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Air

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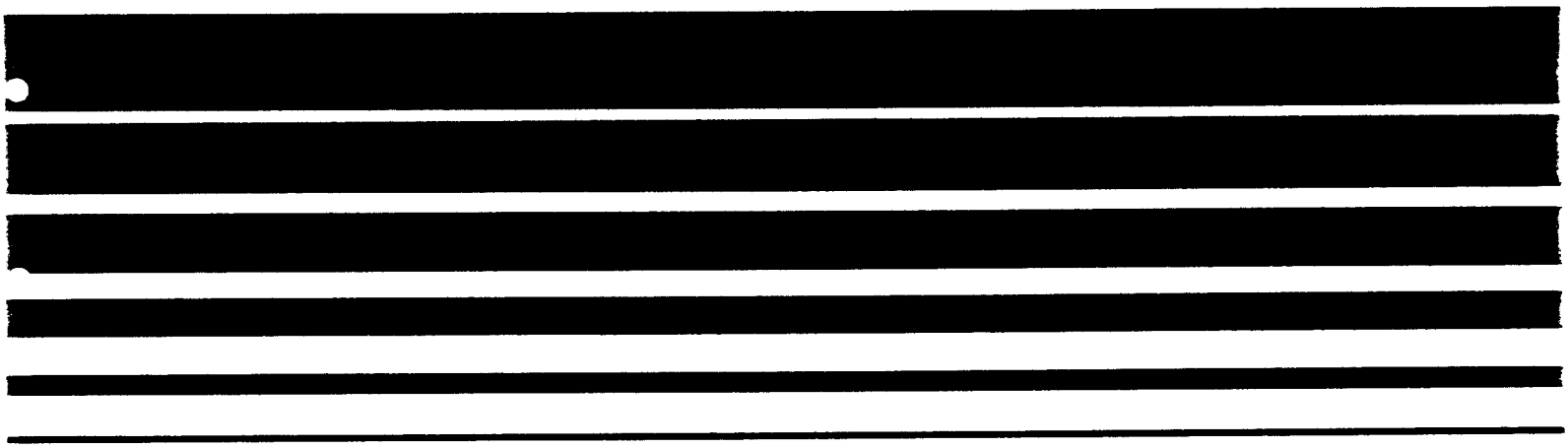
Municipal Waste Combustion Multipollutant Study

Summary Report

Signal Environmental Systems, Inc.
North Andover RESCO
North Andover, Massachusetts



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SUMMARY REPORT
FOR
CDD/CDF, METALS AND PARTICULATE
UNCONTROLLED AND CONTROLLED EMISSIONS

SIGNAL ENVIRONMENTAL SYSTEMS, INC.
NORTH ANDOVER RESCO
NORTH ANDOVER, MASSACHUSETTS

ESED PROJECT NO. 86/19
EPA CONTRACT NO. 68-02-4338
WORK ASSIGNMENT 15

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March 1988

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1.0 INTRODUCTION

The United States Environmental Protection Agency (EPA) has published in the Federal Register (July 7, 1987) an advanced notice for proposed rulemaking which describes upcoming emissions standards development for new municipal waste combustors (MWCs) under Section 111 of the Clean Air Act and for existing MWCs under Section 111(d) of the Act. This Federal Register notice culminates more than a year's work of development of the technical and health-related documents which comprise EPA's Report to Congress on MWCs. The Report to Congress was a joint effort involving the Offices of Air Quality Planning and Standards (OAQPS), Solid Waste (OSW), and Research and Development (ORD).

The Emission Standards and Engineering Division (ESED) of OAQPS, through its Industrial Studies Branch (ISB) and Emissions Measurement Branch (EMB), is responsible for reviewing the existing air emissions data base and gathering additional data where necessary. As a result of this review, several MWC emission tests were performed and are in planning stages to support the emissions standards development which is underway. Of particular importance is a more complete data base on emerging air pollution control technologies for MWCs.

The emissions that are being studied for the source category document are the criteria pollutants--particulate matter (PM), sulfur oxides (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO) and hydrocarbons (THC); other acid gases, such as HCl; chlorinated organics including chlorinated dibenzo-p-dioxins (CDD) and chlorinated dibenzofurans (CDF); and specific metals including arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg), nickel (Ni), lead (Pb) and beryllium (Be).

1.1 BACKGROUND

Signal Environmental Systems, Inc., was required by the Massachusetts Department of Environmental Quality Engineering (MDEQE) to conduct an emission

program to measure the CDD/CDF emissions in the flue gas and the CDD/CDF concentration in the process ash streams at the North Andover RESCO municipal solid waste resource recovery facility in North Andover, Massachusetts. Radian Corporation was contracted by Signal Environmental to perform that program.

In order to provide additional data to evaluate the CDD/CDF and metals removal effectiveness of emissions reduction systems, Signal Environmental and EPA agreed to jointly sponsor an expanded program during the MDEQE-required tests. Signal Environmental sponsored CDD/CDF and total organic chlorine (TOCL) tests at the ESP outlet, and EPA sponsored CDD/CDF tests at the ESP inlet, and metals and particulate testing at the ESP inlet and outlet locations. Ash sampling was sponsored by Signal during the CDD/CDF tests and by EPA during the metals test runs. Radian Corporation also performed the expanded testing program.

This report summarizes the complete set of data collected during the joint sampling program. The main objective of this report is to summarize and analyze the data rather than present the testing details.

Separate test reports were prepared detailing the results of the EPA-sponsored testing and the Signal Environmental-sponsored testing. The test report for the EPA-sponsored testing[1] can be obtained by contacting Clyde E. Riley of EMB/EPA, Mail Drop 14, Research Triangle Park, NC 27711, (919) 541-5242. The test report prepared for Signal Environmental[2] can be obtained by contacting Timothy Porter of Signal Environmental Systems, Liberty Lane, Hampton, NH 03842, (603) 926-1337.

1.2 OBJECTIVES

The objective of the EPA-sponsored test program was to obtain CDD/CDF, metals, and particulate data from a state-of-the art MWC controlled by an electrostatic precipitator (ESP). The North Andover facility was selected by EPA because the facility was a well-designed and operated mass-burn,

waterwall, resource recovery system with a state-of-the-art ESP. The EPA-sponsored test program was designed to obtain:

- Uncontrolled flue gas CDD/CDF emission results that could be compared with the Signal-sponsored CDD/CDF controlled results;

- Data on uncontrolled and controlled flue gas particulate concentrations and specific trace metals emission rates;

- Data on the uncontrolled and controlled emission characteristics and inter-relationships of the particulate matter, CDD/CDF, and trace metals flue gas concentrations;

- Trace metals results for the ESP flyash that was being generated during the trace metal air emissions test program; and

- Continuous emissions monitoring (CEM) information for oxygen, carbon monoxide and carbon dioxide during the particulate/metals test program.

