PNNL-15220

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Statistical Analysis of the Critical Mass Laboratory (209-E) Filter Data

T. L. Welsh

June 2005

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Summary

The potential-to-emit (PTE) calculation for the Critical Mass Laboratory (209-E) exhaust stack, which was developed around 1992, was questioned by the Washington Department of Health (WDOH). WDOH issued a notice of assurance of discontinuance and a commitment was made in the subsequent reply to develop a new PTE. Samples were obtained from the pre-filters and the first bank of HEPA filters in the 209-E exhaust system and analyzed per the sampling and analysis plan (LeBaron 2005). The sample information from the exhaust pre-filters and the first bank of HEPA filters provided in Table 5 will be used to develop a PTE. If the PTE shows that the stack emissions are greater than 0.1 mrem/year, the stack will be designated as a major stack. If the PTE shows that the stack emissions are less than 0.1 mrem/year, the stack will be designated as a minor stack.

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Summary

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Purpose

The purpose of the statistical analysis of the data is to determine the mean concentration for each radionuclide used in determining the PTE.

Sampling Design

In order to obtain samples from the two banks of filters (the pre-filters and the first bank of HEPA filters), a sampling design was developed using the methodology outlined in SW-846 (EPA, 2005). The number of samples was determined using Equation 8 from Table 9-1 varying the mean, variability, and the difference from the threshold (see Appendix B in LeBaron 2005). Equation 8 assumes that the data are from a normal distribution. It was determined that ten samples would be obtained from each bank of filters.

Each of the two banks of filters is a two-by-two array consisting of four filters each. The filter media of all four filters is considered the filter face (filter bank) through which the exhaust air flows. An imaginary grid was superimposed over each filter face and a series of consecutive numbers was assigned to each cell of the grid. Ten random numbers for each filter face (each number representing a cell) were selected using a random number generator from SPLUS (Statistical Sciences, 1993). A sample core (a full penetration sample; from front to back) was obtained for each selected cell. All samples were sent to 222-S Analytical Laboratory for dissolution and analysis.

Analytical Results

The twenty samples were analyzed according to the sampling and analysis plan (LeBaron 2005) at 222-S Analytical Laboratory. The data were reported in Bushaw 2005. The data are listed in Table 1 for the pre-filter sample results and Table 2 for the HEPA filter sample results. The data are illustrated in Figures 1- 10.

To compare the results for analytes measured using two different analytical methods some of the data were converted from µg/sample to µCi/sample (or vice versus) using the specific activities reported in DOE-STD-1027-92 (Chow et.al., 1995). As can be seen in Figure 2, the two analytical methods (GEA versus TRU SPEC) for americium-241 provide equivalent results within the total measurement uncertainty. In addition, after summing the plutonium-239 and plutonium-240 results obtained using ICP/MS, the results are equivalent (within the total measurement uncertainty of the two methods) to the plutonium-239/240 results obtained by the TRU SPEC analytical method (see Figure 4).

Statistical Analysis

If the reported analytical results were a mixture of "real" values and "less than" values, then three methodologies were used to determine a mean concentration. The first method did not use the "less than" values in the statistical analysis. The second method uses the upper bound of the "less than" value (e.g., use 6.51E-04 for <6.51E-04). The third method uses half of the upper bound of the "less than" value. All three methods produce (1) a bias (typically positive) of unknown magnitude in the mean concentration and (2) a bias (direction not known) of unknown magnitude in the variance associated with the mean. The method which produced the largest mean concentration (so as not to underestimate the PTE) is reported.

Normal Distribution

Two independent tests were performed to test the hypothesis that the random sample comes from a normal distribution with unspecified mean and variance versus the alternative that the distribution is not normal. The two tests are called the Lilliefors Test for Normality and the Shapiro-Wilk Test for Normality (Bowen 1988, chapter 9). The normality tests were performed for each set of filter face analytical results.

The hypothesis that the random sample comes from a normal distribution was not rejected using either test at the 0.05 level of significance for all analytes except for the Total Beta results from the HEPA filter samples. If one result (S05051-20) was deleted from the HEPA filter data set for Total Beta, the hypothesis that the random sample comes from a normal distribution would not be rejected. However, the following two statements (Ostle, 1988) indicate that using the mean concentration for the HEPA filter Total Beta result is reasonable. "That is, unless the population distribution is extremely different from a normal distribution and the sample size is extremely small, the sampling distribution of $\overline{X}$ will be approximately normal. Therefore we can obtain reasonably good approximation by using normal theory." "However, for many reasonable distributions, (see chapter 4), the Central Limit Theorem will allow us to use a normal approximation with a sample size as small as n=5."

Mean Concentration and the Variability Associated with the Mean

For each analyte for each data set (filter bank), the data were statistically evaluated using one-way analysis of variance (ANOVA): the data are identified by one variable (the sample). The one-way ANOVA statistical model used to describe the structure of the data is

$$Y_{ij} = \mu + S_i + A_{ij},$$
$$i = 1,2,\ldots,a, \quad j=1,2,\ldots,n_i,$$

where

Y_{ij}	=	concentration from the j^{th} analytical result from the i^{th} sample
μ	=	the grand mean
S_i	=	the effect of the i^{th} sample
A_{ij}	=	the effect of the j^{th} analytical result from the i^{th} sample
a	=	the number of samples (10)
n_i	=	the number of analytical results from the i^{th} sample (1 or 2).

The variable S_i is assumed to be a random effect (the samples were randomly chosen from the filter face). This variable, as well as A_{ij}, are assumed to be normally distributed with means zero and variances $\sigma^2(S)$ and $\sigma^2(A)$, respectively. Estimates of $\sigma^2(S)$ and $\sigma^2(A)$ were obtained using Restricted Maximum Likelihood Estimation (REML) techniques. This method applied to variance component estimation is described in Harville, 1977. The results using the REML techniques were obtained using the statistical analysis package S-PLUS (Statistical Sciences, 1993).

The estimator, $\hat{\mu}$, is the maximum likelihood estimate of the mean. This estimator was determined by the structure of the data reflected by the statistical model. The estimate of $\hat{\mu}$ was obtained using REML techniques in S-PLUS. The estimated standard deviation of the mean (where the mean is the maximum likelihood estimate), $\hat{\sigma}_{\hat{\mu}}$, is the square root of a function of the variance estimates $\sigma^2(S)$ and $\sigma^2(A)$. Since the data are unbalanced, $\hat{\sigma}_{\hat{\mu}}$, is a complicated function of these two variances.

The mean analyte concentration ($\hat{\mu}$) and the relative standard deviation (RSD) associated with the mean ($\hat{\sigma}_{\hat{\mu}} / \hat{\mu} \times 100$) are listed in Table 3 for both the Pre-filter sample results and the HEPA filter sample results.

The comparisons of the Pre-filter results to the HEPA filter results indicate a fairly constant ratio. The data, the ratio, and the summary statistics for the ratio data are provided in Table 4. Based on these comparisons, the HEPA filter mean concentration for analytes with all data reported as "less than" values, was determined by multiplying the Pre-filter mean concentration by 0.5. This replaces using an upper value from a "less than" value for the mean concentration which produces a positive bias; the mean concentration is overstated.

