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September 2000

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Source Characterization For Sewage Sludge Incinerators

Data Quality Assessment Report

Metropolitan Sewer District (MSD)
Mill Creek Wastewater Treatment Plant
Cincinnati, Ohio

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SOURCE CHARACTERIZATION FOR SEWAGE SLUDGE INCINERATORS

DATA QUALITY ASSESSMENT REPORT

METROPOLITAN SEWER DISTRICT (MSD)
MILL CREEK WASTERWATER TREATMENT PLANT
CINCINNATI, OHIO

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Office of Air and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

September 2000

EXECUTIVE SUMMARY

The Clean Air Act Amendments of 1990 required the U.S. Environmental Protection Agency's (EPA) Office of Air Quality Planning and Standards to establish standards of performance for sewage sludge incineration. While some emission data exist for sewage sludge incinerators, data on toxic polychlorinated biphenyls from sewage sludge incinerators are very limited. The document Final Emissions Report: Source Characterization for Sewage Sludge Incinerators summarized testing of a multiple hearth incinerator at the Metropolitan Sewer District Mill Creek Wastewater Treatment Plant in Cincinnati, Ohio in July 1999.

This document presents the results of a Data Quality Assessment of the incinerator emissions data (toxic polychlorinated biphenyls (PCB), dioxins/furans (D/F), polyaromatic hydrocarbons (PAHs), as well as CO, CO_2, O_2, and total hydrocarbons (THC) continuous emissions monitoring data). Specifically considered was the question "Were data generated from the fourth test run a statistical outlier?" *Here, we concluded that Run 4 was a statistical outlier if the Run 4 concentration of the measured analytes was significantly different from the average of the Run 2 and 3 concentrations.* Of the four test runs conducted, the first was aborted and the fourth resulted in generally lower emission concentrations than the second and third runs.

Analysis of variance statistical models were utilized to test the hypothesis that the fourth run was a statistical outlier. The results of the DQA were as follows:

- For all tested parameters except CO_2 and O_2, the fourth run was a statistical outlier ($p < 0.05$), and
- For CO_2 and O_2, the fourth run was not a statistical outlier ($p \geq 0.05$).

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1.0 INTRODUCTION

1.1 Summary of Test Program

The Clean Air Act Amendments of 1990 required the U.S. Environmental Protection Agency's (EPA) Office of Air Quality Planning and Standards to establish standards of performance for sewage sludge incineration. These standards are necessary to protect public health and the environment from any adverse effects of pollutant emissions from sewage sludge incineration. The regulations will contain general regulatory requirements, pollutant characterization, and emission limits. To assess control technologies as well as associated strategies for cost-effective standards, the EPA requires data on emissions from sewage sludge incinerators. While some emission data exist for sewage sludge incinerators, data on toxic polychlorinated biphenyls from sewage sludge incinerators are very limited.

The document Final Emissions Report: Source Characterization for Sewage Sludge Incinerators summarized testing of a multiple hearth incinerator at the Metropolitan Sewer District Mill Creek Wastewater Treatment Plant in Cincinnati, Ohio in July 1999.

1.2 Summary of the Data Quality Assessment (DQA)

The purpose of the test program was the measurement of mean concentrations of pollutants in incinerator emissions, sewage sludge, and scrubber water. In the following, the three test runs are referred to as Runs 2, 3, and 4 (the first run was aborted). As described in the Emissions Test Report, the air emissions measurements during the final test run tended to be lower than those for the previous two runs. This DQA report seeks to statistically answer the question "Was Run 4 a statistical outlier?" by formally testing if the Run 4 air emissions measurements were statistically significantly different from the Run 2 and 3 air emissions measurements for the following compounds: toxic polychlorinated biphenyls (PCBs), dioxins/furans (D/F), and polyaromatic hydrocarbons (PAHs). A total of 165 compounds were tested. Additionally, differences between runs for continuous emissions monitoring (CEM) data (CO, CO_2, O_2, and total hydrocarbons (THC)) were statistically tested.

Note that there is no one definition of an outlier. Various methods may be devised to test this question under diverse definitions. *Here, we will conclude that Run 4 was a statistical outlier if the Run 4 concentration of the measured analytes was significantly different from the average of the Run 2 and 3 concentrations.*

1.3 Description of Report Sections

Section 2.0 of this report provides a preliminary review of the air emissions measurements from the three runs, including plots of the continuous emissions monitoring measurements for carbon monoxide, carbon dioxide, oxygen, and total hydrocarbons. Section 3.0 describes the statistical methodology used to formally answer the question "Was Run 4 a statistical outlier?" and checks the assumptions required for the statistical tests to be valid. Section 4.0 presents the results of the data analysis. An Appendix provides supplementary information regarding sample size requirements for future data collection efforts which use the same data collection methods as the present test program.

2.0 PRELIMINARY DATA REVIEW

The data used to answer the question of whether or not Run 4 was a statistical outlier consisted of stack air emission pollutants including PCBs, D/Fs and PAHs, as well as CEM data. Raw data listings of the stack air emissions pollutant measurements were provided in the Emissions Test Report. Measurements for different compounds varied by orders of magnitude; thus, summarization of the measurements across compounds required some form of standardization. Within each compound, the mean and standard deviation of the measurements were computed across Runs 2, 3 and 4. For each run, a standardized value was calculated by subtracting the compound mean from the measurement and then dividing the result by the compound standard deviation. If all the runs were similar, then the standardized values would have been centered around zero. Figure 2-1 illustrates the distributions of the standardized run measurements across 165 PCB, D/F, and PAH compounds.

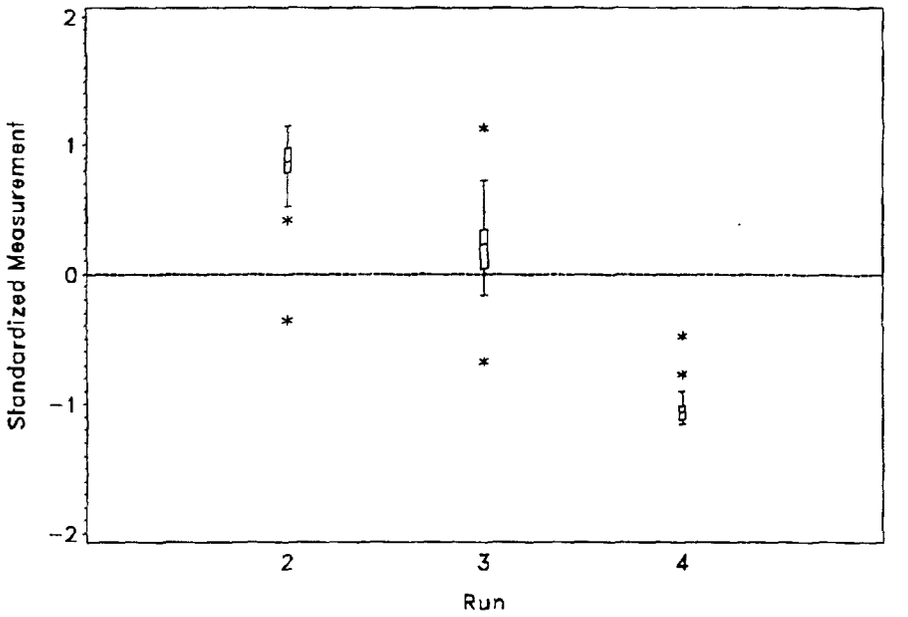

Figure 2-1. Boxplots of Standardized PCB, D/F and PAH Measurements by Run (see page 3 for description of boxes)

The boxplots indicate the following for each run:

- The locations of the 25th and 75th percentiles (lower and upper lines of the box).
- The median (middle line in the box).
- The most extreme values within 1.5 × the inter-quartile range[1] of the box (the ends of the solid lines extending from the box).
- Individual values that are most extreme (represented by asterisk stars).
- The horizontal dashed line at zero indicates where the median would lie if the measurements from the three runs were all coming from the same underlying distribution, that is, if there were no systematic differences between runs.

Another method used to descriptively summarize the difference between Run 4 and the previous two runs was as follows. Within each compound, a mean and standard deviation were computed from Runs 2 and 3 only, and the number of standard deviations that the Run 4

[1] The inter-quartile range is defined as the difference between the 75th and 25th percentiles.

measurements fell below this mean was calculated. Table 2-1 presents the frequency of compounds for which the Run 4 measurement was 1, 2, 3 or 4 standard deviations below the mean of Runs 2 and 3. For almost every compound, the Run 4 measurement was at least one standard deviation below the mean of the Run 2 and 3 measurements. For almost a third of the compounds, the Run 4 measurement was at least *four standard deviations* below the Run 2 and 3 mean.

Table 2-1. Percentage of Compounds for Which Run 4 was 1 to 4 Standard Deviations Below the Run 2 and 3 Mean

Standard Deviations	Percentage
1	98.18%
2	85.45%
3	49.09%
4	32.73%

For PCB measurements in particular, lower Run 4 emission concentrations may be attributable to low pre-sampling surrogate recovery in Run 4. After correcting for this, the Run 4 PCB measurements were larger. Figures 2-2 and 2-3 illustrate the standardized PCB measurements for each run, for the uncorrected and corrected measurements, respectively. The uncorrected measurements (Figure 2-2) consistently decreased over the three runs. After correction of the data (Figure 2-3), the run measurements are closer together, but still appear to have a decreasing trend. Table 2-2 provides the percentage of Run 4 PCB measurements that are from 1 to 4 standard deviations from the Run 2 and 3 distributions, for the uncorrected and the corrected data. Again, while correcting for low pre-sampling surrogate recovery reduces the differences between runs, they still seem to be different. This will be formally tested in Section 4.0 of this report.