The results from the North Andover Facility have been incorporated into the data base for the comprehensive source category document, and will be used in support of any future regulatory development which is undertaken for the MWC source category.

1.3 BRIEF PROCESS OPERATION AND DESCRIPTION

Figure 1-1 presents a process diagram of the two identical combustor systems at the North Andover facility. Unit No. 2 was tested during this program. Unit No. 2 is a reciprocating grate, mass-burn type combustor with a waterwall boiler that produces superheated steam. Unit No. 2 is designed to burn 750 tons/day of municipal waste. The flue gas passes from the combustor into the superheater, generator, and economizer sections before the particulate emissions are controlled by an ESP.

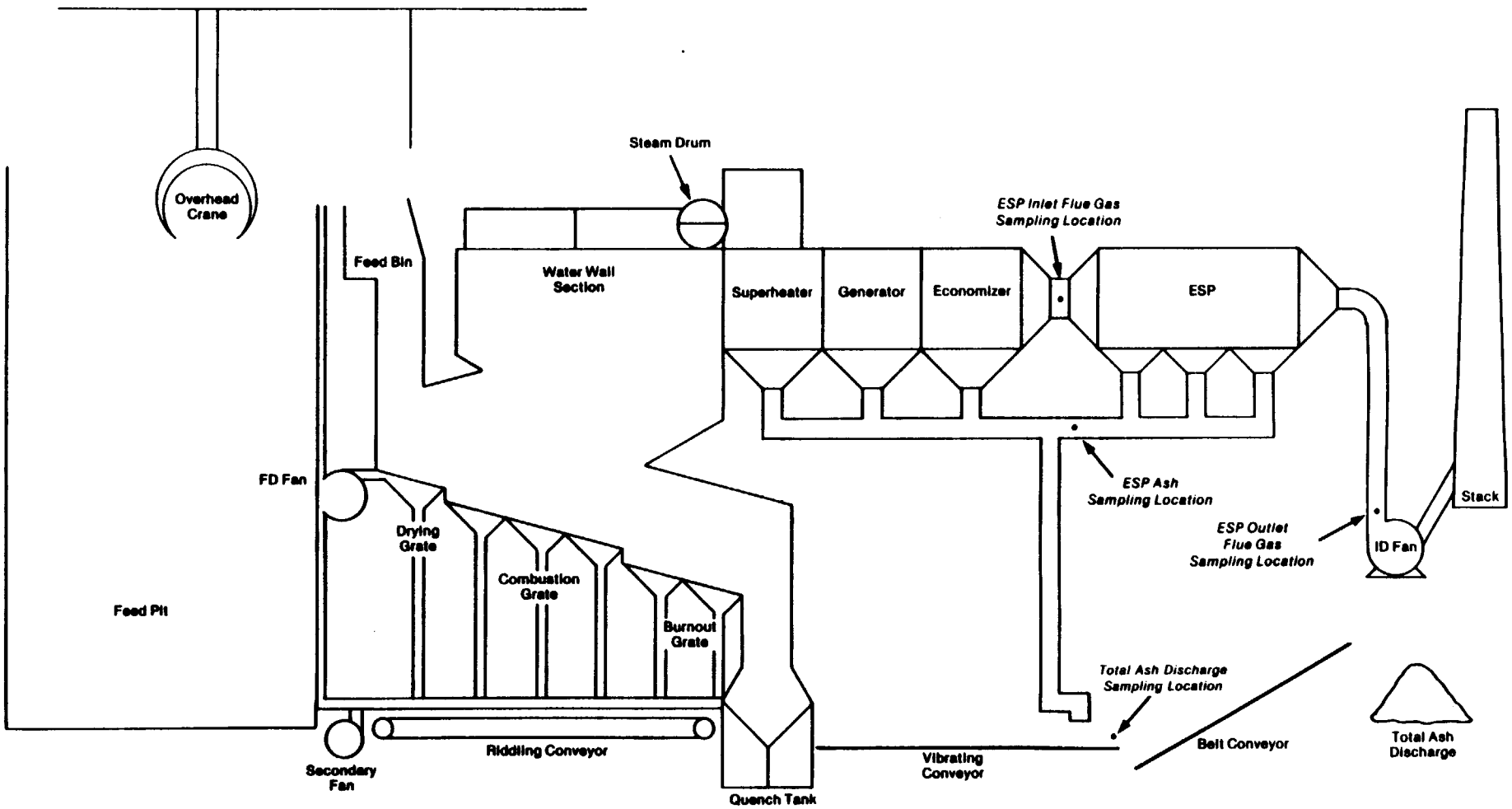

Figure 1 - 1. North Andover RESCO Process Line with Sampling Locations

The refuse is typical residential and commercial solid waste. No sorting or shredding is performed prior to combustion. The refuse is brought to the enclosed tipping area by truck and unloaded into the receiving pit. A manually operated overhead crane is used to transfer the refuse from the receiving pit to the combustor charging chute. A Martin inclined grate and ash discharge system is used at the North Andover facility.

A more detailed description of the North Andover system is presented in Sections 3.1 and 3.2 of this report. This description was prepared by Midwest Research Institute (MRI). Combustor operating data recorded during the test program are also summarized in Section 3.0. The operation of the ESP was monitored during the test program. However, Signal Environmental Systems considers the ESP operating data to be confidential and they are not included in this report.

Analyses of the combustor operating data had two purposes: 1) to evaluate the operation of the combustor, and 2) to correlate their operation to the emissions results. Key operating parameters such as steam load, superheater inlet gas temperature, oxygen at the economizer, and Radian's CEM data for oxygen, carbon monoxide, and carbon dioxide were evaluated for trends. The trends in operating parameters are discussed in Section 3.3 of this report.

The emissions data and the observed trends in operating parameters were reviewed to determine if there were any correlations between emissions and any of the operating parameters. No apparent correlations were observed. A statistical analysis was not performed to test for correlations.