The final mean concentrations for the Pre-filter sample results and the HEPA filter sample results are listed in Table 5. If the HEPA filter mean concentration was determined from the Pre-filter mean concentration then the uncertainty for this HEPA filter result was calculated using both the variability in the Pre-filter result and the variability in the mean ratio result.

Reference standards and/or spike analyses were performed as specified in the analytical procedures. All reference standards were within statistical process control limits. The reference standards and the spike recoveries provide assurances that the analytical procedures are producing valid results. The reference standard or spike results provide estimates of the "systematic" uncertainty associated with the analytical procedures for the sample matrix. The systematic uncertainties ranged from 3% (1 RSD) to 14%. The total measurement uncertainty for a mean concentration was determined by adding in quadrature the variance associated with the mean (1 RSD^2) and the systematic variance estimate (1 RSD^2). The systematic uncertainty along with the total measurement uncertainty are provided for each analyte per filter type in Table 6. Except for cesium-137 and strontium-89/90 the total measurement uncertainty ranges from approximately 5% to approximately 20%.

Conclusion

The mean concentrations from which the PTE will be developed are listed in Table 5.

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Table 1. Pre-Filter Sample Results

Customer ID	Analysis	Alpha Env Solid/Misc µCi/sample	Am-241 TRU-SPEC µCi/sample	Am-241 GEA µCi/sample	Beta in Env Samples µCi/sample	Pu239 ICP/MS µg/sample
S05051-01	1	3.82E-02	1.28E-02	1.20E-02	2.59E-03	2.73E-01
S05051-01	2	3.61E-02	1.29E-02	1.16E-02	2.45E-03	2.70E-01
S05051-02	1	5.86E-02	1.98E-02	1.89E-02	4.17E-03	4.29E-01
S05051-03	1	3.18E-02	1.11E-02	1.05E-02	2.09E-03	2.51E-01
S05051-04	1	4.49E-02	1.55E-02	1.49E-02	2.93E-03	3.28E-01
S05051-05	1	4.87E-02	1.59E-02	1.55E-02	3.43E-03	3.60E-01
S05051-06	1	4.89E-02	1.60E-02	1.54E-02	3.16E-03	3.60E-01
S05051-06	2	4.65E-02	n/a	n/a	3.20E-03	n/a
S05051-07	1	1.97E-02	6.45E-03	6.03E-03	1.33E-03	1.41E-01
S05051-08	1	2.81E-02	9.22E-03	8.49E-03	1.96E-03	1.91E-01
S05051-09	1	6.40E-02	2.12E-02	2.08E-02	4.50E-03	4.77E-01
S05051-10	1	6.34E-02	2.02E-02	1.95E-02	4.38E-03	4.55E-01
Customer ID	Analysis	Pu240 ICP/MS µg/sample	Pu244/Cm244 ICP/MS µg/sample	Pu/Am242 ICP/MS µg/sample	Pu/Am241 ICP/MS µg/sample	Pu238 TRU-SPEC µCi/sample
S05051-01	1	2.97E-02	1.96E-05	9.70E-04	4.37E-03	2.46E-03
S05051-01	2	2.91E-02	1.90E-05	9.52E-04	4.33E-03	2.62E-03
S05051-02	1	4.57E-02	2.27E-05	1.47E-03	6.92E-03	3.65E-03
S05051-03	1	2.63E-02	1.56E-05	8.27E-04	3.88E-03	<2.39E-03
S05051-04	1	3.48E-02	2.00E-05	1.12E-03	5.35E-03	3.44E-03
S05051-05	1	3.91E-02	3.82E-05	1.30E-03	5.80E-03	4.06E-03
S05051-06	1	3.91E-02	2.32E-05	1.25E-03	5.76E-03	3.84E-03
S05051-06	2	n/a	n/a	n/a	n/a	n/a
S05051-07	1	1.49E-02	2.79E-05	4.78E-04	2.30E-03	<1.70E-03
S05051-08	1	2.06E-02	3.46E-05	6.69E-04	3.20E-03	<2.13E-03
S05051-09	1	5.10E-02	3.50E-05	1.61E-03	7.54E-03	<5.26E-03
S05051-10	1	4.90E-02	1.72E-05	1.56E-03	7.41E-03	4.93E-03
Customer ID	Analysis	Pu239/240 TRU-SPEC µCi/sample	U233 ICP/MS Acid Add µg/sample	U234 ICP/MS Acid Add µg/sample	U235 ICP/MS Acid Add µg/sample	U236 ICP/MS Acid Add µg/sample
S05051-01	1	2.07E-02	1.91E-05	5.97E-05	1.70E-03	1.35E-04
S05051-01	2	2.13E-02	2.18E-05	6.35E-05	1.76E-03	1.20E-04
S05051-02	1	3.23E-02	2.83E-05	1.03E-04	2.95E-03	2.29E-04
S05051-03	1	2.23E-02	1.74E-05	5.84E-05	1.54E-03	1.11E-04
S05051-04	1	3.04E-02	2.39E-05	7.96E-05	2.31E-03	1.62E-04
S05051-05	1	3.41E-02	2.06E-05	8.46E-05	2.08E-03	1.56E-04
S05051-06	1	3.21E-02	2.46E-05	7.34E-05	2.05E-03	1.60E-04
S05051-06	2	n/a	n/a	n/a	n/a	n/a
S05051-07	1	1.41E-02	1.03E-05	4.15E-05	1.35E-03	6.45E-05
S05051-08	1	1.83E-02	1.39E-05	5.02E-05	1.35E-03	9.93E-05
S05051-09	1	4.70E-02	3.04E-05	1.21E-04	3.30E-03	2.26E-04
S05051-10	1	4.25E-02	3.36E-05	1.15E-04	3.58E-03	2.15E-04

Table 1. Pre-Filter Sample Results (continued)

Customer ID	Analysis	U238 ICP/MS Acid Add µg/sample	Cs137 GEA µCi/sample	Cs137 GEA µCi/sample		
S05051-01	1	1.50E-01	<6.14E-05	<6.14E-05		
S05051-01	2	1.57E-01	<6.24E-05	<6.24E-05		
S05051-02	1	2.46E-01	<6.39E-05	<6.39E-05		
S05051-03	1	1.36E-01	<6.39E-05	<6.39E-05		
S05051-04	1	1.92E-01	<6.51E-05	<6.51E-05		
S05051-05	1	1.71E-01	<6.35E-05	<6.35E-05		
S05051-06	1	1.76E-01	<6.35E-05	<6.35E-05		
S05051-06	2	n/a	n/a	n/a		
S05051-07	1	9.38E-02	<6.39E-05	<6.39E-05		
S05051-08	1	1.20E-01	<6.42E-05	<6.42E-05		
S05051-09	1	2.30E-01	<6.38E-05	<6.38E-05		
S05051-10	1	2.49E-01	<6.47E-05	<6.47E-05		

