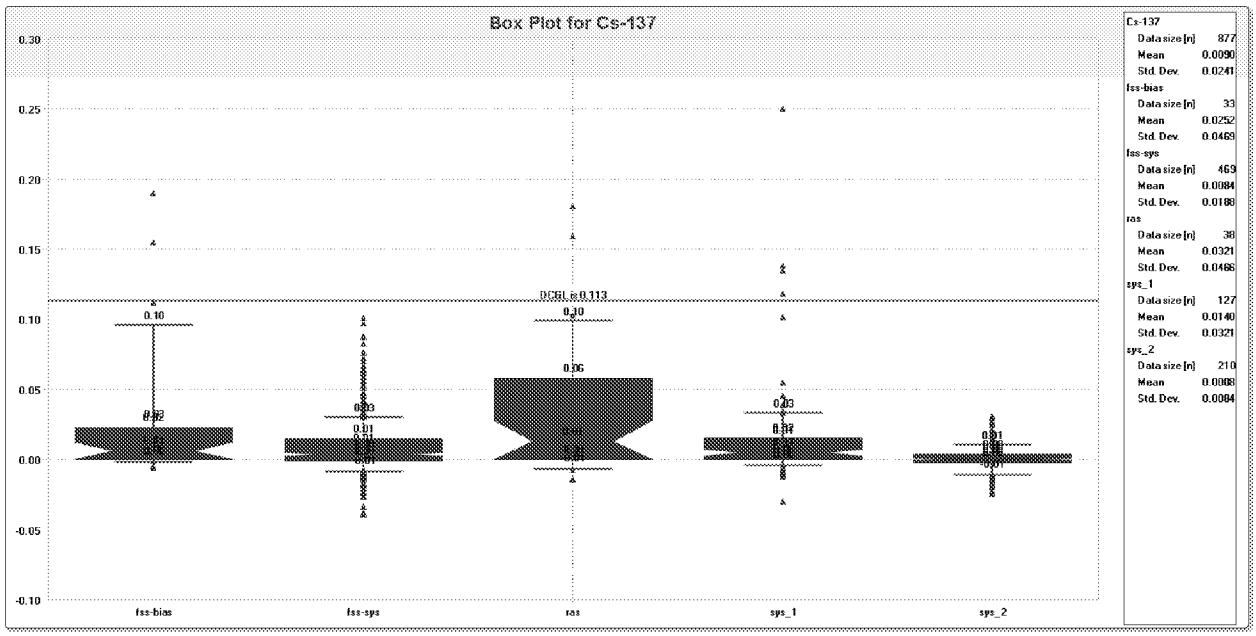

Figure 14. Box Plots Comparing Cs-137– Data of 11 Survey Units of North Pier Combined