Some tentative results were drawn from a review of the emissions data. It appears that the ESP does not effectively control CDD/CDF emissions, although it does effectively control particulate emissions. The CDD/CDF control efficiencies obtained may be obscured by analytical uncertainties, however. The uncontrolled and controlled flue gas emissions averaged 342 ng/dscm and 422 ng/dscm for total CDD/CDF at 12 percent CO_2,

respectively. The ESP also did not affect the CDD or CDF isomer distribution in the flue gas. The ESP ash and total ash discharge contained 103 ng/g and 13.5 ng/g total CDD/CDF, respectively, on the average.

Particulate emissions were controlled by the ESP at an average control efficiency of 99.46 percent. The control efficiencies for metals in the flue gas were highest for total chromium and arsenic. Cadmium was collected less efficiently, while nickel was collected least efficiently of the four metals analyzed. A potential for nickel and chromium contamination from the stainless steel nozzle exists when sampling flue gas streams containing HCl. During this test program, to minimize this contamination, rinses of the stainless steel nozzle were not included in the metals samples. The extent of possible contamination was not quantified. A wide variety of metals was detected in the ESP ash.

1.4 EMISSIONS MEASUREMENT PROGRAM

1.4.1 Test Matrix

The emissions measurement program at the North Andover facility was conducted from July 8 to July 16, 1986. Table 1-1 presents the actual test matrix that was used for the program and the organization that sponsored each type of sample. Total organic chloride/particulate sampling at the ESP inlet was scheduled for Runs 1-6, but had to be cancelled because of logistical problems.

1.4.2 Sampling Locations

Flue gas sampling was conducted at two locations. The ESP outlet sampling location was about 0.5 equivalent diameters (4.1 feet) upstream of the ID fan. At this point, six ports were located horizontally across the vertical square ducting and another small port, located about a foot downstream, was used for the CEM probe.

TABLE 1-1. ACTUAL TEST MATRIX FOR NORTH ANDOVER RESCO[a]

Run	CDD/CDF ESP Inlet	CDD/CDF ESP Outlet	TOCL/PM ESP Outlet[b]	Metals/PM ESP Inlet	Metals/PM ESP Outlet	ESP Ash	Total Combined Ash	CEMs[c]
1	--	Signal	Signal-TOCL EPA-PM	--	--	Signal	Signal	Signal
2	EPA[d]	Signal	Signal-TOCL EPA-PM	--	--	Signal	Signal	Signal
3	EPA	Signal	Signal-TOCL EPA-PM	--	--	Signal	Signal	Signal
4	EPA	Signal	Signal-TOCL EPA-PM	--	--	Signal	Signal	Signal
5	EPA	Signal	Signal-TOCL EPA-PM	--	--	Signal	Signal	Signal
6	EPA[d]	Signal	Signal-TOCL EPA-PM	--	--	Signal	Signal	Signal
7	--	--	--	EPA	EPA	EPA	--	EPA
8	--	--	--	EPA	EPA	EPA	--	EPA
9	--	--	--	EPA	EPA	EPA	--	EPA

[a]Dashes indicate that the sample was not collected. Also, Signal = Signal Environmental Systems, Inc.

[b]PM = particulate matter. TOCL = total organic chloride.

[c]Continuous emissions monitors were used to measure O_2, CO_2, CO and THC at the ESP outlet.

[d]The ESP inlet CDD/CDF samples for Runs 2 and 6 were not analyzed because of sampling and combustor problems that occurred during the runs.

The ESP inlet sampling location was between the economizer and the ESP. Eight ports were located across the top of the horizontal square duct about 0.8 equivalent duct diameters (6.5 feet) upstream of the expansion joint for the entrance to the ESP.

The ESP ash was collected from a drag conveyor at an intermediate point before mixing with the bottom ash. The total combined ash was collected as the ash fell from a vibrating conveyor onto a belt conveyor prior to being placed in the temporary storage area.

1.4.3 Sampling

Sampling for CDD/CDF in the flue gas was conducted according to the December 1984 draft of the American Society of Mechanical Engineers (ASME) and EPA Environmental Standards Workshop protocol for sampling and analysis of chlorinated organic compounds. The CDD/CDF sampling at the ESP inlet and ESP outlet was conducted simultaneously. At the ESP outlet, the TOCL samples were also collected according to the ASME/EPA protocol. The ASME/EPA protocol for the TOCL train was modified to collect EPA Method 5 particulate samples along with TOCL samples in one train.

Trace metals testing was conducted simultaneously at the ESP inlet and ESP outlet during Runs 7, 8 and 9. Sampling followed EPA Alternate Method 12, which allows for the determination of particulate loading concurrently with lead and cadmium in the sampling train. The EPA Method 12 train has been demonstrated specifically for lead and cadmium only. However, for purposes of this study, the method was used as a screening analysis for the other metals of interest. The method was also modified by using neutron activation (NAA) as the analysis method rather than atomic absorption. However, NAA is not a validated analytical method. The analytical results for arsenic, nickel, cadmium, and total chromium are included in this report. The results for the other metals are included in Appendix I of Reference 1.

Samples of the ESP ash and total combined ash for CDD/CDF analysis were collected during the flue gas sampling time period. The ashes from the ESP,

superheater, generator, and economizer sections and the boiler tubes were combined with the bottom ash as they were transferred to the temporary storage area to form the total combined ash discharge. The ash sampling scheme was developed specifically for the North Andover RESCO facility based on the ASTM protocol for coal sampling (a grab sampling technique).[3]

Continuous emission monitoring (CEM) for oxygen (O_2), carbon monoxide (CO), carbon dioxide (CO_2) and total hydrocarbons (THC) was conducted by Radian at the ESP outlet sampling location during the entire test program. The purpose of the continuous monitoring effort was to 1) observe fluctuations in flue gas parameters, and 2) provide an indication of combustion conditions. The CEM results were also used to adjust ESP outlet emissions data to a 12 percent CO_2 basis. For the ESP inlet emissions data, EPA Method 3 (Orsat analysis) results were used.

Plant personnel collected the incinerator and ESP operating data. The CEM data and the operating data were used to determine if the incinerator was operating at normal conditions.

A summary of the sampling log for the test program is presented in Table 1-2. The summary shows the samples collected and sampling times as well as any problems that occurred.

1.4.4 Laboratory Analysis

The laboratory analyses were performed by three organizations. The CDD/CDF analyses were performed entirely by Triangle Laboratories, Inc., in Research Triangle Park, NC. The trace metals analyses were performed by the Nuclear Energy Services of North Carolina State University in Raleigh, NC. The particulate samples were weighed at the Radian/RTP Laboratory.

The CDD/CDF samples were analyzed by high resolution gas chromatography and high resolution mass spectrometry (GC/MS). The congeners that are reported are listed in Table 1-3. The total mono- through octa-chlorinated homologues are reported, along with all the individual 2378-substituted CDD/CDF isomers such as 2378-TCDD.