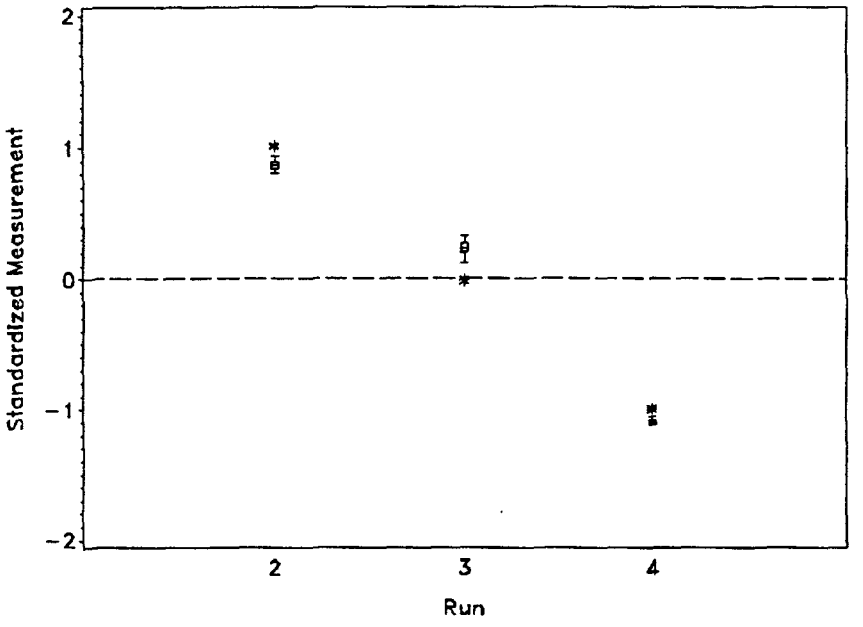

Figure 2-2. Boxplots of Standardized PCB Measurements (Uncorrected for Pre-sampling Surrogate Recovery) (see page 3 for description of boxes)

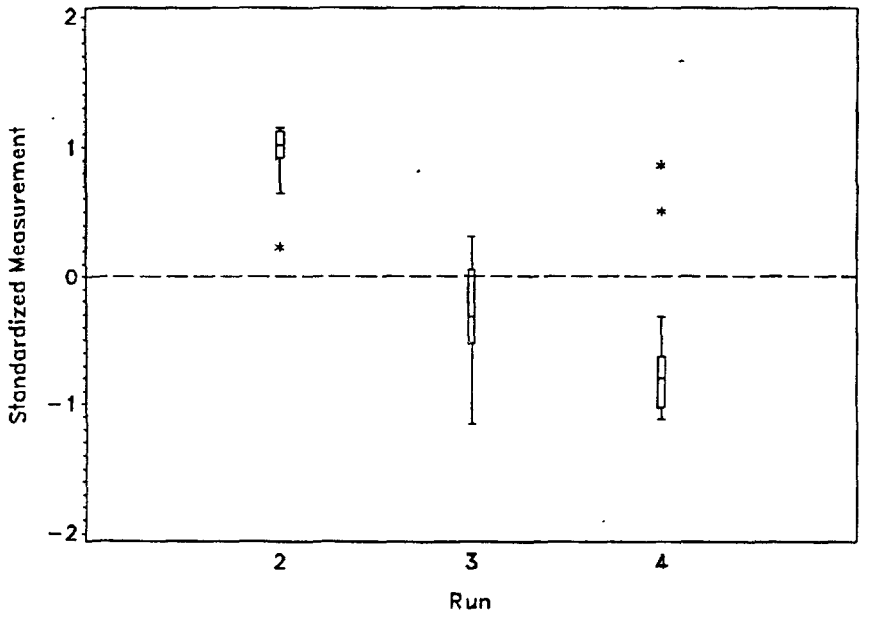

Figure 2-3. Boxplots of Standardized PCB Measurements (Corrected for Pre-sampling Surrogate Recovery) (see page 3 for description of boxes)

Table 2-2. PCB Measurements Only: Percentage of Compounds for Which Run 4 Was 1 to 4 Standard Deviations Below the Run 2 and 3 Distributions

	Percentage	
Standard Deviations	Uncorrected	Corrected
1	100.00%	84.62%
2	100.00%	61.54%
3	76.92%	30.77%
4	30.77%	15.38%

The PCB, D/F, and PAH data were composited over each day. Continuous measurements were also taken which provide additional insight into the differences among the three runs. Figures 2-4 through 2-7 graph the concentrations of CO, CO_2, O_2 and THC, respectively, during Runs 2, 3, and 4. As mentioned in the Emissions Test Report in Section 4.4 of the Final Emission Report, "at approximately 11:45 a.m. on Wednesday, July 21, 1999 (Run 3), the upper hearths (2, 3, 4) of incinerator 6 overheated. This caused premature burning and generation of excess THC emissions. The instantaneous THC concentration hit a peak of 228 ppm. The operator reduced the rate of recycling of shaft cooling air to the lower hearths to remove some heat from the incinerator. This procedure reestablished control within a few minutes. This was the only process disruption of any sort during any of the test runs." Similar spikes in CO, CO_2, and O_2 concentrations may be seen in Figures 2-4 through 2-6.

Table 2-3 provides some information regarding the size of the spikes around noon during Run 3. For CO and CO_2, the observed concentrations just after noon during Run 3 were 21% and 23% larger, respectively, than the Run 3 maximum morning measurement, and 63% and 19% larger, respectively, than the Run 3 maximum afternoon measurement. For O_2, the observed concentration just after noon during Run 3, was 16% smaller than each of the Run 3 morning and afternoon minimum measurements.

Table 2-3. Spikes in CEM Measurements During Run 3

Measurement	Morning Range	Noon Spike	Afternoon Range
CO	949 to1714 ppm_{dv}	2074 ppm_{dv}	898 to 1275 ppm_{dv}
CO_2	4.18 to 6.74% v	8.26% v	4.91 to 6.94% v
O_2	11.28 to 15.03% v	9.49% v	11.25 to 13.6% v

For THC, the concentration levels following the overheating incident dropped off dramatically (see Figure 2-7) from their Run 2 and pre-Noon Run 3 levels and remained lower throughout Run 4. This result is consistent with the observed PCB, D/F, and PAH air measurements, in which Run 2 tended to have the highest levels, Run 4 tended to have the lowest levels, and Run 3 was in-between.