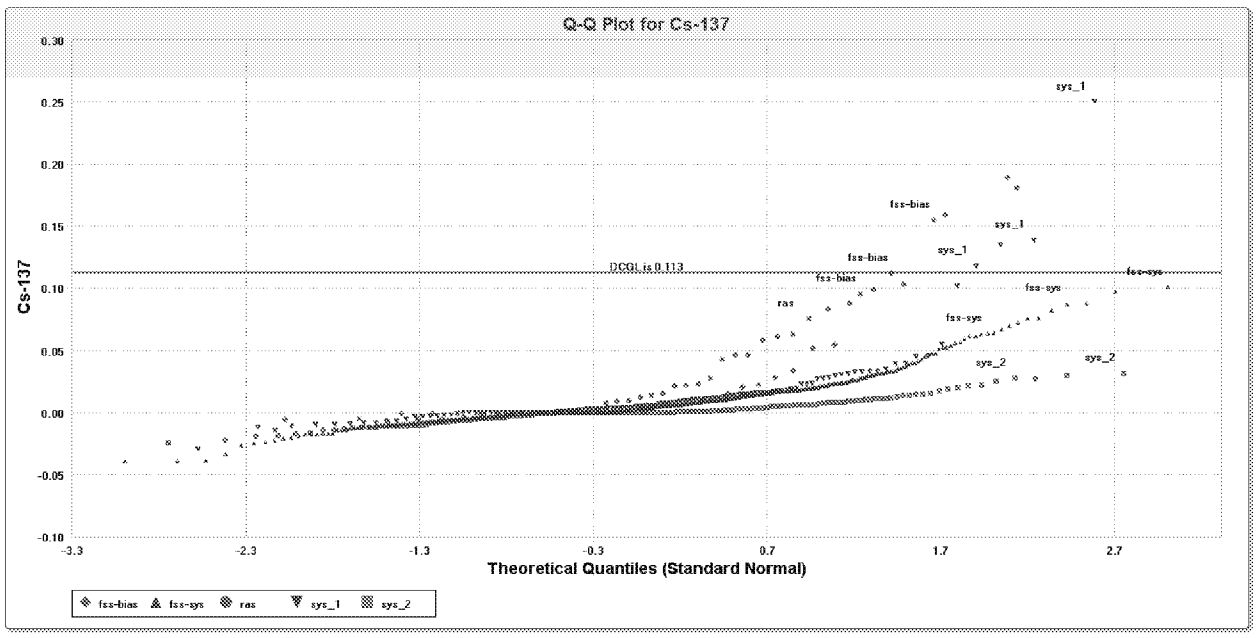

Figure A15. Q-Q Plots Comparing of Cs-137 – Data of 11 Survey Units of North Pier Combined

Evaluation of Survey Unit 1(U1)

Figures A16 and A17 respectively have box plots and Q-Q plots comparing Cs-137 observed in Unit 1 (U1) during the sampling phases listed above. A quick look at Figures A16 and A17, reveals that Cs-137 values do not follow the "desired" pattern; values of Cs-137 observed during Sys-2 are lower than the values observed during FSS-Sys phase suggesting that values during Sys-2 sampling might have been altered/manipulated.

To identify dates of abnormal suspicious activities, box plots comparing Cs-137 in U1 by dates were generated as shown on Figure A18. Figure A18 identifies unusual activity (abnormally low values of Cs-

137) on May 31, 2012, suggesting that unusual activity might have taken place during phase Sys-2 and on May 31, 2012.