TABLE 1-2. SUMMARY OF SAMPLING LOG AT THE NORTH ANDOVER FACILITY
July 8 to 16, 1986

DATE	RUN	SAMPLES COLLECTED	SAMPLING[a] PERIOD	NOTES
7/8/86	1	Controlled CDD/CDF ESP ash, total combined ash, CEMs, controlled PM, controlled TOCL	13:20 - 18:37	Uncontrolled CDD/CDF sampling for Run 1 was cancelled because the ESP inlet sampling location was not ready in time to test concurrently with ESP outlet. Port scrapings on the filter invalidated controlled particulate sample.
7/9/86	2	Uncontrolled and controlled CDD/CDF, ESP ash, total combined ash, CEMs, controlled PM, controlled TOCL	10:15 - 19:29	For the inlet CDD/CDF train, three probe liners were used and recovered. Two of the liners were broken during port changes.
7/10/86	3	Uncontrolled and controlled CDD/CDF, ESP ash, total combined ash, CEMs, controlled PM, controlled TOCL	10:29 - 16:30	No sampling or combustor operating problems occurred.
7/11/86	4	Uncontrolled and controlled CDD/CDF, ESP ash, total combined ash, CEMs, controlled PM, controlled TOCL	11:30 - 16:09	Sampling time increased to 240 minutes from 192 minutes. No sampling or combustor operating problems occurred.
7/12/86	5	Uncontrolled and controlled CDD/CDF, ESP ash, total combined ash, CEMs, controlled PM, controlled TOCL	11:40 - 17:52	Combustor developed a broken grate bar during sampling. Underfire air ports were manually cleaned. Combustor operation was determined by Signal to be normal. The grate bar was repaired overnight.

TABLE 1-2. SUMMARY OF SAMPLING LOG AT THE NORTH ANDOVER FACILITY
July 8 to 16, 1986
(Continued)

DATE	RUN	SAMPLES COLLECTED	SAMPLING[a] PERIOD	NOTES
7/13/86	6	Uncontrolled and controlled CDD/CDF, ESP ash, total combined ash, CEMs, controlled PM, controlled TOCL	12:40 - 20:46	The combustor was determined by Signal not to be operating at normal conditions. The basis for this decision has not been provided by Signal. Also, the CDD/CDF samples were not collected simultaneously at the ESP inlet and ESP outlet.
7/14/86	7	Uncontrolled and controlled metals and PM, ESP ash, CEMs	14:20 - 20:00	Outlet probe liner broke at the nozzle; liner changed.
7/15/86	8	Uncontrolled and controlled metals and PM, ESP ash, CEMs	9:30 - 13:50	No sampling or combustor operating problems occurred.
7/16/86	9	Uncontrolled and controlled metals and PM, ESP ash, CEMs	9:38-14:06	No sampling or combustor operating problems occurred.

[a]The sampling period includes time for port changes and other breaks in sampling.

TABLE 1-3. CHLORINATED ORGANIC COMPOUNDS ANALYZED FOR NORTH ANDOVER TEST PROGRAM

DIOXINS
Monochloro dibenzo-p-dioxin (MCDD)
Total dichlorinated dibenzo-p-dioxins (DCDD)
Total Trichlorinated dibenzo-p-dioxins (TrCDD)
2,3,7,8 Tetrachlorodibenzo-p-dioxin (2,3,7,8 TCDD)
Total Tetrachlorinated dibenzo-p-dioxins (TCDD)
1,2,3,7,8 Pentachlorodibenzo-p-dioxin (1,2,3,7,8 PCDD)
Total Pentachlorinated dibenzo-p-dioxins (PCDD)
1,2,3,4,7,8 Hexachlorodibenzo-p-dioxin (1,2,3,4,7,8 HxCDD)
1,2,3,6,7,8 Hexachlorodibenzo-p-dioxin (1,2,3,6,7,8 HxCDD)
1,2,3,7,8,9 Hexachlorodibenzo-p-dioxin (1,2,3,7,8,9 HxCDD)
Total Hexachlorinated dibenzo-p-dioxins (HxCDD)
Total Heptachlorinated dibenzo-p-dioxins (HpCDD)
Total Octachlorinated dibenzo-p-dioxins (OCDD)
FURANS
Monochloro dibenzofuran (MCDF)
Total dichlorinated dibenzofurans (DCDF)
Total Trichlorinated dibenzofurans (TrCDF)
2,3,7,8 Tetrachlorodibenzofurans (2,3,7,8 TCDF)
Total Tetrachlorinated dibenzofurans (TCDF)
1,2,3,7,8 Pentachlorodibenzofuran (1,2,3,7,8 PCDF)
2,3,4,7,8 Pentachlorodibenzofuran (2,3,4,7,8 PCDF)
Total Pentachlorinated dibenzofurans (PCDF)
1,2,3,4,7,8 Hexachlorodibenzofuran (1,2,3,4,7,8 HxCDF)
1,2,3,6,7,8 Hexachlorodibenzofuran (1,2,3,6,7,8 HxCDF)
1,2,3,7,8,9 Hexachlorodibenzofuran (1,2,3,7,8,9 HxCDF)
Total Hexachlorinated dibenzofurans (HxCDF)
Total Heptachlorinated dibenzofurans (HpCDF)
Total Octachlorinated dibenzofurans (OCDF)

The trace metal samples were analyzed by neutron activation analysis (NAA). With this method, the samples are exposed to neutrons causing them to emit gamma rays which are counted and compared to standards for quantification. NAA cannot be used for lead and beryllium because these metals do not emit gamma rays. The flue gas trace metals results for arsenic, cadmium, chromium and nickel are presented in this report. The NAA analytical method is not a validated method, however, and the results should be used for screening purposes only. The results of NAA analysis of the ESP ash are presented in Section 2 of this report.

The particulate concentrations were determined by gravimetric analysis. The appropriate portions of the sample train were dessicated, evaporated, and weighed to determine the amount of particulate matter collected during sampling.

1.5 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

A QA/QC program was established prior to testing at North Andover RESCO. Completeness and data quality were emphasized during the test program, so QA/QC provisions were incorporated into each sampling or analytical task. The details of the QA/QC results are included in the emission test reports (References 1 and 2).

All but two of the CDD/CDF analyses met the QA/QC criteria. The internal standard recoveries for these two samples were outside the desired criteria, but did not make the samples invalid. Field, laboratory, and method blanks were also analyzed for CDD/CDF. They contained insignificant concentrations of CDD/CDF.