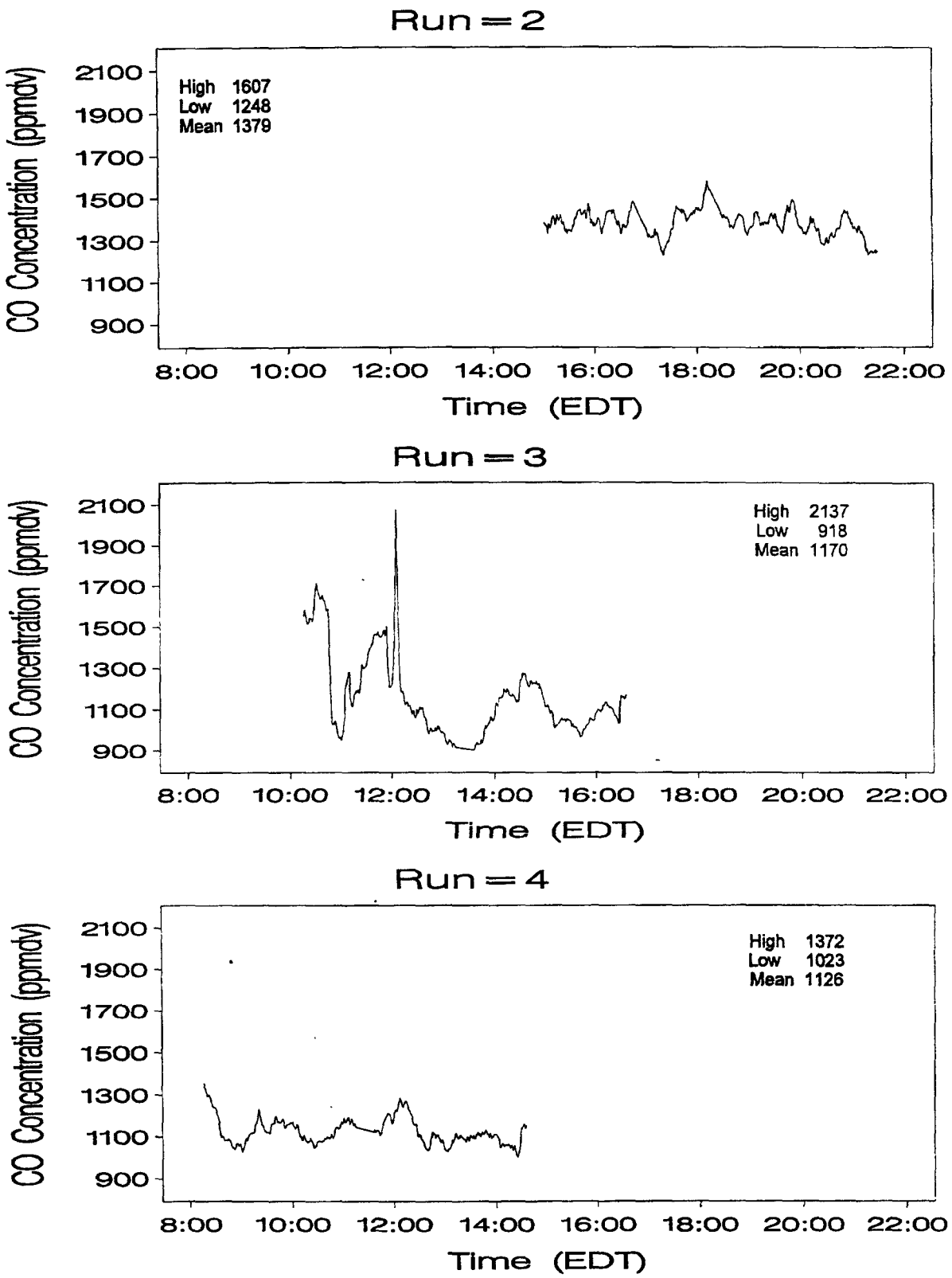

Figure 2-4. Continuous Emissions Monitoring: Carbon Monoxide

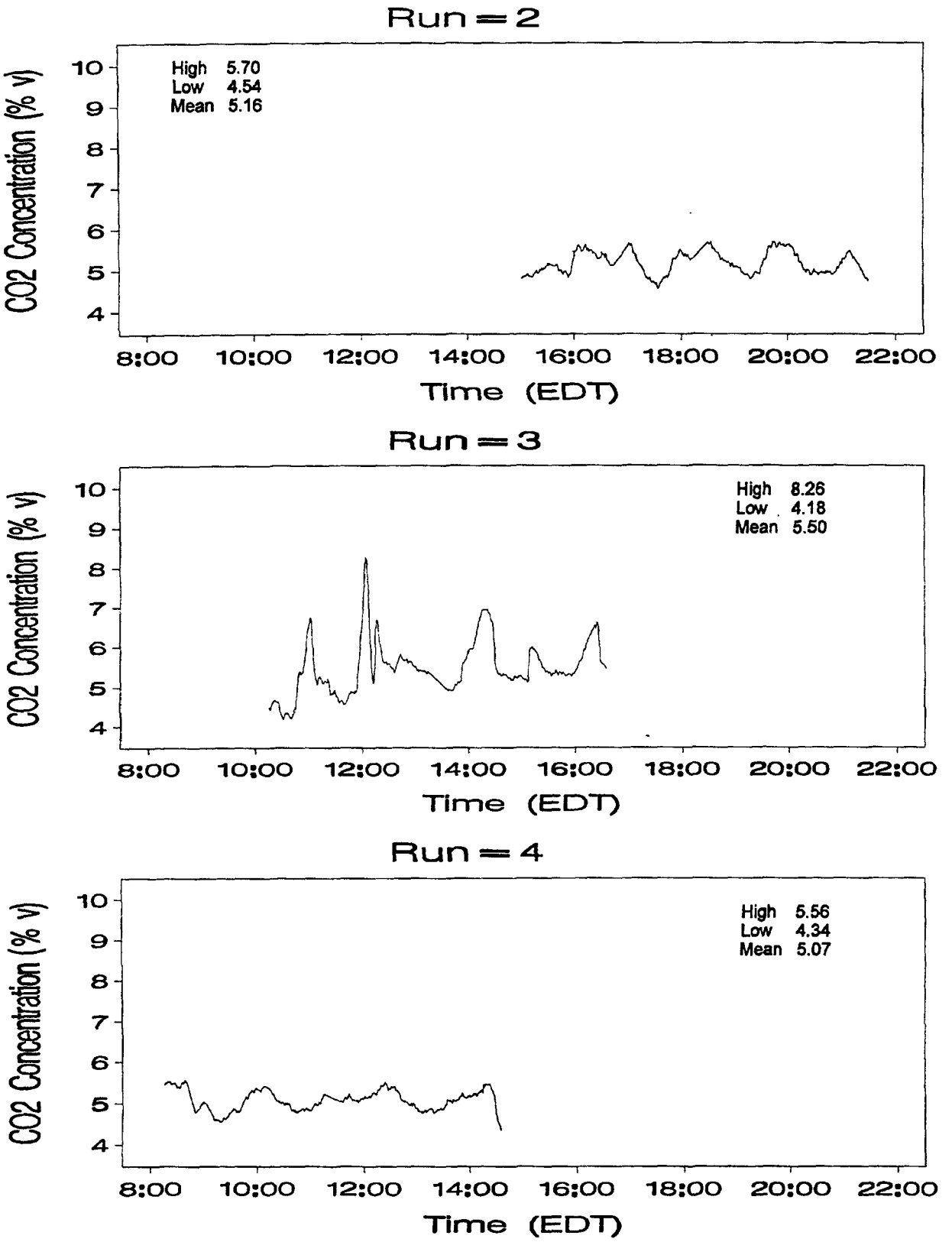

Figure 2-5. Continuous Emissions Monitoring: Carbon Dioxide

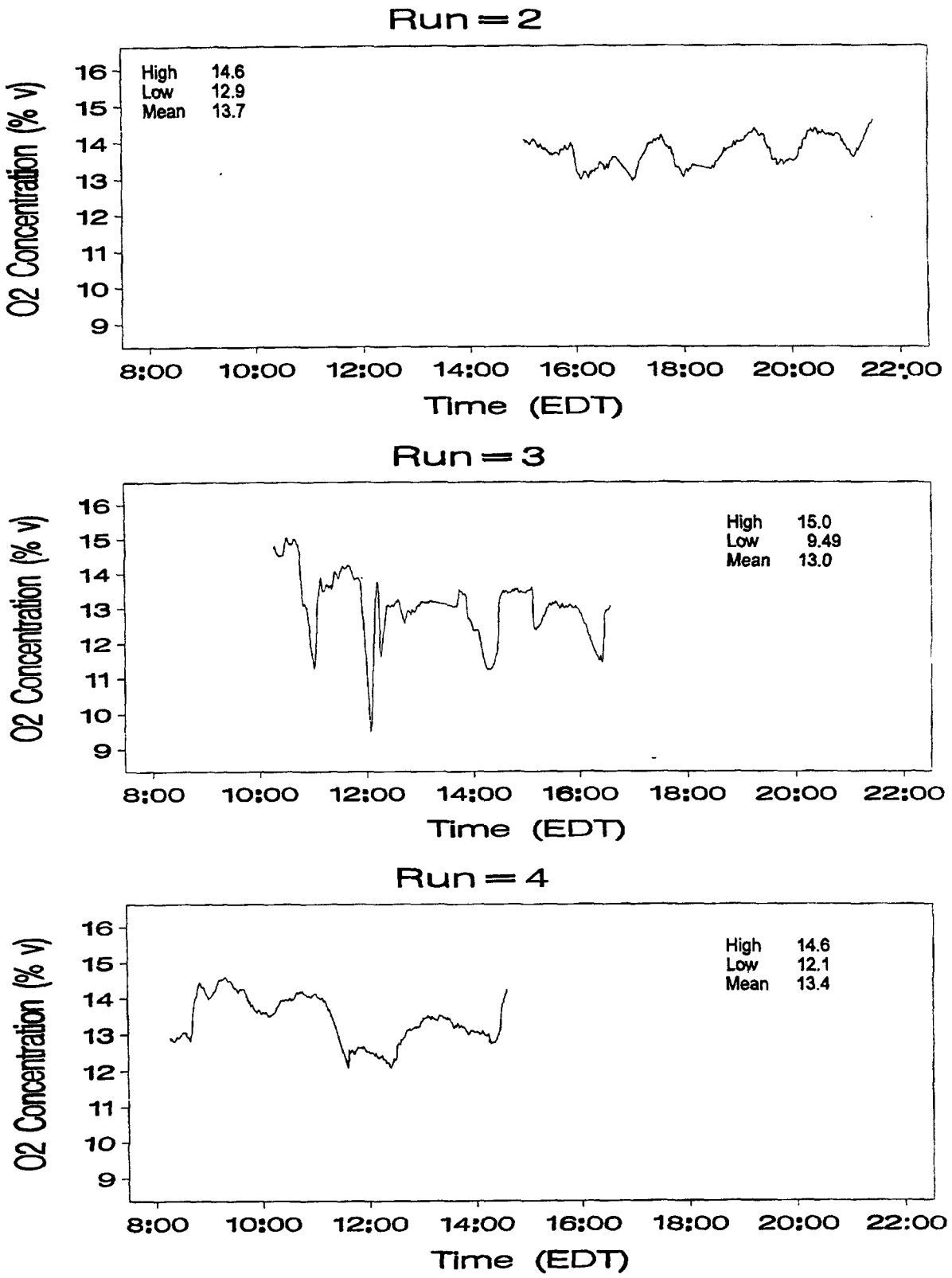

Figure 2-6. Continuous Emissions Monitoring: Oxygen

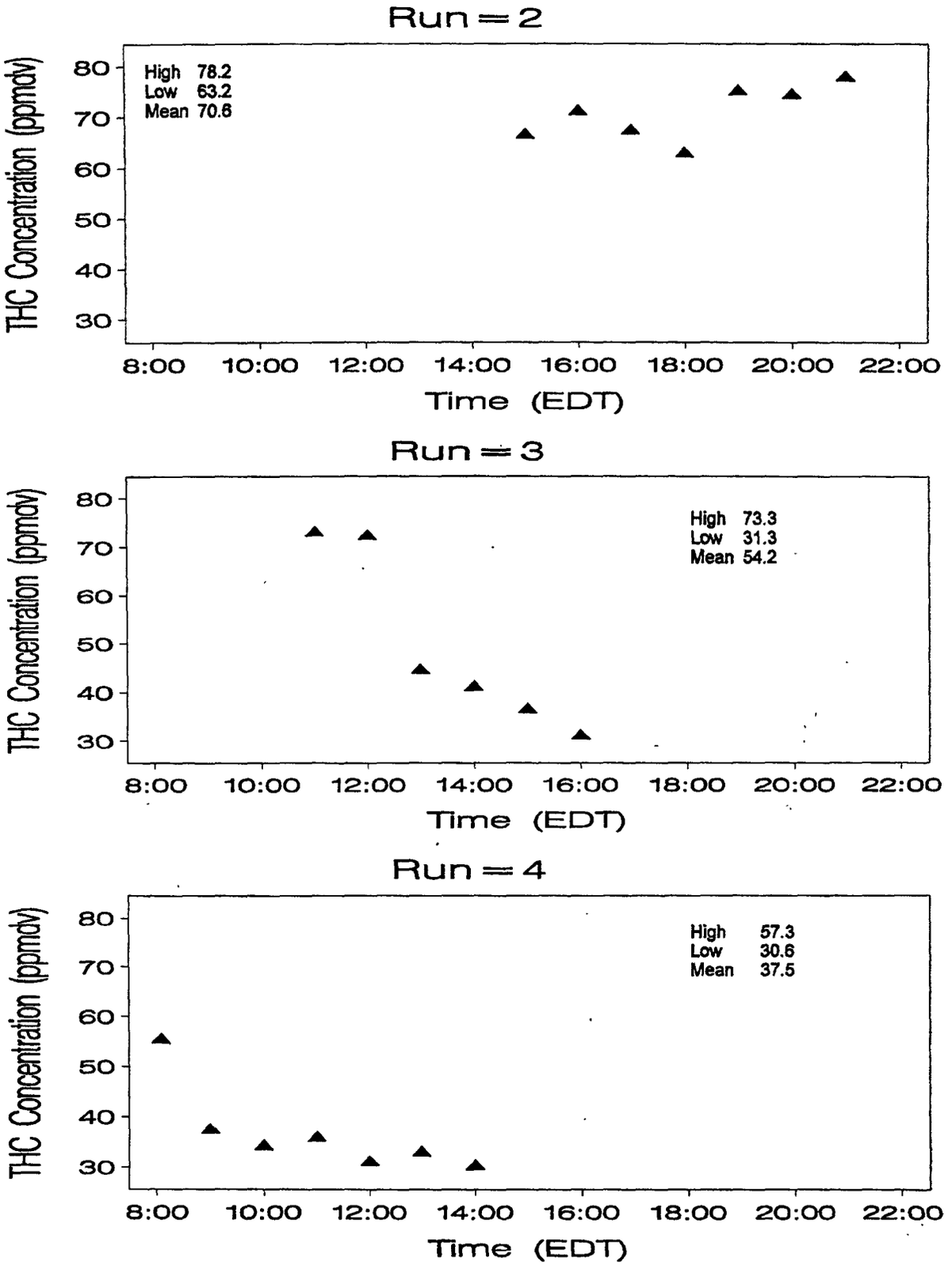

Figure 2-7. Continuous Emissions Monitoring: Total Hydrocarbons

3.0 STATISTICAL METHODOLOGY

The determination of whether or not Run 4 was a statistical outlier was formally tested using an analysis of variance (ANOVA) of the standardized stack air emission PCB, D/F and PAH data, as well as of the CEM data. Additionally, analyses were performed using each of the uncorrected and corrected PCB data as described in Section 2.0.

The ANOVA model used for the PCB, D/F and PAH analyses was

$$z_{ij} = \alpha_i + \varepsilon_{ij} \qquad (1)$$

where z_{ij} is the standardized measurement for the ith run and the jth compound, α_i is the mean for the ith run, and ε_{ij} is the error term. The error terms are assumed to be independent across compounds and normally distributed within each run.

As mentioned in Section 1.2, it was concluded that Run 4 was a statistical outlier provided the mean concentration of the measured analytes was significantly different than the average of the Run 2 and Run 3 mean concentrations. That is, the null hypothesis H_0: $(\alpha_2 + \alpha_3)/2 = \alpha_4$ was tested versus the alternative hypothesis H_1: $(\alpha_2 + \alpha_3)/2 \neq \alpha_4$. According to our definition of a statistical outlier, these hypotheses were equivalent to H_0: *Run 4 was not a statistical outlier* and H_1: *Run 4 was a statistical outlier.*

Residuals from the model may be used to visually inspect the normality assumption for the errors. Figures 3-1 to 3-3 present boxplots of the residuals from the fitted ANOVA models for the PCB, D/F and PAH analysis and for the uncorrected and corrected PCB analyses. The residuals appeared to be approximately normally