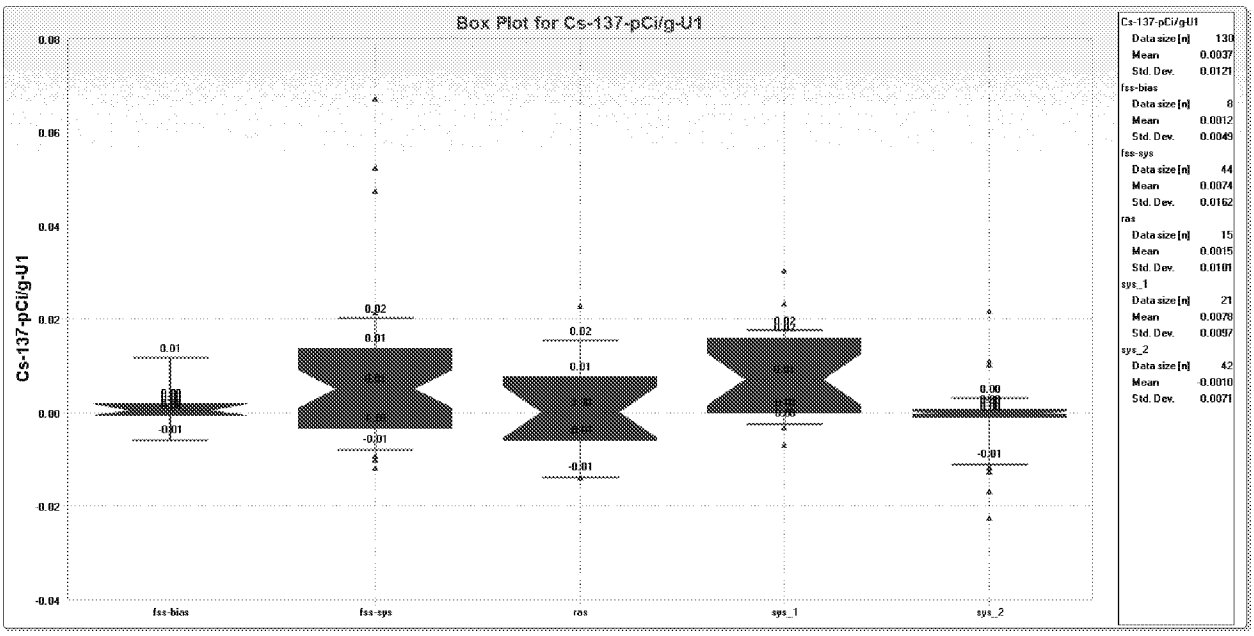

Figure A16. Box Plots Comparing Cs-137 during Sampling Phases – Survey Unit 1

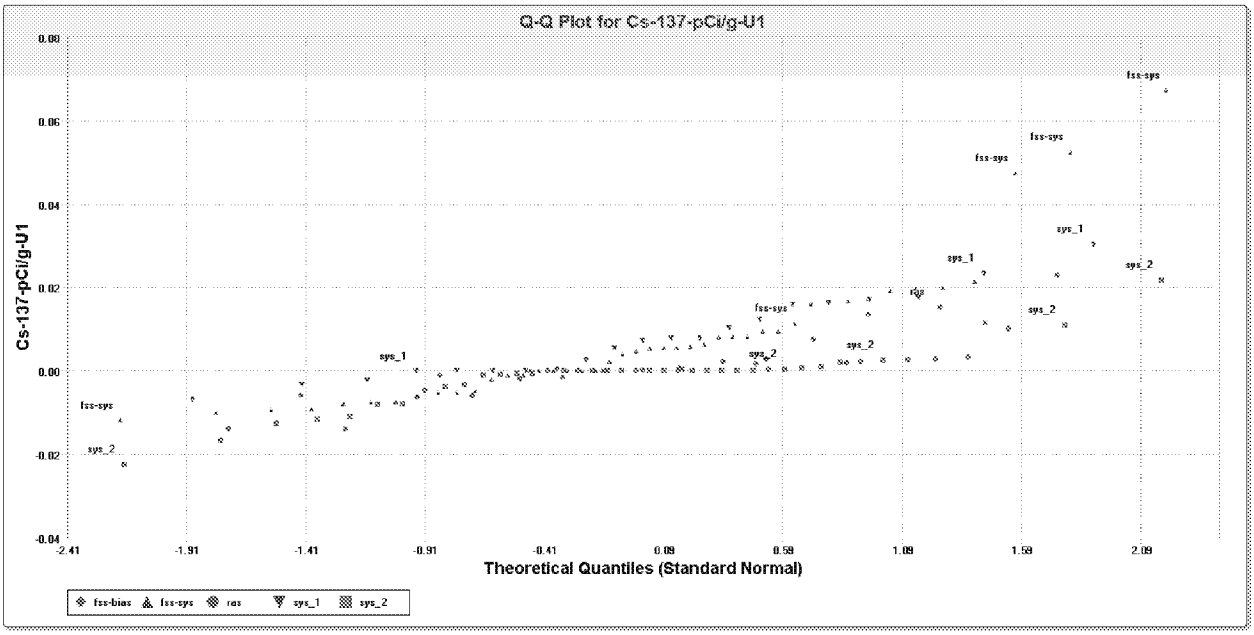

Figure A17. Box Plots Comparing Cs-137 during Sampling Phases –Survey Unit 1

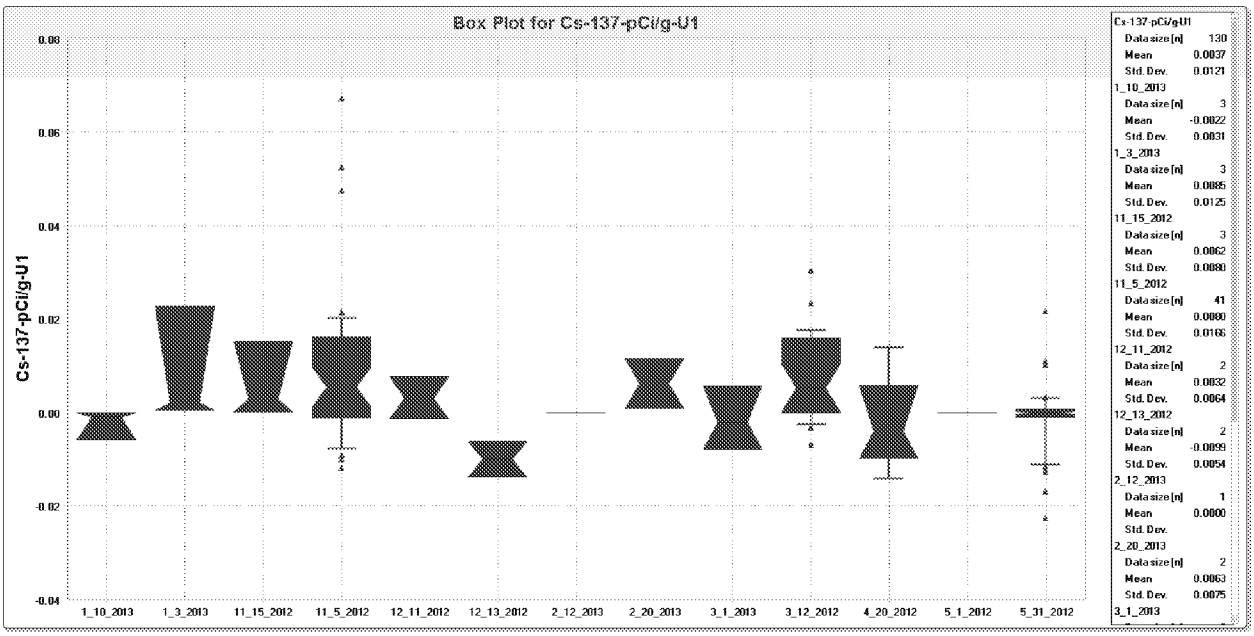

Figure A18. Box Plots Comparing Cs-*137 by Sampled Dates –Survey Unit 1

Suggestion for Survey Unit 1: The Navy may want to confirm these observations by performing two sample hypothesis tests such as Wilcoxon-Mann-Whitney (same as Wilcoxon Rank Sum test – MARSSIM, 2000). Specifically, Navy may want to perform two-sample hypothesis test on U1 data with null hypothesis, H_0: Cs-137 during FSS-Sys $\geq$ Sys-2 versus the alternative hypothesis, H_1: Cs-137 during FSS-Sys<Sys-2.

- *Navy should closely review U1 data collected during Sys-2 on May 31, 2012 to determine all possible potentially altered anomalies.*

Evaluation of Survey Unit 7 (U7)

Figures A19 and A20 respectively have box plots and Q-Q plots comparing Cs-137 in U7 during the sampling phases. Figure A21 has box plots comparing Cs-137 in U7 by sampled dates. From Figures A19 and A20, it is noted that Cs-137 values do not follow the desired pattern; values of Cs-137 observed during Sys-2 are lower than the values observed during FSS-Sys phase suggesting that values during Sys-2 sampling might have been altered. To identify dates of abnormal activities, box plots comparing Cs-137 in U7 by dates were generated as shown on Figure A21. Figure 21 identifies the lowest unusual activity on June 4, 2012.