Table 2. HEPA Filter Sample Results

Customer ID	Analysis	Alpha Env Solid/Misc µCi/sample	Am-241 TRU-SPEC µCi/sample	Am-241 GEA µCi/sample	Beta in Env Samples µCi/sample	Pu239 ICP/MS µg/sample
S05051-11	1	2.54E-02	7.30E-03	7.99E-03	2.15E-03	1.80E-01
S05051-11	2	2.53E-02	7.98E-03	6.36E-03	2.51E-03	1.86E-01
S05051-12	1	1.68E-02	5.41E-03	5.96E-03	1.49E-03	1.16E-01
S05051-13	1	1.71E-02	5.55E-03	5.44E-03	1.49E-03	1.14E-01
S05051-14	1	2.20E-02	8.07E-03	6.28E-03	1.82E-03	1.80E-01
S05051-15	1	2.46E-02	7.89E-03	8.74E-03	2.06E-03	1.73E-01
S05051-16	1	2.28E-02	7.88E-03	7.86E-03	2.14E-03	1.75E-01
S05051-16	2	2.33E-02	n/a	n/a	2.19E-03	n/a
S05051-17	1	2.16E-02	7.04E-03	7.36E-03	2.19E-03	1.57E-01
S05051-18	1	1.74E-02	5.91E-03	5.52E-03	1.53E-03	1.28E-01
S05051-19	1	2.21E-02	7.90E-03	8.40E-03	1.93E-03	1.70E-01
S05051-20	1	1.85E-02	6.83E-03	6.58E-03	4.48E-03	1.42E-01

Customer ID	Analysis	Pu240 ICP/MS µg/sample	Pu244/Cm244 ICP/MS µg/sample	Pu/Am242 ICP/MS µg/sample	Pu/Am241 ICP/MS µg/sample	Pu238 TRU-SPEC µCi/sample
S05051-11	1	1.92E-02	<4.50E-05	5.54E-04	2.36E-03	<4.65E-03
S05051-11	2	1.96E-02	<2.50E-05	5.63E-04	2.47E-03	<3.56E-03
S05051-12	1	1.30E-02	<4.50E-05	4.56E-04	1.71E-03	<2.52E-03
S05051-13	1	1.28E-02	<4.50E-05	4.74E-04	1.58E-03	<2.68E-03
S05051-14	1	1.92E-02	<4.50E-05	6.20E-04	2.53E-03	<2.68E-03
S05051-15	1	1.85E-02	<4.50E-05	6.00E-04	2.41E-03	<3.15E-03
S05051-16	1	1.90E-02	<4.50E-05	6.50E-04	2.49E-03	<3.02E-03
S05051-16	2	n/a	n/a	n/a	n/a	n/a
S05051-17	1	1.73E-02	<4.50E-05	5.71E-04	2.26E-03	<4.49E-03
S05051-18	1	1.40E-02	<4.50E-05	4.74E-04	1.74E-03	<2.17E-03
S05051-19	1	1.84E-02	<4.50E-05	6.12E-04	2.40E-03	<2.15E-03
S05051-20	1	1.58E-02	<4.50E-05	5.26E-04	1.96E-03	<3.71E-03

Table 2. HEPA Filter Sample Results (continued)

Customer ID	Analysis	Pu239/240 TRU-SPEC µCi/sample	U233 ICP/MS Acid Add µg/sample	U234 ICP/MS Acid Add µg/sample	U235 ICP/MS Acid Add µg/sample	U236 ICP/MS Acid Add µg/sample
S05051-11	1	1.62E-02	<4.50e-05	3.70E-05	1.24E-03	6.50E-05
S05051-11	2	1.74E-02	<4.50e-05	3.70E-05	1.30E-03	8.55E-05
S05051-12	1	1.06E-02	<4.50e-05	3.80E-05	9.95E-04	5.90E-05
S05051-13	1	1.07E-02	<4.50e-05	2.20E-05	1.15E-03	5.50E-05
S05051-14	1	1.59E-02	<4.50e-05	4.25E-05	1.36E-03	6.55E-05
S05051-15	1	1.50E-02	<4.50e-05	3.15E-05	1.76E-03	6.90E-05
S05051-16	1	1.54E-02	<4.50e-05	5.45E-05	1.29E-03	7.10E-05
S05051-16	2	n/a	n/a	n/a	n/a	n/a
S05051-17	1	1.40E-02	<4.50e-05	4.95E-05	1.60E-03	6.20E-05
S05051-18	1	1.14E-02	<4.50e-05	2.70E-05	1.16E-03	6.15E-05
S05051-19	1	1.46E-02	<4.50e-05	3.70E-05	1.44E-03	7.45E-05
S05051-20	1	1.30E-02	<4.50e-05	5.30E-05	1.39E-03	6.75E-05

Customer ID	Analysis	U238 ICP/MS Acid Add µg/sample	Cs137 GEA µCi/sample	Sr89/90 Env. Misc µCi/sample		
S05051-11	1	1.04E-01	<3.95E-04	<4.93E-05		
S05051-11	2	1.07E-01	<3.56E-04	<3.18E-05		
S05051-12	1	8.68E-02	<3.71E-04	<3.20E-05		
S05051-13	1	8.30E-02	<3.87E-04	<5.07E-05		
S05051-14	1	1.30E-01	<3.72E-04	<5.50E-05		
S05051-15	1	1.22E-01	<3.87Ee-04	<3.77E-05		
S05051-16	1	1.08E-01	<3.44E-04	<3.32E-05		
S05051-16	2	n/a	n/a	n/a		
S05051-17	1	1.52E-01	<3.60E-04	<3.11E-05		
S05051-18	1	1.03E-01	<3.40E-04	<3.29E-05		
S05051-19	1	1.14E-01	<3.87E-04	<4.67E-05		
S05051-20	1	1.52E-01	<3.44E-04	<3.23E-05		