distributed, despite the presence of a few outliers. Formal tests of the normality hypothesis were conducted using the SAS UNIVARIATE procedure. These tests supported the normality assumption for all three runs. For the corrected PCB analysis, however, the formal test of normality did not support the normality assumption for the Run 3 residuals. However, as shown in Figure 3-3, the departure from normality was not drastic. Thus, the results presented in Section 4.0 for the corrected PCB analysis may still be considered valid for the sample size evaluated. These ANOVA tests were performed using the SAS GLM procedure.

The model fit to the CEM data was identical to model (1) other than the fact that the error terms were not assumed to be independent. Due to the high levels of correlation typically found between time series observations close in time, the CEM data required a modified ANOVA approach which accounted for the non-independence of the errors. First, for each of the CO, CO_2 and O_2 parameters, observations within the same run were assumed to be correlated. Observations j minutes apart within the same run were assumed to have a correlation of ρ^j. The correlation structure was allowed to vary between runs with observations from different runs assumed to be independent. For THC, this model was too complex for the few hourly observations available during the 6-hour sampling period. A more simplified model was used in which observations one hour apart were assumed to have a common correlation, again varying by run. These ANOVA tests were carried out using the SAS MIXED procedure.

Formal tests for normality of the CEM analyses residuals (as shown in Figures 3-4 to 3-7) all support the hypothesis of normality, with the possible exception of the THC residuals (With only six or seven THC observations per run, the test for normality is inconclusive.)

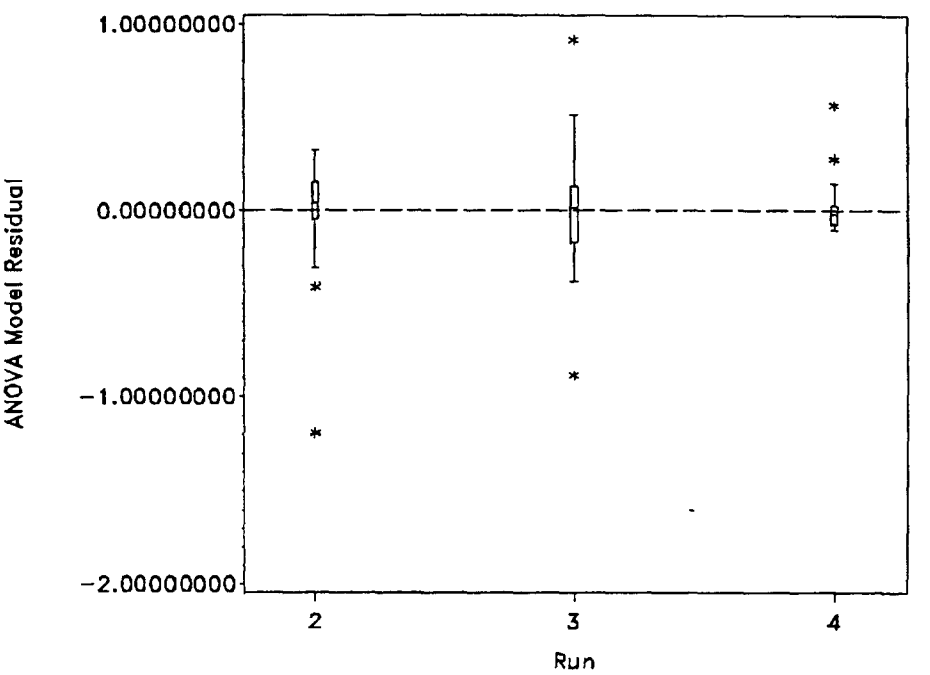

Figure 3-1. Boxplots of ANOVA Model Residuals from PCB, D/F and PAH Analysis (see p.3 for description of boxes)