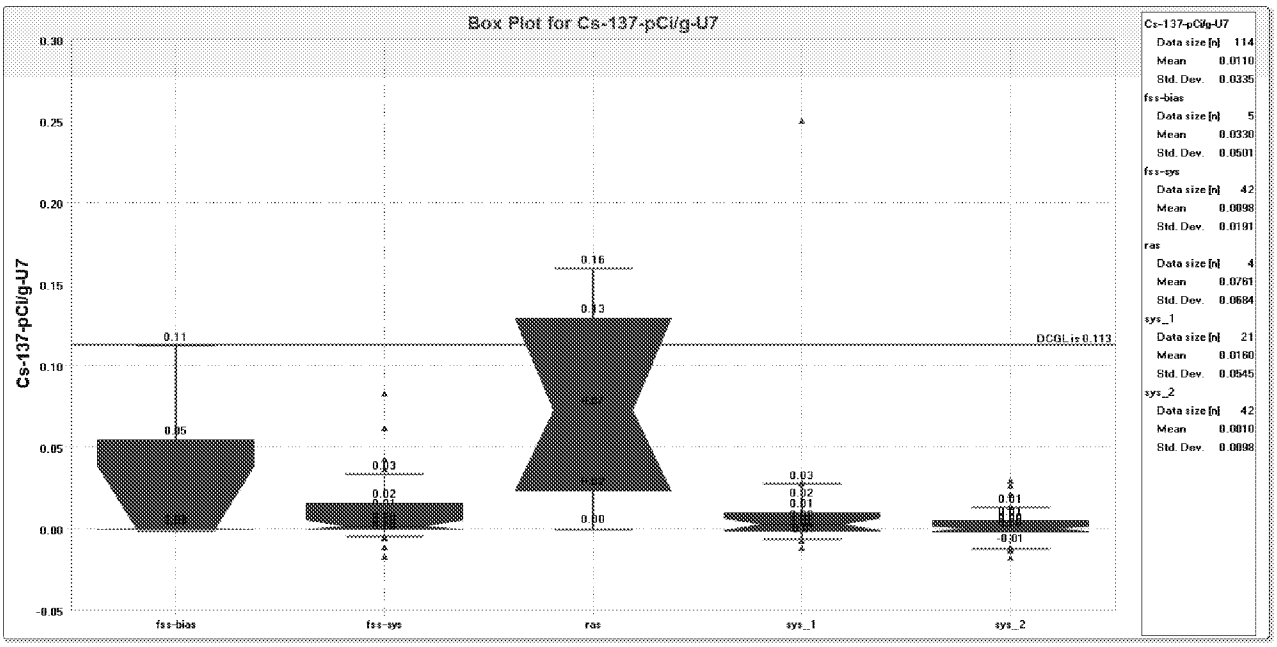

Figure A19. Box Plots Comparing Cs-137 during Sampling Phases – Survey Unit 7

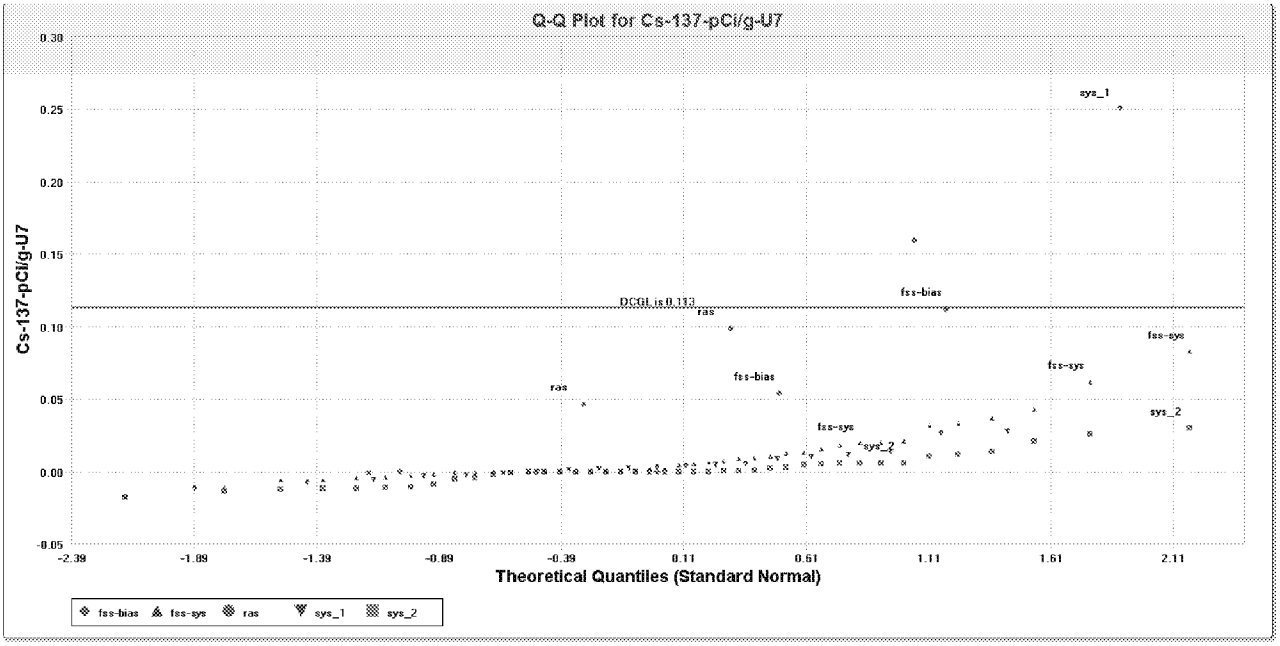

Figure A20. Q-Q Plots Comparing Cs-137 during Sampling Phases – Survey Unit 7

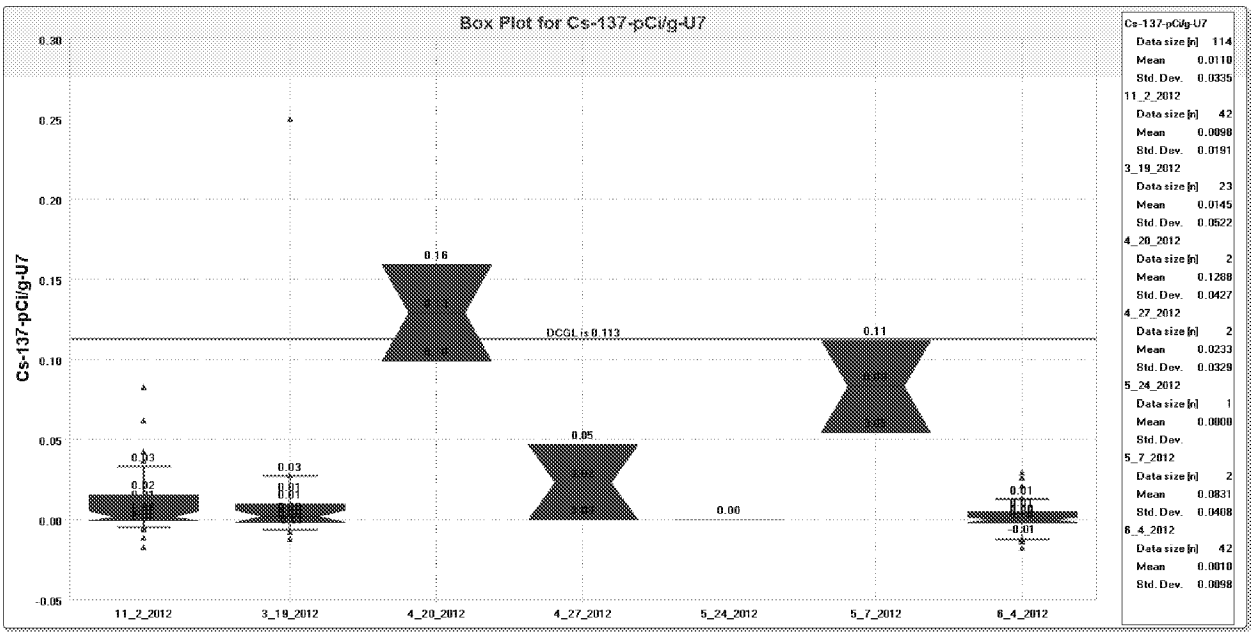

Figure A21. Box Plots Comparing Cs-137 by Sampled Dates –Survey Unit 7

It appears that unusual/altering activity might have taken place during phase Sys-2 and on June 4, 2012.

<u>Suggestion for Survey Unit 7:</u> It is suggested that the Navy confirm these observations by performing two sample statistical tests such as Wilcoxon-Mann-Whitney (WMW) test. Specifically, Navy may want to perform two-sample hypothesis test on U7 data with null hypothesis, H_0: Cs-137 during FSS-Sys $\geq$ Sys-2 versus the alternative hypothesis, H_1: Cs-137 during FSS-Sys<Sys-2.

It is recommended that Navy closely reviews U7 data collected during Sys-2 on June 4, 2012, to determine all possible potentially altered anomalies.