The TOCL/Particulate analysis met the QA/QC criteria for all samples. Blank analyses yielded results which would not affect the sample analyses.

Blank analyses for metals sampling revealed that no significant contamination was caused by recovery and handling of the metals sampling trains. The neutron activation analysis used for determining metals

concentrations yielded less than 10 percent difference in the analysis of three sets of duplicate samples. Analysis of metals reference standards showed that 91 percent of the analyses were within tolerances established by the National Bureau of Standards.

1.6 DESCRIPTION OF REPORT SECTIONS

The summary of results is presented in Section 2. The evaluation of the incinerator and ESP operating data is included in Section 3. Summaries of the sampling methods and QA/QC results are presented in Sections 4 and 5, respectively.

2.0 SUMMARY OF RESULTS

Included in this section are the results of CDD/CDF, TOCL, particulates, and metals sampling for both the uncontrolled and controlled flue gas streams at North Andover RESCO. Also presented is a discussion of the results and an explanation of data variability, where applicable. Combustor or ESP operating abnormalities are analyzed in relation to pertinent data.

Where applicable, dual units (English and metric) are presented side-by-side in each table. For results such as CDD/CDF concentrations, only the most suitable units (ng/dscm in this case) are presented.

2.1 COMPARISON OF INLET AND OUTLET CDD/CDF RESULTS

CDD/CDF results for the uncontrolled and controlled flue gas, ESP ash, and total ash discharge samples are presented and discussed in this section. A total of five complete CDD/CDF sample sets were collected. However, only the three uncontrolled flue gas samples which were most representative in terms of sampling and combustor operating parameters were analyzed for CDD/CDF. These samples were collected during Runs 3, 4 and 5. The sample from Run 1 was not collected because the inlet sampling location was not ready. The sample for Run 2 was not analyzed because the probe liner broke three times; two of these breakages were during port changes. Since the controlled and uncontrolled CDD/CDF samples were not collected simultaneously during Run 6, the Run 6 sample was not analyzed. The controlled results for Run 6 are not reported because the combustor was determined by Signal to be operating at abnormal conditions.

In comparisons of CDD/CDF flue gas data for the uncontrolled versus controlled streams, only Runs 3, 4 and 5 are presented. The concentrations are normalized to 12% CO_2 to allow comparison to other data in the EPA MSW data base.

2.1.1 CDD/CDF Emissions Results

The uncontrolled and controlled CDD/CDF emissions results are summarized along with average flue gas characteristics in Table 2-1. For the uncontrolled flue gas, the average total CDDs were 169 ng/dscm at 12 percent CO_2 and the average total CDFs were 173 ng/dscm at 12 percent CO_2. For the controlled flue gas, the average total CDDs were 100 ng/dscm at 12% CO_2 and the average total CDFs were 323 ng/dscm at 12 percent CO_2.

Uncontrolled homologue and isomer-specific results for Runs 3, 4 and 5 are summarized in Table 2-2, and the controlled results for Runs 1-5 are presented in Table 2-3. The data in these tables are normalized to 12 percent CO_2. The average total uncontrolled CDD result was 169 ng/dscm at 12 percent CO_2 and the average total uncontrolled CDF results was 173 ng/dscm at 12 percent CO_2. The average total controlled CDD result was 124 ng/dscm at 12 percent CO_2, while the average total controlled CDF result was 336 ng/dscm at 12 percent CO_2.

2.1.2 ESP Control Efficiency of CDD/CDF

The control device efficiencies are calculated for the CDD/CDF results for Runs 3, 4 and 5. The control efficiencies are calculated based on mass rates to account for possible inleakage across the ESP. The control efficiencies are calculated separately for each congener and are summarized along with the flue gas concentrations in Table 2-4.

From the data in Table 2-4, it appears that the ESP was not effective at controlling CDD/CDF emissions. The control efficiencies for the individual homologues as well as for total CDD and CDF varied widely for the three runs. The control efficiencies ranged from -151 percent to 63 percent for total CDD, total CDF, and total CDD/CDF. For particulates, however, as described later in Section 2.3, control efficiency averaged 99.46 percent.

TABLE 2-1. SUMMARY OF AVERAGE CDD/CDF EMISSIONS FOR NORTH ANDOVER RESCO

Emission	Run 3		Run 4		Run 5		Average	
	Uncontrolled	Controlled	Uncontrolled	Controlled	Uncontrolled	Controlled	Uncontrolled	Controlled
Flue Gas Characteristics								
Volume gas sampled (dscf)	75.9	88.0	97.0	106.5	97.3	106.2	90.1	100.2
Flow rate (dscfm)	84,600	86,000	87,500	85,400	88,600	82,500	86,900	84,600
Temperature (^{o}F)	580	556	584	567	591	566	585	563
Percent moisture by volume	13.1	12.8	12.9	12.6	14.2	13.6	13.4	13.0
Percent isokinetic	100.1	104.1	99.0	101.5	98.0	104.8	99.0	103.5
CO (ppm by volume, dry)[a]	NA	25.7	NA	45.2	NA	25.7	NA	32.2
CO_2 (percent by volume, dry)[a]	10.0	8.9	10.0	9.6	9.9	9.8	10.0	9.4
O_2 (percent by volume, dry)[a]	10.0	10.5	10.3	10.7	10.1	10.1	10.1	10.4
Average opacity (percent)	NA	0.12	NA	0.12	NA	0.13	NA	0.12
Process operations								
Steam load (10^3 lbs/hr)	166		166		167		166	
Dioxin Results								
Total CDD (ng/dscm)	280	102	56	59	87	81	141	81
Total CDD (corrected to 12% CO_2, ng/dscm)	336	124	67	74	105	101	169	100
Furan Results								
Total CDF (ng/dscm)	161	396	129	166	140	224	143	262
Total CDF (corrected to 12% CO_2, ng/dscm)	193	480	155	210	170	278	173	323
Dioxin/Furan Results								
Total CDD-CDF (ng/dscm)	441	498	185	225	227	306	284	343
Total CDD-CDF (corrected to 12% CO_2, ng/dscm)	528	604	222	284	275	378	342	422

[a]Controlled values are averages of data taken over the sampling period from continuous emissions monitors. Uncontrolled values were obtained using EPA Method 3 (Orsat analysis).

NA = parameter not monitored at the ESP inlet location.