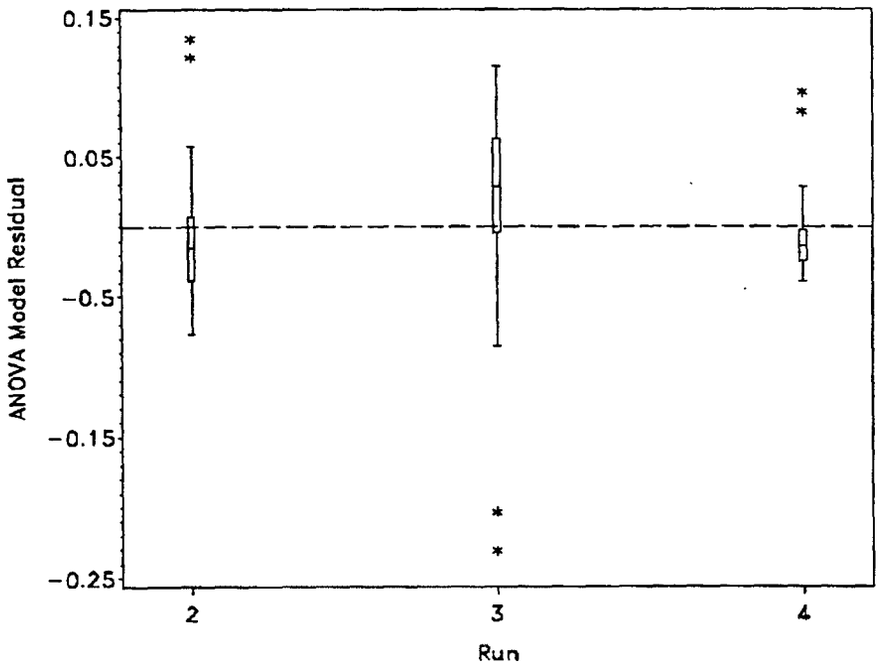

Figure 3-2. Boxplots of ANOVA Model Residuals from Uncorrected PCB Analysis (see page 3 for description of boxes)

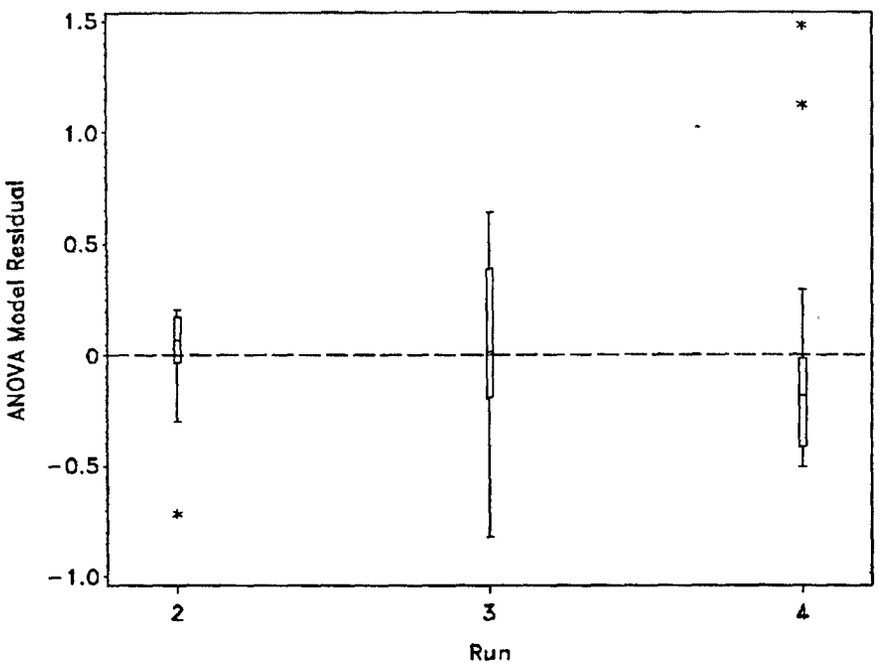

Figure 3-3. Boxplots of ANOVA Model Residuals from Corrected PCB Analysis (see page 3 for description of boxes)

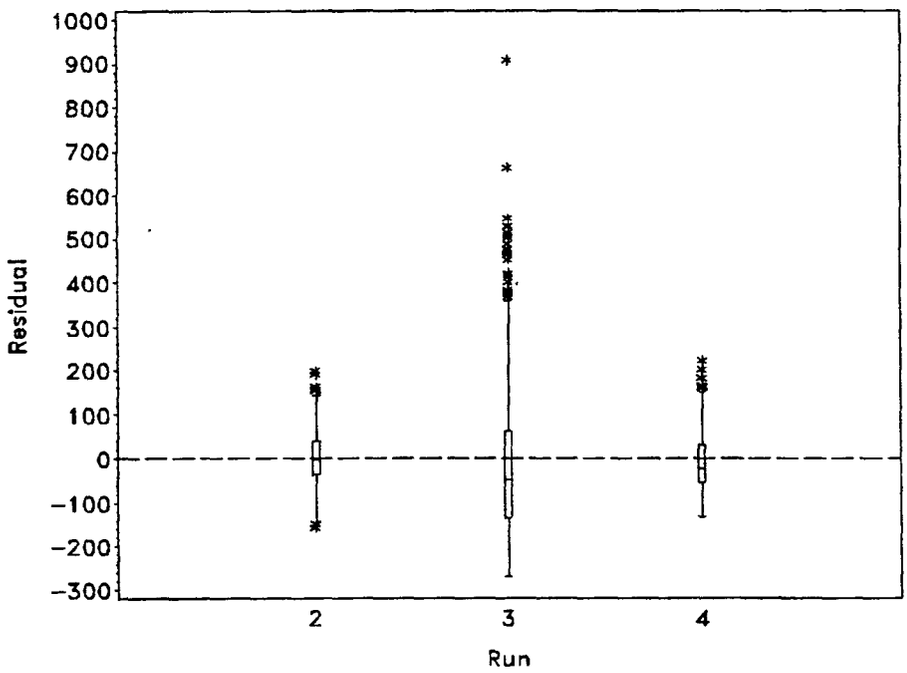

Figure 3-4. Boxplots of ANOVA Model Residuals from Carbon Monoxide Analysis (see page 3 for description of boxes)

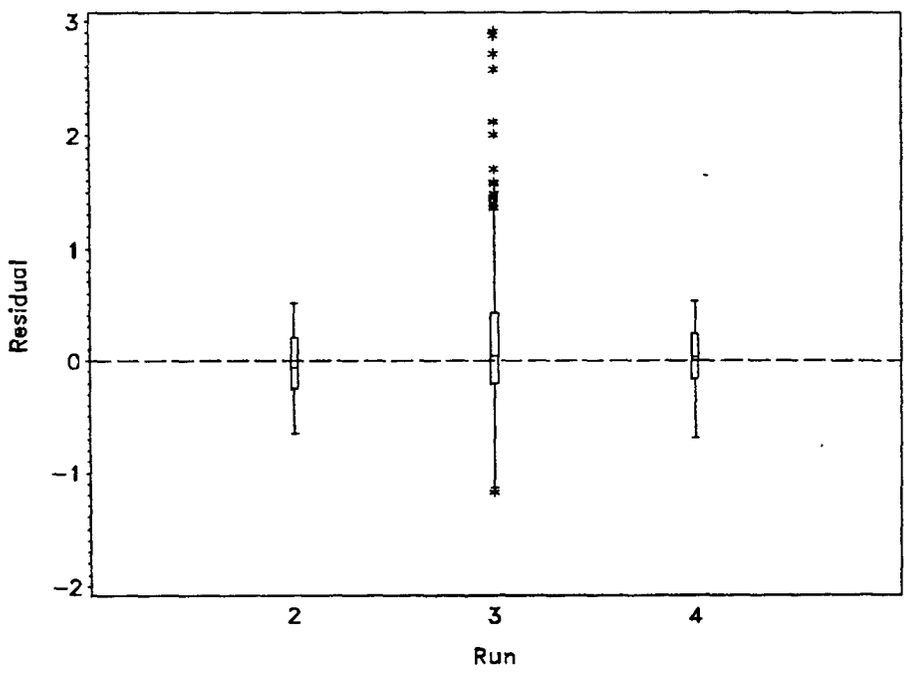

Figure 3-5. Boxplots of ANOVA Model Residuals from Carbon Dioxide Analysis (see page 3 for description of boxes)

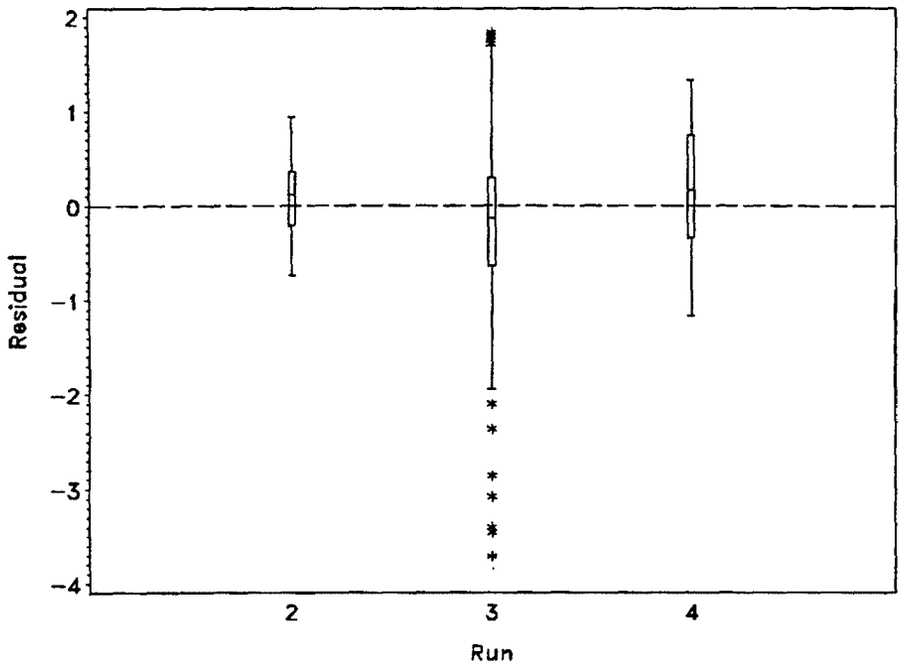

Figure 3-6. Boxplots of ANOVA Model Residuals from Oxygen Analysis (see page 3 for description of boxes)