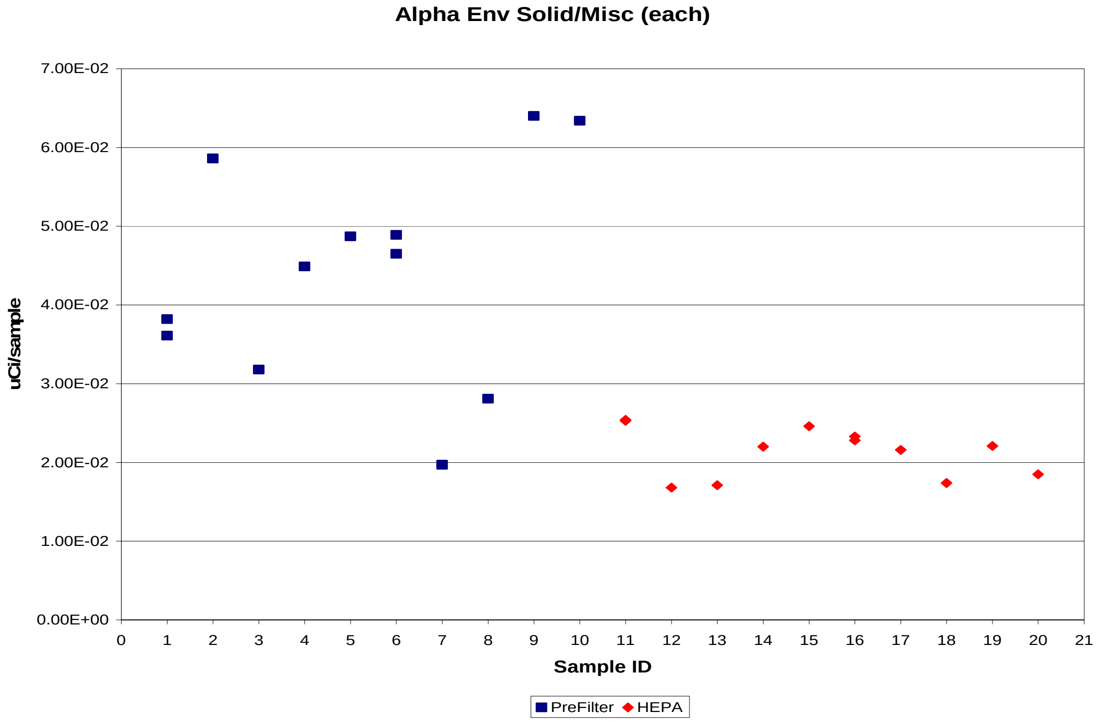

Figure 1. Total Alpha Analytical Results

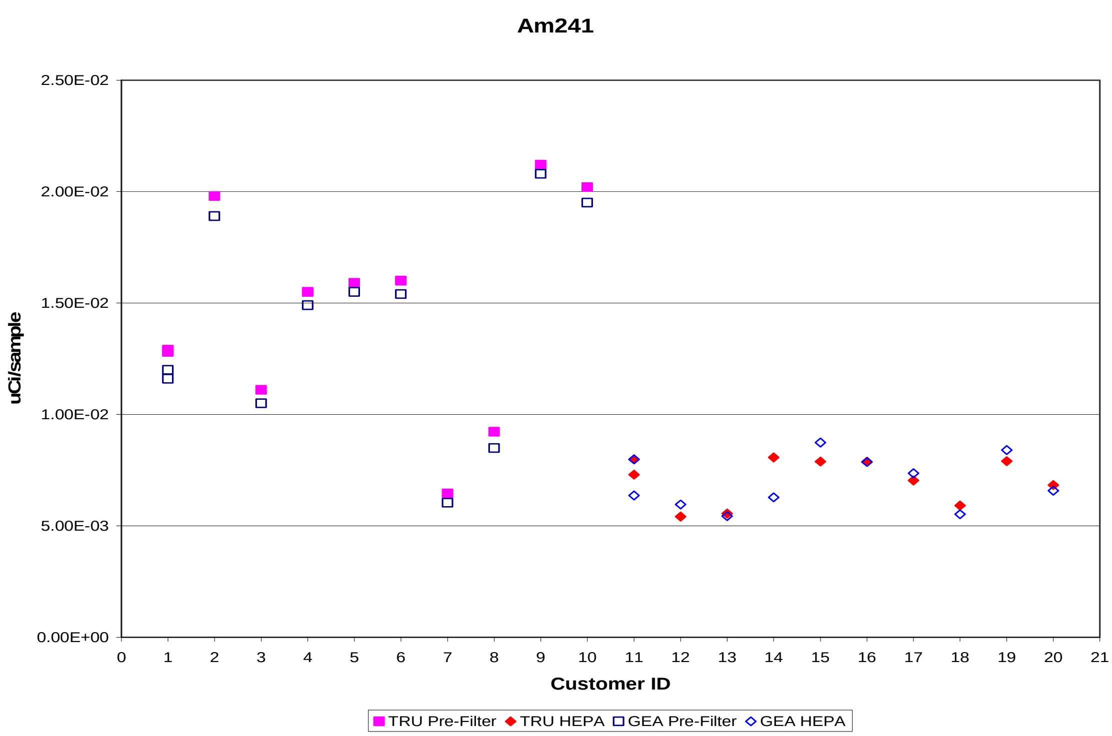

Figure 2. Americium 241 Analytical Results

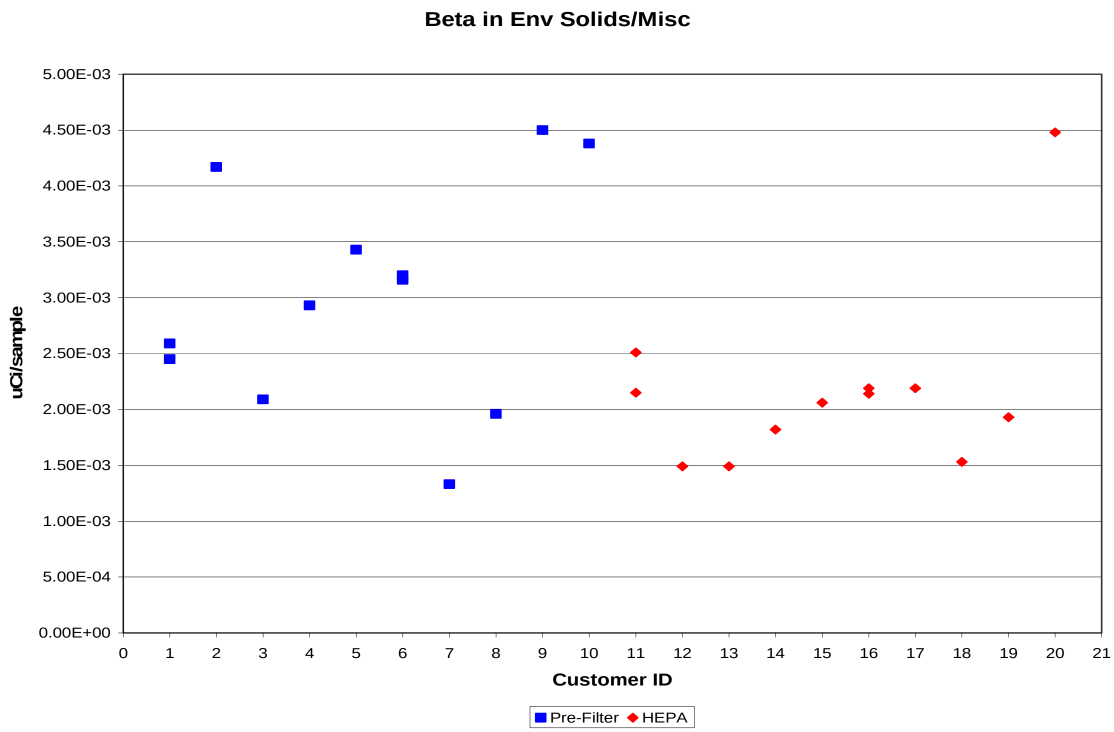

Figure 3. Total Beta Analytical Results

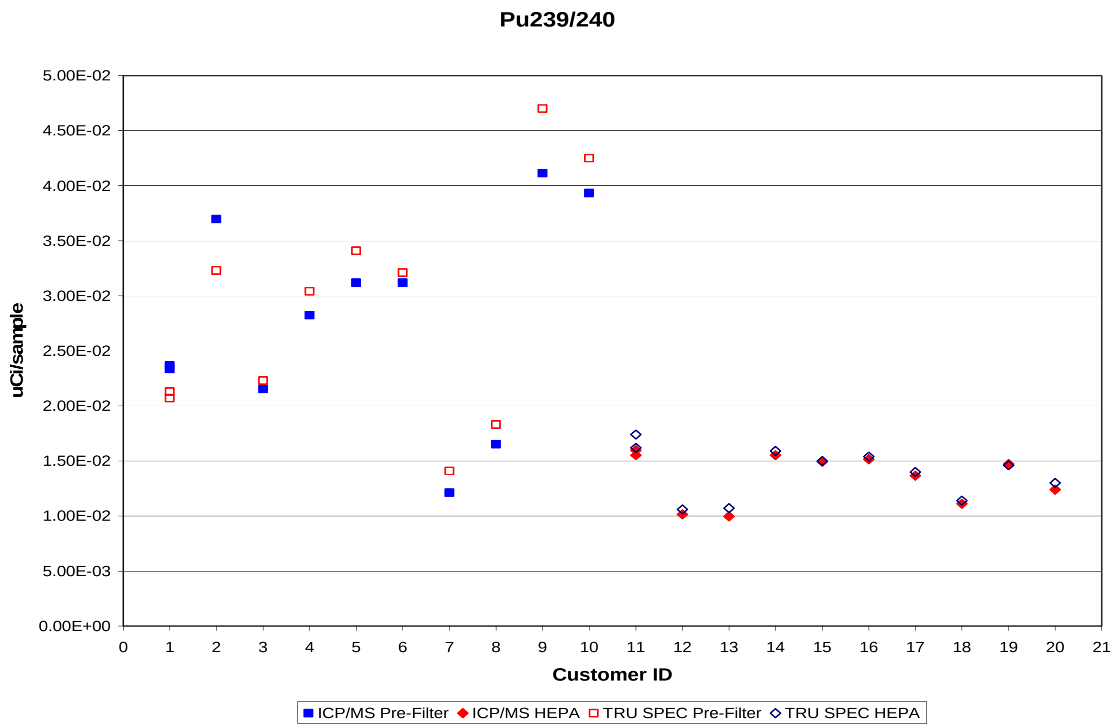

Figure 4. Plutonium-239/240 Analytical Results

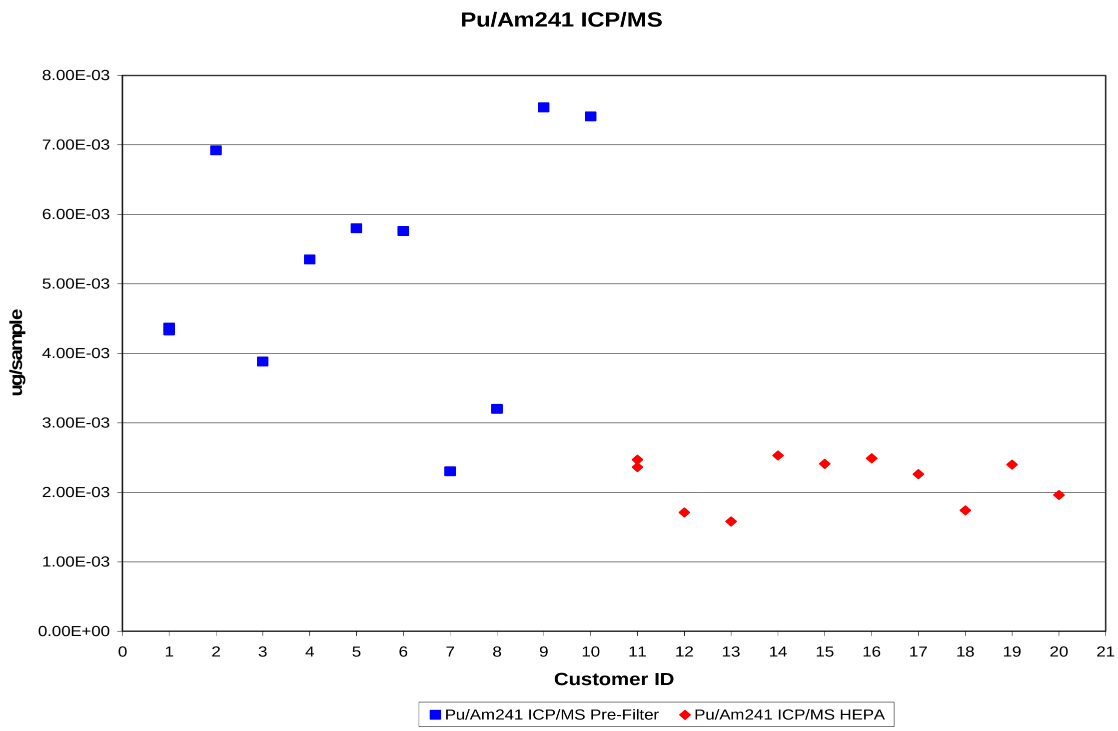

Figure 5. Plutonium/Americium-241 Analytical Results

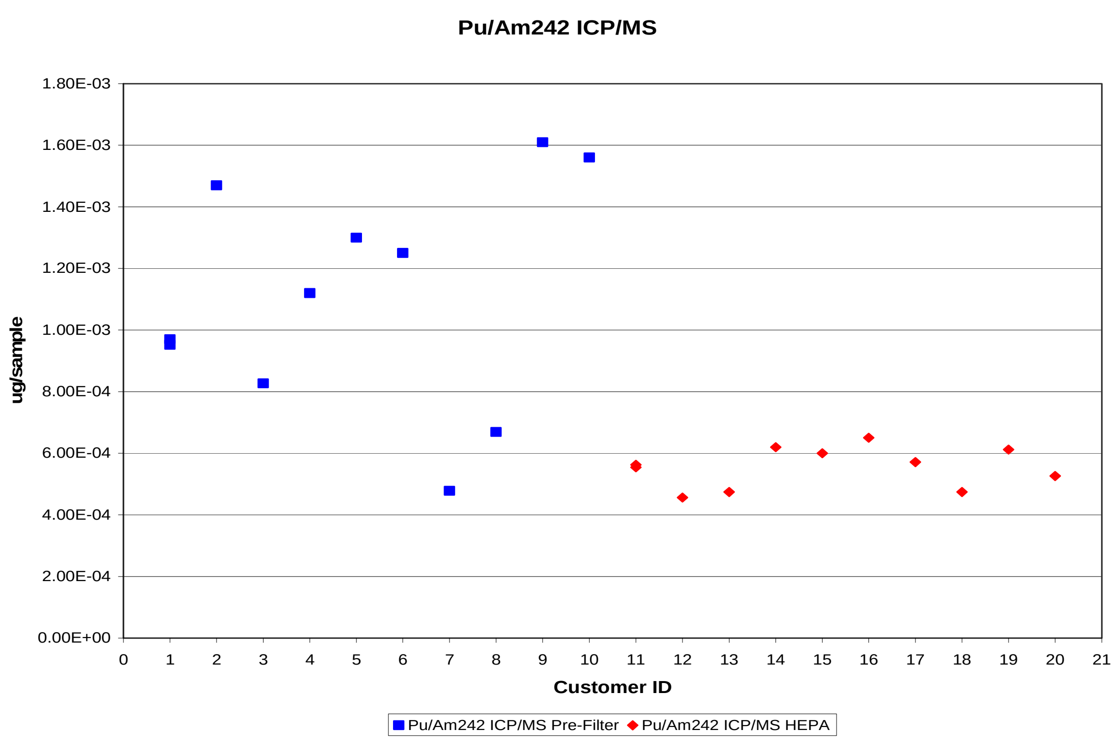

Figure 6. Plutonium/Americium-242 Analytical Results

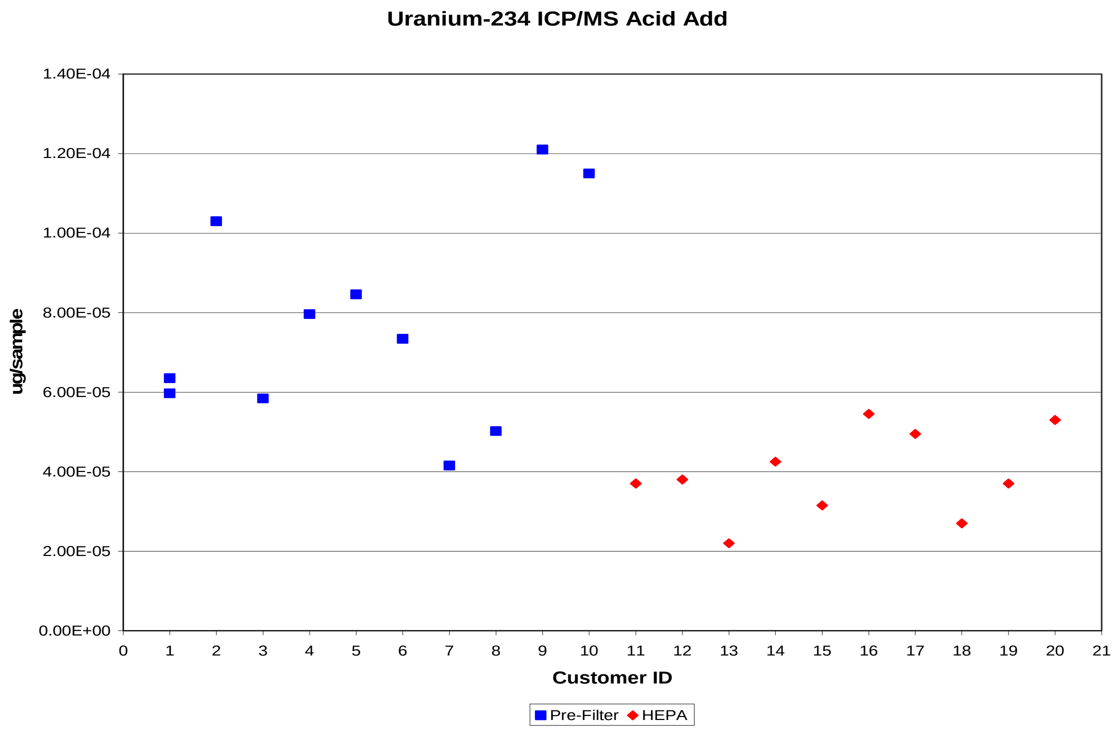

Figure 7. Uranium-234 Analytical Results