TABLE 2-2. UNCONTROLLED CDD/CDF EMISSIONS AT NORTH ANDOVER RESCO

ISOMER	CONCENTRATION (ng/dscm, corrected to 12% CO2) Run 3	Run 4	Run 5	Average
DIOXINS				
Mono-CDD	[0.002][a]	[0.0004]	[0.0004]	0.00
Di-CDD	4.23	2.14	1.93	2.77
Tri-CDD	21.9	5.49	6.68	11.4
2378 TCDD	3.75	0.271	0.522	1.51
Other TCDD	31.2	5.55	7.97	14.9
12378 PCDD	2.05	0.694	0.908	1.22
Other PCDD	63.5	7.54	11.6	27.6
123478 HxCDD	2.70	0.672	1.10	1.49
123678 HxCDD	6.60	1.24	1.63	3.16
123789 HxCDD	3.04	2.02	[0.004]	1.69
Other HxCDD	85.9	9.70	18.7	38.1
Hepta-CDD	69.1	14.9	23.8	35.9
Octa-CDD	41.8	16.7	29.7	29.4
TOTAL CDD	336	66.9	105	169
FURANS				
Mono-CDF	1.38	3.22	0.140	1.58
Di-CDF	26.6	25.9	13.2	21.9
Tri-CDF	73.4	57.4	62.1	64.3
2378 TCDF	11.4	9.02	11.7	10.7
Other TCDF	35.6	27.0	34.2	32.3
12378 PCDF	2.15	1.93	2.40	2.16
23478 PCDF	4.13	3.53	4.40	4.02
Other PCDF	12.7	9.18	13.3	11.7
123478 HxCDF	4.58	2.93	4.29	3.93
123678 HxCDF	1.56	1.01	2.47	1.68
123789 HxCDF	[0.002]	0.057	[0.002]	0.019
Other HxCDF	6.66	3.86	6.11	5.54
Hepta-CDF	9.64	7.99	12.4	10.0
Octa-CDF	2.84	1.97	3.34	2.71
TOTAL CDF	193	155	170	173
TOTAL CDD/CDF	528	222	275	342
Norm. ratio[b]	1.20	1.20	1.21	

[a] Not detected. Detection limit given in brackets. Congeners that were not detected were considered zero when summing total CDD, CDF, and CDD/CDF.

[b] Norm. ratio = normalization ratio of 12 percent CO2 to actual CO2 measured which is used to normalize the results to a standard basis.

TABLE 2-3. CONTROLLED CDD/CDF EMISSIONS AT NORTH ANDOVER RESCO

ISOMER	CONCENTRATION (ng/dscm, corrected to 12% CO2) Run 1	Run 2	Run 3	Run 4	Run 5	Average
DIOXINS	[a]					
Mono-CDD	[0.002]	[0.002]	[0.005]	[0.003]	[0.007]	0.00
Di-CDD	3.95	3.67	1.75	2.18	2.16	2.75
Tri-CDD	10.2	11.03	3.80	5.13	4.96	7.03
2378 TCDD	1.27	1.73	0.628	0.619	0.748	0.998
Other TCDD	19.1	21.59	7.26	7.69	8.18	12.8
12378 PCDD	2.85	3.06	1.42	0.970	1.57	1.97
Other PCDD	28.0	33.4	11.9	8.21	10.4	18.4
123478 HxCDD	[12.9]	[14.3]	1.70	0.949	1.58	0.847
123678 HxCDD	[12.8]	[13.5]	2.75	1.49	2.08	1.26
123789 HxCDD	[14.3]	[16.4]	[0.054]	0.293	4.19	0.896
Other HxCDD	5.20	9.06	26.0	14.2	15.6	14.0
Hepta-CDD	46.2	53.2	37.2	17.6	27.1	36.3
Octa-CDD	36.7	30.4	29.1	15.0	22.0	26.6
TOTAL CDD	154	167	124	74.3	101	124
FURANS						
Mono-CDF	0.901	0.521	2.03	1.73	0.497	1.14
Di-CDF	40.0	28.6	8.39	23.5	21.7	24.4
Tri-CDF	96.0	99.6	59.6	64.7	59.5	75.9
2378 TCDF	23.4	28.4	21.0	12.9	14.9	20.1
Other TCDF	76.0	83.5	49.4	45.1	42.7	59.3
12378 PCDF	7.02	7.27	4.56	2.72	3.84	5.08
23478 PCDF	15.1	13.4	11.4	4.50	7.03	10.3
Other PCDF	64.9	38.6	29.9	15.7	19.8	33.8
123478 HxCDF	[6.47]	[7.06]	18.5	6.15	9.31	6.80
123678 HxCDF	[6.74]	[7.35]	5.06	2.82	2.49	2.08
123789 HxCDF	[9.17]	[10.5]	[0.034]	[0.010]	[0.041]	0.00
Other HxCDF	2.47	4.65	0.672	7.99	14.1	5.99
Hepta-CDF	34.8	32.7	119	19.2	40.2	49.2
Octa-CDF	6.59	5.90	151	2.96	41.5	41.6
TOTAL CDF	367	343	480	210	278	336
TOTAL CDD/CDF	521	510	604	284	378	460
Norm. ratio [b]	1.28	1.35	1.21	1.26	1.24	

[a] Not detected. Detection limit given in brackets. Congeners that were not detected were considered zero when summing total CDD, CDF, and CDD/CDF.

[b] Norm. ratio = normalization ratio of 12 percent CO2 to actual CO2 measured which is used to normalize the results to a standard basis.