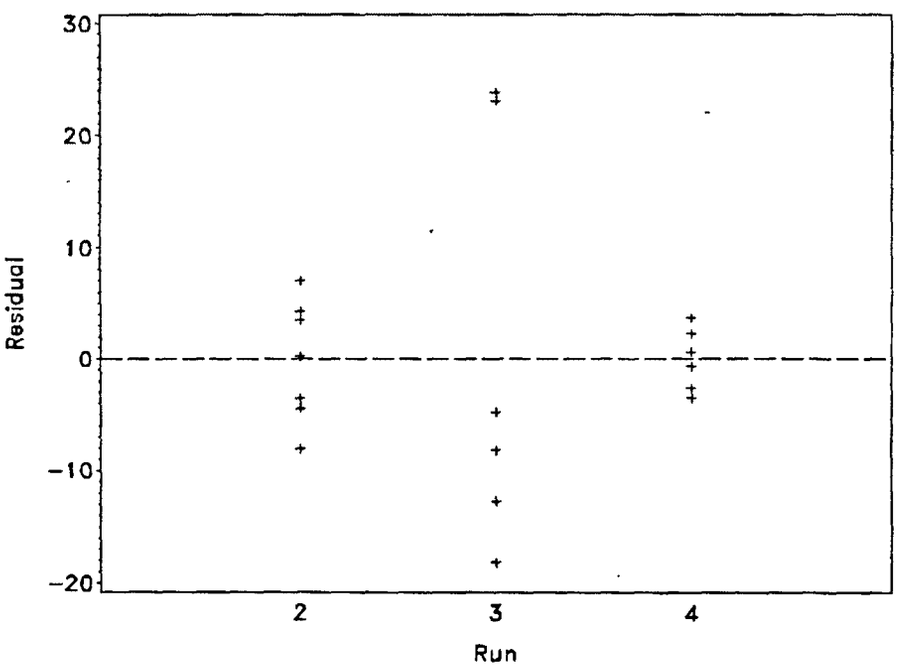

Figure 3-7. Boxplots of ANOVA Model Residuals from THC Analysis (see page 3 for description of boxes)

4.0 ANOVA MODEL RESULTS

Table 4-1 presents estimated run means and tests of significance for the difference between the average of the Run 2 and 3 means and the Run 4 mean. Results are given for the analysis of all 165 PCB, D/F and PAH compounds, for the uncorrected and corrected PCB compounds only, and for the CO, CO_2, O_2 and THC measurements. For each analysis, if the p-value was less than or equal to 0.05, then we may reject the null hypothesis H_0: *Run 4 was not a statistical outlier* in favor of the alternative hypothesis H_0: *Run 4 was a statistical outlier,* at the 5% significance level. The interpretation is that there is only a 5% chance of incorrectly concluding Run 4 was an outlier, when in fact it was not an outlier. In other words, we will claim that Run 4 was an outlier only when strong evidence exists in favor of that conclusion.

The results of the DQA were as follows:

- For all but CO_2 and O_2, we conclude that Run 4 was a statistical outlier.
- For CO_2 and O_2, we conclude that Run 4 was not a statistical outlier.

Table 4-1. ANOVA Model Results

Analysis	α_i = Run i Mean[1] (Standard Error)		P-Value for Test of Run 2 and 3 vs. Run 4[2]
PCB, D/F and PAH	α_2	0.8312 (0.0325)	< 0.0001
	α_3	0.2138 (0.0325)	
	α_4	-1.0450 (0.0325)	
Uncorrected PCB	α_2	0.8785 (0.0216)	< 0.0001
	α_3	0.2033 (0.0216)	
	α_4	-1.0818 (0.0216)	
Corrected PCB[3]	α_2	0.9445 (0.1314)	< 0.0001
	α_3	-0.3309 (0.1314)	
	α_4	-0.6136 (0.1314)	
Carbon Monoxide (ppmdv)	α_2	1382.46 (12.7632)	< 0.0001
	α_3	1166.56 (43.4856)	
	α_4	1132.57 (14.0177)	
Carbon Dioxide (%v)	α_2	5.1852 (0.1574)	0.3956
	α_3	5.3495 (0.3063)	
	α_4	5.0319 (0.2170)	
Oxygen (%v)	α_2	13.6666 (0.2667)	0.8062
	α_3	13.1966 (0.4281)	
	α_4	13.2653 (0.6287)	
Total Hydrocarbons (ppmdv)	α_2	71.1887 (2.5890)	< 0.0001
	α_3	49.4412 (9.5997)	
	α_4	34.0097 (1.2665)	

1 This is the mean of the 165 standardized compound measurements for run i. The standardized values are unitless.

2 A test of $(\alpha_2 + \alpha_3)/2 - \alpha_4$.

3 PCB analytical results were adjusted to account for spiked pre-field surrogate standard recoveries for each of the 13 congeners analyzed (see Final Emissions Report - Table 6-7a).

APPENDIX

SAMPLE SIZE DETERMINATION FOR FUTURE DATA COLLECTION EFFORTS

For each compound, computation of the relative standard error (RSE) of the mean, defined as the standard error of the compound mean divided by the compound mean, was carried out along with a study examining the reduction in RSE with an increase in the number of days of sampling.

The conclusion of the DQA was that Run 4 was a statistical outlier under the definition of a statistical outlier (See Section 1.2). While the Run 4 mean concentration was significantly lower than the Run 2 and 3 mean concentration for all but CO_2 and O_2, this difference could be interpreted as normal daily variability. Thus, calculation of the RSE, and its reduction with an increase in the number of days of sampling, were carried out under two possible scenarios:

Scenario 1: Run 4 data represent actual temporal variability and must be incorporated in order to unbiasedly estimate the true variability in pollutant concentration means.

Scenario 2: Run 4 data are outlying and do not represent actual pollutant data. As such, the variability of the pollutant concentration means should be estimated based only on the data from Runs 2 and 3.

Due to the multiple CEM measurements taken within each run, the CEM observations may not be assumed to be independent. The correlation between observations close in time is accounted for through the use of the error structure described in Section 3.0. It is assumed that future sampling days will have 360 minutely CO, CO_2 or O_2 measurements, or 6 hourly THC measurements. The average of the run standard errors is the estimate of σ for the RSE calculation. In this setting, σ represents the standard deviation of the mean of a single run. The estimate of μ is the mean of the measurements.

Tables A-1 to A-10 provide the estimated RSE values for up to 10 runs. The shaded column indicates the observed RSE for the present data. These values may be used as a guide to future sample size needs *assuming that the future study has the same objectives as the present*

study and that data are to be collected in the same manner. These RSE calculations are not applicable to studies which collect data on the same compounds using different methods.

Table A-1. RSE of Toxic PCB Results Using Data from Runs 2, 3 and 4

Congener	Relative Standard Error (RSE = 100 × σ/μ)							
	N=3	N=4	N=5	N=6	N=7	N=8	N=9	N=10
3,3',4,4'-tetrachlorobiphenyl (PCB-77)	[illegible]	29.7%	26.5%	24.2%	22.4%	21.0%	19.8%	18.8%
2,3,3',4,4'-pentachlorobiphenyl (PCB-105)	[illegible]	23.9%	21.4%	19.5%	18.1%	16.9%	16.0%	15.1%
2,3,4,4',5-pentachlorobiphenyl (PCB-114)	[illegible]	24.1%	21.6%	19.7%	18.2%	17.0%	16.1%	15.2%
2,3',4,4',5-pentachlorobiphenyl (PCB-118)	[illegible]	22.4%	20.1%	18.3%	17.0%	15.9%	14.9%	14.2%
2',3,4,4',5-pentachlorobiphenyl (PCB-123)	[illegible]	26.0%	23.2%	21.2%	19.6%	18.4%	17.3%	16.4%
3,3',4,4',5-pentachlorobiphenyl (PCB-126)	[illegible]	26.8%	24.0%	21.9%	20.3%	19.0%	17.9%	16.9%
2,3,3',4,4',5-hexachlorobiphenyl (PCB-156)	[illegible]	25.1%	22.5%	20.5%	19.0%	17.8%	16.8%	15.9%
2,3,3',4,4',5'-hexachlorobiphenyl (PCB-157)	[illegible]	24.2%	21.6%	19.8%	18.3%	17.1%	16.1%	15.3%
2,3',4,4',5,5'-hexachlorobiphenyl (PCB-167)	[illegible]	24.2%	21.6%	19.8%	18.3%	17.1%	16.1%	15.3%
3,3',4,4',5,5'-hexachlorobiphenyl (PCB-169)	[illegible]	29.3%	26.2%	23.9%	22.1%	20 7%	19.5%	18.5%
2,2',3,3',4,4',5-heptachlorobiphenyl (PCB-170)	[illegible]	21.6%	19.3%	17.6%	16.3%	15.3%	14.4%	13.7%
2,2',3,4,4',5,5'-heptachlorobiphenyl (PCB-180)	[illegible]	25.7%	23.0%	21.0%	19.4%	18.2%	17.1%	16.3%
2,3,3',4,4',5,5'-heptachlorobiphenyl (PCB-189)	[illegible]	19.4%	17.4%	15.8%	14.7%	13.7%	12.9%	12.3%

Table A-2. RSE of Toxic PCB Results Using Data from Runs 2 and 3 Only (excluding Run 4)