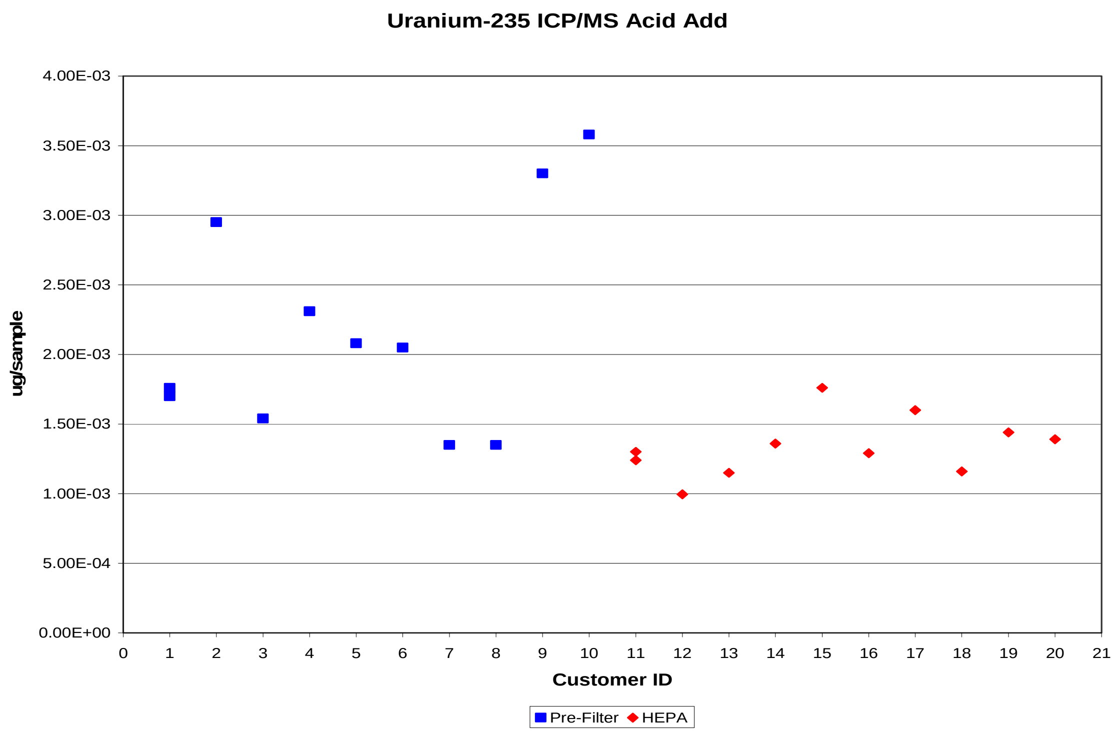

Figure 8. Uranium-235 Analytical Results

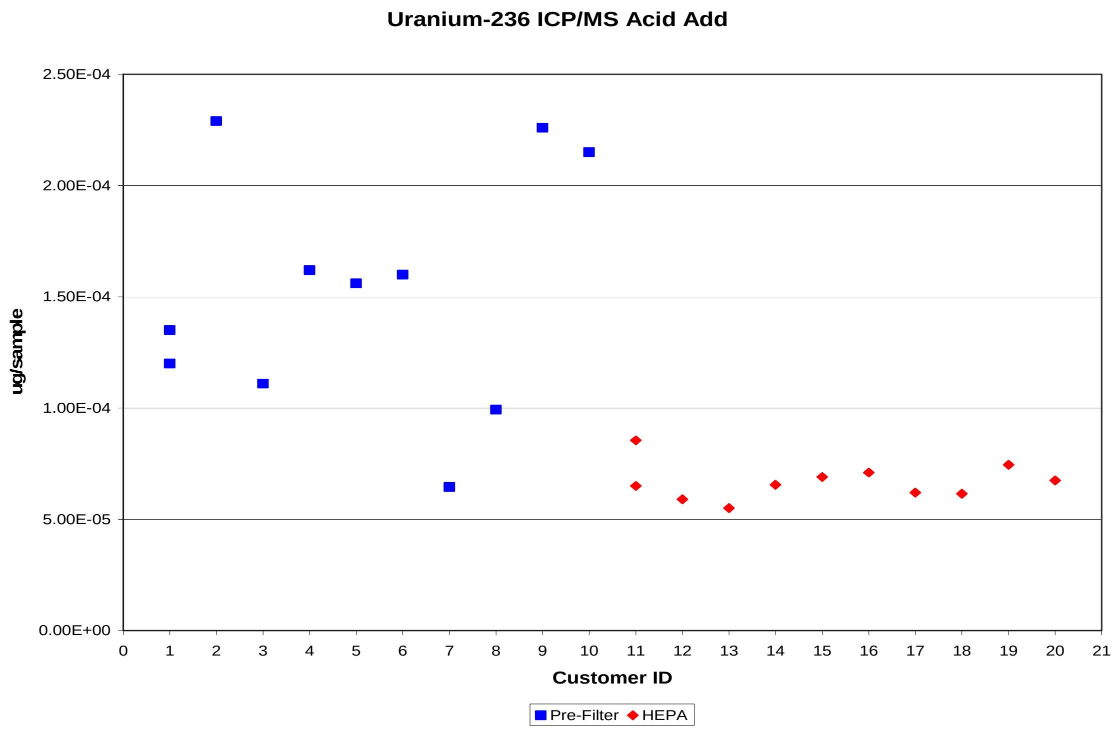

Figure 9. Uranium-236 Analytical Results

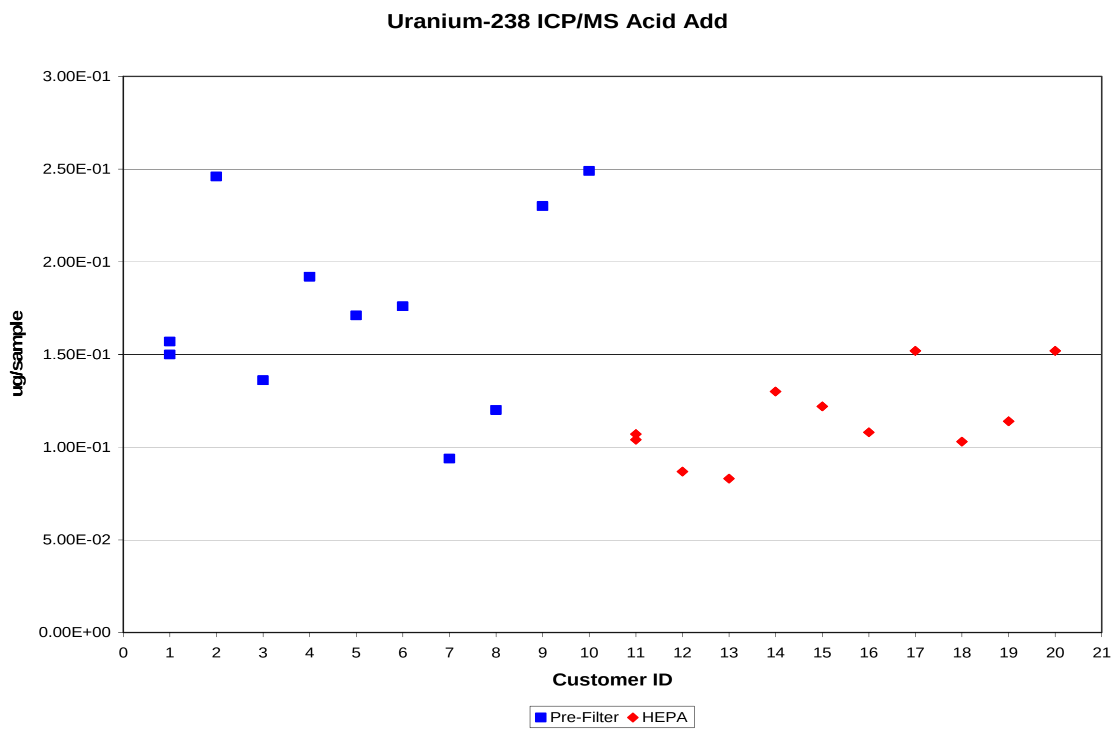

Figure 10. Uranium-238 Analytical Results

Table 3. Mean Concentrations and the Associated Variability

Analyte	Units	Mean Concentration		Random Uncertainty RSD associated with the mean (%)	
		Pre-Filter	HEPA Filter	Pre-Filter	HEPA Filter
Alpha Env: Solid/Misc (Each)	µCi/sample	4.44E-02	2.09E-02	10.8	4.8
Am-241 by TRU-SPEC Resin IonEx	µCi/sample	1.48E-02	7.01E-03	10.5	4.7
Americium-241 by GEA	µCi/sample	1.42E-02	6.93E-03	10.9	5.3