TABLE 2-4. CDD/CDF CONTROL EFFICIENCIES FOR NORTH ANDOVER RESCO

ISOMER	RUN 3 Uncontrolled (ng/dscm @ 12% CO2)	RUN 3 Controlled (ng/dscm @ 12% CO2)	RUN 3 Control Efficiency (%) [a]	RUN 4 Uncontrolled (ng/dscm @ 12% CO2)	RUN 4 Controlled (ng/dscm @ 12% CO2)	RUN 4 Control Efficiency (%) [a]	RUN 5 Uncontrolled (ng/dscm @ 12% CO2)	RUN 5 Controlled (ng/dscm @ 12% CO2)	RUN 5 Control Efficiency (%) [a]	Average Control [b]
DIOXINS										
Mono-CDD	[0.001] [c]	[0.005]	ND [d]	[0.0004]	[0.003]	ND	[0.0004]	[0.007]	ND	ND
Di-CDD	4.23	1.75	58	2.14	2.18	5.5	1.94	2.16	-1.6	+
Tri-CDD	21.9	3.80	83	5.49	5.13	13	6.71	4.96	33	+
2378 TCDD	3.75	0.63	83	0.27	0.62	-112	0.52	0.75	-30	-
Other TCDD	31.2	7.26	77	5.55	7.69	-29	8.00	8.18	6.9	+
12378 PCDD	2.05	1.42	30	0.69	0.97	-30	0.91	1.57	-56	-
Other PCDD	63.5	11.9	81	7.54	8.21	-0.9	11.7	10.4	19	+
123478 HxCDD	2.70	1.70	37	0.67	0.95	-31	1.00	1.58	-44	-
123678 HxCDD	6.60	2.75	58	1.24	1.49	-11	1.64	2.08	-15	+
123789 HxCDD	3.04	[0.054]	100	2.02	0.29	87	[0.004]	4.19	-- (e)	+
Other HxCDD	85.9	26.0	69	9.70	14.2	-35	18.7	15.6	24	+
Hepta-CDD	69.1	37.2	46	14.9	17.6	-10	23.9	27.1	-3.3	+
Octa-CDD	41.8	29.1	30	16.7	15.0	17	29.8	22.0	33	+
TOTAL CDD	336	124	63	66.9	74.3	-3.0	105	101	13	+
FURANS										
Mono-CDF	1.38	2.03	-48	3.22	1.73	50	0.14	0.50	-221	-
Di-CDF	26.6	8.39	68	25.9	23.5	16	13.3	21.7	-49	+
Tri-CDF	73.4	59.6	18	57.4	64.7	-4.6	62.3	59.5	13	+
2378 TCDF	11.4	21.0	-85	9.02	12.9	-33	11.8	14.9	-15	-
Other TCDF	35.6	49.4	-40	27.0	45.1	-55	34.3	42.7	-13	-
12378 PCDF	2.15	4.56	-114	1.93	2.72	-31	2.41	3.84	-45	-
23478 PCDF	4.13	11.4	-177	3.53	4.50	-18	4.42	7.03	-45	-
Other PCDF	12.7	29.9	-137	9.18	15.7	-59	13.3	19.8	-35	-
123478 HxCDF	4.58	18.5	-307	2.93	6.15	-95	4.30	9.31	-97	-
123678 HxCDF	1.56	5.06	-226	1.01	2.82	-159	1.50	2.49	-51	-
123789 HxCDF	[0.002]	[0.034]	ND	0.06	[0.010]	100	[0.002]	[0.041]	ND	+
Other HxCDF	6.66	0.67	90	3.86	7.99	-92	6.13	14.1	-110	-
Hepta-CDF	9.64	119	-1142	7.99	19.2	-123	12.4	40.2	-195	-
Octa-CDF	2.84	151	-5258	1.97	2.96	-39	3.35	41.5	-1027	-
TOTAL CDF	193	480	-151	155	210	-26	170	278	-49	-
TOTAL CDD/CDF	528	604	-15	222	284	-19	275	378	-25	-

[a] Control efficiencies were calculated based on mass flow rates.

[b] Average control indicates if the average control efficiency is greater or less than zero (+ = greater than zero, - = less than zero).

[c] Not detected. Detection limit given in brackets. Congeners that were not detected were considered zero when summing CDD, CDF, and CDD/CDF.

[d] ND = not determined. Congener not detected in either uncontrolled or controlled flue gas; no basis to assume control or non-control.

[e] Uncontrolled concentration not detected and controlled concentration detected. Control efficiency could not be calculated.

The actual control efficiencies for CDD/CDFs in the gas may be obscured by sampling and analytical uncertainties in the calculated values. Measured CDD/CDF concentrations are considered to have an analytical uncertainty of ±50 percent. Calculated control efficiencies between 67 and -200 percent may actually be either positive or negative when the analytical uncertainty is considered.

2.1.3 CDD/CDF ESP Ash and Total Ash Discharge Results

The ESP ash sample was collected from an access door on the screw conveyor prior to the ESP ash being mixed with the other process ash. A sample was collected every 30 minutes during flue gas sampling. Ash sampling began 45 minutes after the start of the flue gas sampling. Approximately 4 pounds of ESP ash were collected during each run and composited. An aliquot of the composite sample was placed in a 950 mL amber glass bottle. Approximately 10 grams of this aliquot was extracted by Triangle Laboratories for CDD/CDF analysis.

The results of the CDD/CDF analysis of the ESP ash are summarized in Table 2-5. The average 2378-TCDD concentration was 0.2 ng/g and the average 2378-TCDF concentration was 1.9 ng/g. The average total CDD concentration was 55 ng/g and the average total CDF concentration was 48 ng/g. The average total CDD/CDF concentration was 103 ng/g.

The total ash discharge sample was collected at the end of the vibrating conveyor at the point where the ash was falling onto the belt conveyor which transported the ash to the storage facility. Prior to the sampling point, the bottom ash passed through a 10-inch scalper and rotating magnetic separator. The magnetic separator for ferrous recovery was not operating during the first three runs, but was brought back on-line for Runs 4-6. Then, the ESP ash and boiler ash were added to the bottom ash on the vibrating conveyor belt to form the total ash discharge.

The total ash discharge sample was riffled three times before it was coned and quartered into a 15 kg sample. Metal components larger than two