Congener	Relative Standard Error (RSE)								
	N=2	N=3	N=4	N=5	N=6	N=7	N=8	N=9	N=10
3,3',4,4'-tetrachlorobiphenyl (PCB-77)	[illegible]	19.5%	16.9%	15.1%	13.8%	12.8%	11.9%	11.3%	10.7%
2,3,3',4,4'-pentachlorobiphenyl (PCB-105)	[illegible]	7.7%	6.7%	6.0%	5.5%	5.1%	4.7%	4.5%	4.2%
2,3,4,4',5-pentachlorobiphenyl (PCB-114)	[illegible]	9.8%	8.5%	7.6%	7.0%	6.4%	6.0%	5.7%	5.4%
2,3',4,4',5-pentachlorobiphenyl (PCB-118)	[illegible]	7.7%	6.7%	6.0%	5.5%	5.0%	4.7%	4.5%	4.2%
2',3,4,4',5-pentachlorobiphenyl (PCB-123)	[illegible]	7.9%	6.9%	6.1%	5.6%	5.2%	4.9%	4.6%	4.3%
3,3',4,4',5-pentachlorobiphenyl (PCB-126)	[illegible]	11.6%	10.1%	9.0%	8.2%	7.6%	7.1%	6.7%	6.4%
2,3,3',4,4',5-hexachlorobiphenyl (PCB-156)	[illegible]	9.7%	8.4%	7.5%	6.9%	6.4%	6.0%	5.6%	5.3%
2,3,3',4,4',5'-hexachlorobiphenyl (PCB-157)	[illegible]	12.9%	11.2%	10.0%	9.1%	8.4%	7.9%	7.4%	7.1%
2,3',4,4',5,5'-hexachlorobiphenyl (PCB-167)	[illegible]	10.1%	8.7%	7.8%	7.1%	6.6%	6.2%	5.8%	5.5%
3,3',4,4',5,5'-hexachlorobiphenyl (PCB-169)	[illegible]	11.6%	10.0%	9.0%	8.2%	7.6%	7.1%	6.7%	6.3%
2,2',3,3',4,4',5-heptachlorobiphenyl (PCB-170)	[illegible]	8.9%	7.7%	6.9%	6.3%	5.8%	5.4%	5.1%	4.9%
2,2',3,4,4',5,5'-heptachlorobiphenyl (PCB-180)	[illegible]	9.4%	8.1%	7.3%	6.6%	6.2%	5.8%	5.4%	5.1%
2,3,3',4,4',5,5'-heptachlorobiphenyl (PCB-189)	[illegible]	13.3%	11.5%	10.3%	9.4%	8.7%	8.1%	7.7%	7.3%

Table A-3. RSE of Dioxin Results Using Data from Runs 2, 3, and 4

Congener	[illegible]	Relative Standard Error, RSE = 100 [illegible]						
	[illegible]	N = 5	N = 6	N = 7	N = 8	N = 9	N = 10
2,3,7,8-TCDD	[illegible]	28.4%	25.4%	23.2%	21.4%	20.1%	18.9%	17.9%
Total TCDD	[illegible]	30.5%	27.3%	24.9%	23.1%	21.6%	20.3%	19.3%
1,2,3,7,8-PCDD	[illegible]	27.8%	24.9%	22.7%	21.0%	19.7%	18.5%	17.6%
Total PCDD	[illegible]	28.3%	25.3%	23.1%	21.4%	20.0%	18.8%	17.9%
1,2,3,4,7,8-HxCDD	[illegible]	21.9%	19.6%	17.9%	16.6%	15.5%	14.6%	13.9%
1,2,3,6,7,8-HxCDD	[illegible]	24.7%	22.1%	20.2%	18.7%	17.5%	16.5%	15.6%
1,2,3,7,8,9-HxCDD	[illegible]	21.1%	18.8%	17.2%	15.9%	14.9%	14.0%	13.3%
Total HxCDD	[illegible]	16.2%	14.5%	13.2%	12.2%	11.4%	10.8%	10.2%
1,2,3,4,6,7,8-HpCDD	[illegible]	19.5%	17.5%	15.9%	14.8%	13.8%	13.0%	12.3%
Total HpCDD	[illegible]	42.9%	38.4%	35.0%	32.4%	30.3%	28.6%	27.1%
Octa CDD	[illegible]	20.8%	18.6%	17.0%	15.8%	14.7%	13.9%	13.2%
Total CDD	[illegible]	27.7%	24.8%	22.7%	21.0%	19.6%	18.5%	17.5%

Table A-4. RSE of Dioxin Results Using Data from Runs 2 and 3 Only (excluding Run 4)

Dioxin Congener	Relative Standard Error (RSE) = 100 * [illegible]	N = 3	N = 4	N = 5	N = 6	N = 7	N = 8	N = 9	N = 10
2,3,7,8-TCDD	[illegible]	22.7%	19.7%	17.6%	16.1%	14.9%	13.9%	13.1%	12.4%
Total TCDD	[illegible]	2.0%	1.7%	1.5%	1.4%	1.3%	1.2%	1.1%	1.1%
1,2,3,7,8-PCDD	[illegible]	14.6%	12.6%	11.3%	10.3%	9.5%	8.9%	8.4%	8.0%
Total PCDD	[illegible]	7.2%	6.2%	5.6%	5.1%	4.7%	4.4%	4.2%	3.9%
1,2,3,4,7,8-HxCDD	[illegible]	4.5%	3.9%	3.4%	3.1%	2.9%	2.7%	2.6%	2.4%
1,2,3,6,7,8-HxCDD	[illegible]	2.9%	2.5%	2.2%	2.0%	1.9%	1.7%	1.6%	1.6%
1,2,3,7,8,9-HxCDD	[illegible]	8.3%	7.2%	6.4%	5.9%	5.4%	5.1%	4.8%	4.5%
Total HxCDD	[illegible]	5.9%	5.1%	4.6%	4.2%	3.9%	3.6%	3.4%	3.2%
1,2,3,4,6,7,8-HpCDD	[illegible]	4.5%	3.9%	3.5%	3.2%	3.0%	2.8%	2.6%	2.5%
Total HpCDD	[illegible]	39.2%	33.9%	30.3%	27.7%	25.6%	24.0%	22.6%	21.5%
Octa CDD	[illegible]	15.4%	13.3%	11.9%	10.9%	10.1%	9.4%	8.9%	8.4%
Total CDD	[illegible]	5.2%	4.5%	4.1%	3.7%	3.4%	3.2%	3.0%	2.9%

Table A-5. RSE of Furan Results Using Data from Runs 2, 3, and 4

Congener	Relative Standard Error (RSE = 100 × σ/μ)							
	N=3	N=4	N=5	N=6	N=7	N=8	N=9	N=10
2,3,7,8-TCDF	[illegible]	25.3%	22.7%	20.7%	19.2%	17.9%	16.9%	16.0%
Total TCDF	[illegible]	19.3%	17.3%	15.8%	14.6%	13.7%	12.9%	12.2%
1,2,3,7,8-PCDF	[illegible]	25.2%	22.5%	20.5%	19.0%	17.8%	16.8%	15.9%
2,3,4,7,8-PCDF	[illegible]	27.0%	24.1%	22.0%	20.4%	19.1%	18.0%	17.0%
Total PCDF	[illegible]	27.0%	24.1%	22.0%	20.4%	19.1%	18.0%	17.1%
1,2,3,4,7,8-HxCDF	[illegible]	22.2%	19.8%	18.1%	16.8%	15.7%	14.8%	14.0%
1,2,3,6,7,8-HxCDF	[illegible]	20.8%	18.6%	17.0%	15.7%	14.7%	13.8%	13.1%
2,3,4,6,7,8-HxCDF	[illegible]	22.2%	19.9%	18.1%	16.8%	15.7%	14.8%	14.1%
1,2,3,7,8,9-HxCDF	[illegible]	.	.	.	.	.	.	.
Total HxCDF	[illegible]	24.0%	21.5%	19.6%	18.2%	17.0%	16.0%	15.2%
1,2,3,4,6,7,8-HpCDF	[illegible]	19.6%	17.5%	16.0%	14.8%	13.9%	13.1%	12.4%
1,2,3,4,7,8,9-HpCDF	[illegible]	21.7%	19.4%	17.7%	16.4%	15.3%	14.4%	13.7%
Total HpCDF	[illegible]	21.6%	19.3%	17.7%	16.4%	15.3%	14.4%	13.7%
Octa CDF	[illegible]	18.8%	16.8%	15.4%	14.2%	13.3%	12.6%	11.9%
Total CDF	[illegible]	22.7%	20.3%	18.5%	17.2%	16.1%	15.1%	14.4%
Total CDD+CDF	[illegible]	23.3%	20.9%	19.1%	17.6%	16.5%	15.6%	14.8%

Table A-6. RSE of Furan Results Using Data from Runs 2 and 3 Only (excluding Run 4)