Beta in Env. Samples (Each)	µCi/sample	3.05E-03	2.15E-03	11.3	12.9
Cesium-137 by GEA	µCi/sample	<6.51E-05 [a]	<3.95E-04 [a]	NA	NA
Plutonium-239 by ICP/MS	µg/sample	3.26E-01	1.54E-01	10.9	5.5
Plutonium-240 by ICP/MS	µg/sample	3.50E-02	1.67E-02	10.9	5.0
Pu 244/Cm 244 by ICP/MS	µg/sample	2.54E-05	<4.50E-05 [a]	10.1	NA
Pu/Am 242 ICP/MS	µg/sample	1.12E-03	5.54E-04	10.8	3.9
Pu/Am-241 by ICP/MS	µg/sample	5.25E-03	2.15E-03	10.8	5.4
Pu-238 by TRU-SPEC Resin IonEx	µCi/sample	3.74E-03 [b]	<4.65E-03	8.5	NA
Pu-239/240 by TRU-SPEC Resin	µCi/sample	2.94E-02	1.37E-02	11.3	5.1
Pu239+Pu240 by ICP/MS by addition	µCi/sample	2.83E-02	1.34E-02	10.9	5.3
Sr-89/90 Env. Misc. (ea.)	µCi/sample	1.32E-04 [c]	<5.50E-05 [a]	45.0	NA
Uranium-233 by ICP/MS Acid Add	µg/sample	2.24E-05	<4.50E-05 [a]	10.4	NA
Uranium-234 by ICP/MS Acid Add	µg/sample	7.88E-05	3.92E-05	10.9	8.7
Uranium-235 by ICP/MS Acid Add	µg/sample	2.22E-03	1.34E-03	11.4	5.3
Uranium-236 by ICP/MS Acid Add	µg/sample	1.55E-04	6.60E-05	11.4	3.2
Uranium-238 by ICP/MS Acid Add	µg/sample	1.77E-01	1.16E-01	9.5	6.5

a the largest "less than" value
b "less than" values deleted from the statistical analysis
c only result that was not a "less than" value; RSD is from the counting statistics
NA not available with the stated data