Congener	Relative Standard Error (RSE = 100 × [illegible])								
	N=2	N=3	N=4	N=5	N=6	N=7	N=8	N=9	N=10
2,3,7,8-TCDF	[illegible]	14.3%	12.4%	11.1%	10.1%	9.4%	8.8%	8.3%	7.8%
Total TCDF	[illegible]	10.0%	8.6%	7.7%	7.1%	6.5%	6.1%	5.8%	5.5%
1,2,3,7,8-PCDF	[illegible]	14.9%	12.9%	11.6%	10.5%	9.8%	9.1%	8.6%	8.2%
2,3,4,7,8-PCDF	[illegible]	17.3%	15.0%	13.4%	12.2%	11.3%	10.6%	10.0%	9.5%
Total PCDF	[illegible]	16.3%	14.1%	12.6%	11.5%	10.6%	10.0%	9.4%	8.9%
1,2,3,4,7,8-HxCDF	[illegible]	14.0%	12.1%	10.8%	9.9%	9.1%	8.5%	8.1%	7.6%
1,2,3,6,7,8-HxCDF	[illegible]	12.8%	11.1%	9.9%	9.0%	8.4%	7.8%	7.4%	7.0%
2,3,4,6,7,8-HxCDF	[illegible]	14.8%	12.9%	11.5%	10.5%	9.7%	9.1%	8.6%	8.1%
1,2,3,7,8,9-HxCDF	[illegible]	.	.	.	.	.	.	.	.
Total HxCDF	[illegible]	14.3%	12.4%	11.1%	10.1%	9.4%	8.8%	8.3%	7.8%
1,2,3,4,6,7,8-HpCDF	[illegible]	12.1%	10.5%	9.4%	8.6%	7.9%	7.4%	7.0%	6.6%
1,2,3,4,7,8,9-HpCDF	[illegible]	14.5%	12.6%	11.3%	10.3%	9.5%	8.9%	8.4%	8.0%
Total HpCDF	[illegible]	13.6%	11.8%	10.5%	9.6%	8.9%	8.3%	7.8%	7.4%
Octa CDF	[illegible]	7.6%	6.6%	5.9%	5.4%	5.0%	4.7%	4.4%	4.2%
Total CDF	[illegible]	12.9%	11.2%	10.0%	9.1%	8.5%	7.9%	7.5%	7.1%
Total CDD+CDF	[illegible]	6.7%	5.8%	5.2%	4.7%	4.4%	4.1%	3.9%	3.7%

Table A-7. RSE of PAH Results Using Data from Runs 2, 3, and 4

Compound	Relative Standard Error (RSE = 100 × [illegible])							
	N = 3	N = 4	N = 5	N = 6	N = 7	N = 8	N = 9	N = 10
Acenaphthene	[illegible]	34.4%	30.8%	28.1%	26.0%	24.3%	22.9%	21.8%
Acenaphthylene	[illegible]	34.8%	31.1%	28.4%	26.3%	24.6%	23.2%	22.0%
Anthracene	[illegible]	30.3%	27.1%	24.7%	22.9%	21.4%	20.2%	19.1%
Benzo(a)anthracene	[illegible]	38.2%	34.2%	31.2%	28.9%	27.0%	25.5%	24.2%
Benzo(b)fluoranthene	[illegible]	30.9%	27.7%	25.3%	23.4%	21.9%	20.6%	19.6%
Benzo(k)fluoranthene	[illegible]	41.3%	37.0%	33.7%	31.2%	29.2%	27.6%	26.1%
Benzo(g,h,i)perylene	[illegible]	32.1%	28.7%	26.2%	24.3%	22.7%	21.4%	20.3%
Benzo(a)pyrene	[illegible]	27.9%	25.0%	22.8%	21.1%	19.7%	18.6%	17.7%
Chrysene	[illegible]	39.2%	35.1%	32.0%	29.7%	27.7%	26.2%	24.8%
Dibenzo(a,h)anthracene	[illegible]	33.2%	29.7%	27.1%	25.1%	23.5%	22.1%	21.0%
Fluoranthene	[illegible]	29.8%	26.7%	24.4%	22.5%	21.1%	19.9%	18.9%
Fluorene	[illegible]	38.2%	34.2%	31.2%	28.9%	27.0%	25.5%	24.2%
Indeno(1,2,3-c,d)pyrene	[illegible]	32.8%	29.3%	26.8%	24.8%	23.2%	21.8%	20.7%
Naphthalene	[illegible]	19.1%	17.1%	15.6%	14.5%	13.5%	12.7%	12.1%
Phenanthrene	[illegible]	29.6%	26.5%	24.2%	22.4%	20.9%	19.7%	18.7%
Pyrene	[illegible]	32.6%	29.1%	26.6%	24.6%	23.0%	21.7%	20.6%

Table A-8. RSE of PAH Results Using Data from Runs 2 and 3 Only (excluding Run 4)

Compound	Relative Standard Error (RSE) = 100 × (Std. Dev. / Mean)								
	N = 2	N = 3	N = 4	N = 5	N = 6	N = 7	N = 8	N = 9	N = 10
Acenaphthene	[illegible]	12.7%	11.0%	9.8%	8.9%	8.3%	7.7%	7.3%	6.9%
Acenaphthylene	[illegible]	2.3%	2.0%	1.8%	1.6%	1.5%	1.4%	1.3%	1.2%
Anthracene	[illegible]	39.3%	34.0%	30.4%	27.8%	25.7%	24.1%	22.7%	21.5%
Benzo(a)anthracene	[illegible]	36.0%	31.2%	27.9%	25.5%	23.6%	22.1%	20.8%	19.7%
Benzo(b)fluoranthene	[illegible]	10.9%	9.5%	8.5%	7.7%	7.2%	6.7%	6.3%	6.0%
Benzo(k)fluoranthene	[illegible]	30.6%	26.5%	23.7%	21.6%	20.0%	18.7%	17.7%	16.7%
Benzo(g,h,i)perylene	[illegible]	23.5%	20.4%	18.2%	16.6%	15.4%	14.4%	13.6%	12.9%
Benzo(a)pyrene	[illegible]	32.2%	27.9%	25.0%	22.8%	21.1%	19.7%	18.6%	17.7%
Chrysene	[illegible]	24.9%	21.5%	19.3%	17.6%	16.3%	15.2%	14.4%	13.6%
Dibenzo(a,h)anthracene	[illegible]	17.3%	15.0%	13.4%	12.2%	11.3%	10.6%	10.0%	9.5%
Fluoranthene	[illegible]	7.8%	6.8%	6.0%	5.5%	5.1%	4.8%	4.5%	4.3%
Fluorene	[illegible]	0.7%	0.6%	0.5%	0.5%	0.5%	0.4%	0.4%	0.4%
Indeno(1,2,3-c,d)pyrene	[illegible]	17.3%	15.0%	13.4%	12.3%	11.4%	10.6%	10.0%	9.5%
Naphthalene	[illegible]	11.3%	9.8%	8.8%	8.0%	7.4%	6.9%	6.5%	6.2%
Phenanthrene	[illegible]	4.5%	3.9%	3.5%	3.2%	3.0%	2.8%	2.6%	2.5%
Pyrene	[illegible]	7.8%	6.7%	6.0%	5.5%	5.1%	4.8%	4.5%	4.3%

Table A-9. RSE for CEMs Using Data from Runs 2, 3, and 4

Compound	Relative Standard Error (RSE = 100 × (σ / ȳ))							
	N = 2	N = 3	N = 4	N = 5	N = 6	N = 7	N = 8	N = 9	N = 10
CO	[illegible]	1.0%	0.9%	0.8%	0.7%	0.7%	0.6%	0.6%
CO_2	[illegible]	2.2%	2.0%	1.8%	1.7%	1.5%	1.5%	1.4%
O_2	[illegible]	1.6%	1.5%	1.3%	1.2%	1.2%	1.1%	1.0%
THC	[illegible]	4.4%	4.0%	3.6%	3.3%	3.1%	2.9%	2.8%

Table A-10. RSE for CEMs Using Data from Runs 2 and 3 Only (excluding Run 4)

Compound	Relative Standard Error (RSE = 100 × (σ / ȳ))								
	N = 2	N = 3	N = 4	N = 5	N = 6	N = 7	N = 8	N = 9	N = 10
CO	[illegible]	1.3%	1.1%	1.0%	0.9%	0.8%	0.8%	0.7%	0.7%
CO_2	[illegible]	2.5%	2.2%	2.0%	1.8%	1.7%	1.6%	1.5%	1.4%
O_2	[illegible]	1.5%	1.3%	1.2%	1.1%	1.0%	0.9%	0.9%	0.8%
THC	[illegible]	5.9%	5.1%	4.6%	4.2%	3.9%	3.6%	3.4%	3.2%

TECHNICAL REPORT DATA

(Please read Instructions on reverse before completing)

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

The Clean Air Act Amendments of 1990 require the U.S. Environmental Protection Agency's (EPA) Office of Air Quality Planning and Standards (OAQPS) to establish standards of performance for sewage sludge incineration. These standards are necessary to protect public health and the environment from any adverse effects of pollutant emissions from sewage sludge incineration. The regulations will contain general regulatory requirements, pollutant characterization, and emission limits. To assess control technologies as well as associated strategies for cost-effective standards, EPA requires data on PCB, D/F, and PAH emissions from sewage sludge incinerators . While some emission data exist for sewage sludge incinerators, data on coplanar polychlorinated biphenyls (PCBs) from sewage sludge incinerators are very limited.

The test report summarizes testing of a multiple hearth incinerator at the Metropolitan Sewer District (MSD) Mill Creek Wastewater Treatment Plant in Cincinnati, Ohio in July, 1999. The emission data collected in this test program will be used by EPA/OAQPS and EPA's Office of Water (OW) to support a decision about further data gathering efforts in support of MACT standards for sewage sludge incinerators. During the testing, a second EPA contractor monitored and recorded the process and emission control system operating parameters, and prepared Section 4.0, Process Description And Operation of the report. The report consist of five documents: Executive Summary Report; Volume I-Main Report; Volume II-Appendices A-J; Volume III-Appendices K-P; and a Data Quality Assessment Report.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
PCBs PAHs Dioxins/furans	Air Pollution control	
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