Table 4. Pre-filter versus HEPA filter Mean Concentrations

Analyte	Units	Mean Concentration		HEPA mean/ Pre-filter mean	
		Pre-Filter	HEPA Filter	All Data	Exclude Total Beta
Alpha Env: Solid/Misc (Each)	µCi/sample	4.44E-02	2.09E-02	0.470	0.470
Am-241 by TRU-SPEC Resin IonEx	µCi/sample	1.48E-02	7.01E-03	0.473	0.473
Americium-241 by GEA	µCi/sample	1.42E-02	6.93E-03	0.489	0.489
Beta in Env. Samples (Each)	µCi/sample	3.05E-03	2.15E-03	0.705	---
Plutonium-239 by ICP/MS	µg/sample	3.26E-01	1.54E-01	0.471	0.471
Plutonium-240 by ICP/MS	µg/sample	3.50E-02	1.67E-02	0.478	0.478
Pu/Am 242 ICP/MS	µg/sample	1.12E-03	5.54E-04	0.493	0.493
Pu/Am-241 by ICP/MS	µg/sample	5.25E-03	2.15E-03	0.409	0.409
Pu-239/240 by TRU-SPEC Resin	µCi/sample	2.94E-02	1.37E-02	0.467	0.467
Pu239+Pu240 by ICP/MS by addition	µCi/sample	2.83E-02	1.34E-02	0.473	0.473
Uranium-234 by ICP/MS Acid Add	ug/sample	7.88E-05	3.92E-05	0.497	0.497
Uranium-235 by ICP/MS Acid Add	ug/sample	2.22E-03	1.34E-03	0.603	0.603
Uranium-236 by ICP/MS Acid Add	ug/sample	1.55E-04	6.60E-05	0.426	0.426
Uranium-238 by ICP/MS Acid Add	ug/sample	1.77E-01	1.16E-01	0.654	0.654
Mean				0.508	0.493
Standard Deviation				0.085	0.066
Standard Deviation of the Mean				0.023	0.018

Table 5. Final Mean Concentrations and the Associated Variability

		Mean Concentration		Random Uncertainty RSD associated with the mean (%)	
Analyte	Units	Pre-Filter	HEPA Filter	Pre-Filter	HEPA Filter
Alpha Env: Solid/Misc (Each)	µCi/sample	4.44E-02	2.09E-02	10.8	4.8
Am-241 by TRU-SPEC Resin IonEx	µCi/sample	1.48E-02	7.01E-03	10.5	4.7
Americium-241 by GEA	µCi/sample	1.42E-02	6.93E-03	10.9	5.3
Beta in Env. Samples (Each)	µCi/sample	3.05E-03	2.15E-03	11.3	12.9
Cesium-137 by GEA	µCi/sample	6.51E-05 [a]	3.26E-05 [b]	50.0 [c]	50.2
Plutonium-239 by ICP/MS	µg/sample	3.26E-01	1.54E-01	10.9	5.5
Plutonium-240 by ICP/MS	µg/sample	3.50E-02	1.67E-02	10.9	5.0
Pu 244/Cm 244 by ICP/MS	µg/sample	2.54E-05	1.27E-05 [b]	10.1	11.0
Pu/Am 242 ICP/MS	µg/sample	1.12E-03	5.54E-04	10.8	3.9
Pu/Am-241 by ICP/MS	µg/sample	5.25E-03	2.15E-03	10.8	5.4
Pu-238 by TRU-SPEC Resin IonEx	µCi/sample	3.74E-03 [d]	1.87E-03 [b]	8.5	9.6
Pu-239/240 by TRU-SPEC Resin	µCi/sample	2.94E-02	1.37E-02	11.3	5.1
Pu239+Pu240 by ICP/MS by addition	µCi/sample	2.83E-02	1.34E-02	10.9	5.3
Sr-89/90 Env. Misc. (ea.)	µCi/sample	1.32E-04 [e]	6.60E-05 [b]	45.0	45.2
Uranium-233 by ICP/MS Acid Add	µg/sample	2.24E-05	1.12E-05 [b]	10.4	11.3
Uranium-234 by ICP/MS Acid Add	µg/sample	7.88E-05	3.92E-05	10.9	8.7
Uranium-235 by ICP/MS Acid Add	µg/sample	2.22E-03	1.34E-03	11.4	5.3
Uranium-236 by ICP/MS Acid Add	µg/sample	1.55E-04	6.60E-05	11.4	3.2
Uranium-238 by ICP/MS Acid Add	µg/sample	1.77E-01	1.16E-01	9.5	6.5

a the upper value of the largest “less than” (e.g., 6.51E-05 for <6.51E-05)
b assumes 50% of the Pre-filter result
c assumption; the less than implies that the result could be anywhere below the stated number. using 50% as 1 RSD and 100% as 2 RSD allows the result to be as low as zero
d “less than” values were deleted from the statistical analysis (6 samples instead of 10)
e only result that was not a “less than” value; RSD is from the counting statistics

Table 6. Systematic and Total Measurement Uncertainty Estimates

Analyte	Systematic Uncertainty	Total Measurement Uncertainty associated with the mean (%)	
		Pre-Filter	HEPA Filter
Alpha Env: Solid/Misc (Each)	8	13.4	9.3
Am-241 by TRU-SPEC Resin IonEx	9	13.8	10.2
Americium-241 by GEA	8	13.5	9.6
Beta in Env. Samples (Each)	9	14.4	15.7
Cesium-137 by GEA	8	50.6 [a]	50.8
Plutonium-239 by ICP/MS	3	11.3	6.3
Plutonium-240 by ICP/MS	3	11.3	5.8
Pu 244/Cm 244 by ICP/MS	3	10.5	11.4
Pu/Am 242 ICP/MS	3	11.2	4.9
Pu/Am-241 by ICP/MS	9	14.0	10.5
Pu-238 by TRU-SPEC Resin IonEx	7	11.0	11.9
Pu-239/240 by TRU-SPEC Resin	7	13.3	8.7
Pu239+Pu240 by ICP/MS by addition	3	11.3	6.1
Sr-89/90 Env. Misc. (ea.)	5	45.3	45.5
Uranium-233 by ICP/MS Acid Add	14	17.4	18.0
Uranium-234 by ICP/MS Acid Add	14	17.8	16.5
Uranium-235 by ICP/MS Acid Add	14	18.1	15.0
Uranium-236 by ICP/MS Acid Add	14	18.1	14.4
Uranium-238 by ICP/MS Acid Add	8	12.4	10.3

a assumes a random uncertainty of 50%

b “less than” values were deleted from the statistical analysis (6 samples instead of 10)

c only result that was not a “less than” value; RSD is from the counting statistics

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