TABLE 2-5. CDD/CDF RESULTS OF THE ESP ASH ANALYSES

ISOMER	CONCENTRATION (ng/g or ppb, mass basis) Run 1	Run 2	Run 3	Run 4	Run 5	Average[a]
DIOXINS						
Mono-CDD	[0.001][b]	[0.001]	[0.001]	[0.001]	0.00	0.00
Di-CDD	0.06	0.07	0.04	0.04	0.04	0.05
Tri-CDD	1.00	0.40	0.49	0.36	0.43	0.54
2378 TCDD	0.35	0.09	0.17	0.11	0.14	0.17
Other TCDD	4.31	1.44	2.09	1.22	1.66	2.14
12378 PCDD	1.13	0.43	0.82	0.47	0.65	0.70
Other PCDD	8.00	3.23	5.11	3.35	4.23	4.78
123478 HxCDD	1.79	0.51	1.10	0.66	0.88	0.99
123678 HxCDD	[0.001]	0.80	1.65	0.98	1.32	0.95
123789 HxCDD	[0.001]	[0.001]	[0.001]	[0.001]	0.00	0.00
Other HxCDD	17.4	6.13	12.8	7.69	10.3	10.9
Hepta-CDD	22.3	9.79	18.1	13.0	15.5	15.7
Octa-CDD	30.6	9.72	17.5	14.7	16.1	17.7
TOTAL CDD	86.9	32.6	59.9	42.5	51.2	54.6
FURANS						
Mono-CDF	[0.001]	[0.001]	[0.001]	[0.001]	0.00	0.00
Di-CDF	[0.001]	[0.001]	0.59	0.42	0.51	0.30
Tri-CDF	5.50	3.14	4.03	3.07	3.55	3.86
2378 TCDF	3.36	1.32	1.92	1.27	1.60	1.89
Other TCDF	15.3	5.27	7.62	5.32	6.47	7.99
12378 PCDF	1.22	0.35	0.62	0.42	0.52	0.63
23478 PCDF	2.36	0.85	1.38	0.91	1.15	1.33
Other PCDF	14.5	4.35	7.15	4.90	6.03	7.38
123478 HxCDF	5.41	1.28	2.76	1.87	2.32	2.73
123678 HxDCF	2.56	0.69	1.35	0.83	1.09	1.30
123789 HxCDF	[0.001]	[0.001]	[0.001]	[0.001]	0.00	0.00
Other HxCDF	14.9	2.98	7.33	4.37	5.85	7.09
Hepta-CDF	21.3	5.65	10.7	8.01	9.36	11.0
Octa-CDF	4.94	1.20	2.27	1.75	2.01	2.43
TOTAL CDF	91.3	27.1	47.7	33.1	40.4	47.9
TOTAL CDD/CDF	178	59.7	108	75.7	91.7	103

[a] Average of duplicate analyses.

[b] Not detected. Detection limit given in brackets. Congeners that were not detected were considered zero when summing total CDD, CDF and CDD/CDF.

inches were caught by the riffler and removed from the sample. An average of seven percent (by weight) of the sample was removed by the riffler. The riffled sample was then returned to Radian/RTP for further compositing. A 1 kg aliquot was sent to Triangle Laboratories for CDD/CDF analysis. The remaining ash was archived for possible leachate analyses.

The results of the CDD/CDF analyses of the total ash discharge samples are summarized in Table 2-6. The average total CDD concentration was 8.2 ng/g and the average total CDF concentration 5.3 ng/g. The average total CDD and CDF concentration in the total ash discharge samples was 13.5 ng/g.

The CDD/CDF concentrations reported for the total ash discharge were adjusted for inerts. Inerts are components of the total ash discharge, such as metal and glass larger than one inch in diameter, which are removed from the total ash discharge sample as the sample is placed in the sample bottle. The weights of the discarded inerts were recorded and the CDD/CDF concentrations which are ppb, by weight, were adjusted accordingly.

2.1.4 CDD/CDF Analyte-to-Particulate Ratios

The analyte-to-particulate ratios are calculated by dividing the total CDD/CDF concentration (ng/dscm) in the flue gas by the particulate front half concentration (mg/dscm) in the flue gas which expresses the ratio in microgram of analyte per gram of total particulate. Ratios for the controlled flue gas stream are presented in Table 2-7.

Uncontrolled particulate samples were not collected during Runs 3, 4 and 5; therefore no corresponding uncontrolled CDD/CDF analyte-to-particulate data are available. However, uncontrolled particulate samples were collected during Runs 7, 8 and 9. Thus, the uncontrolled analyte-to-particulate ratios were calculated by dividing average particulate data from Runs 7 to 9 into average CDD/CDF data from Runs 3 to 5 for each isomer. These ratios are presented in Table 2-8, along with the average controlled ratios for runs 2 to 5. Also included in this table are average CDD/CDF concentrations in the ESP ash and total ash discharge samples.

TABLE 2-6. CDD/CDF RESULTS OF THE TOTAL ASH DISCHARGE ANALYSES[a]

ISOMER	CONCENTRATION (ng/g or ppb, mass basis) Run 1	Run 2	Run 3	Run 4	Run 5	Average
DIOXINS						
Mono-CDD	[0.001][b]	[0.001]	[0.001]	[0.001]	[0.001]	0.00
Di-CDD	[0.001]	0.07	0.03	0.01	0.16	0.05
Tri-CDD	0.03	0.32	0.16	0.03	0.43	0.19
2378 TCDD	0.02	0.08	0.08	0.02	0.10	0.06
Other TCDD	0.05	0.50	0.40	0.04	0.61	0.32
12378 PCDD	0.06	0.16	0.22	0.04	0.24	0.14
Other PCDD	0.17	0.66	0.74	0.12	0.94	0.53
123478 HxCDD	0.06	0.14	0.19	0.04	0.22	0.13
123678 HxCDD	0.09	0.17	0.24	0.05	0.25	0.16
123789 HxCDD	[0.002]	[0.001]	[0.002]	[0.002]	[0.001]	0.00
Other HxCDD	0.68	1.37	2.04	0.42	2.38	1.38
Hepta-CDD	0.99	2.07	2.59	0.55	3.52	1.94
Octa-CDD	1.17	3.21	4.78	0.73	6.39	3.26
TOTAL CDD	3.32	8.75	11.5	2.05	15.2	8.17
FURANS						
Mono-CDF	[0.001]	[0.001]	[0.001]	[0.001]	0.03	0.01
Di-CDF	0.06	0.14	0.10	0.07	0.35	0.14
Tri-CDF	0.20	0.93	0.71	0.16	1.28	0.66
2378 TCDF	0.11	0.42	0.04	0.07	0.52	0.23
Other TCDF	0.23	0.92	1.02	0.11	1.05	0.67
12378 PCDF	0.04	0.17	0.18	0.05	0.34	0.16
23478 PCDF	0.07	0.21	0.24	0.04	0.23	0.16
Other PCDF	0.11	0.30	0.30	0.05	0.53	0.26
123478 HxCDF	[0.001]	[0.001]	[0.627]	0.05	0.38	0.09
123678 HxDCF	0.02	[0.001]	[0.001]	[0.001]	[0.001]	0.00
123789 HxCDF	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]	0.00
Other HxCDF	0.22	0.56	0.62	0.06	0.67	0.43
Hepta-CDF	0.27	0.75	0.71	0.12	1.38	0.65
Octa-CDF	0.17	0.57	7.63	[0.006]	1.01	1.88
TOTAL CDF	1.50	4.97	11.5	0.78	7.77	5.31
TOTAL CDD/CDF	4.82	13.7	23.0	2.83	23.0	13.5

[a] Results are adjusted for inerts.

[b] Not detected. Detection limit given in brackets. Congeners that were not detected were considered zero when summing total CDD, CDF, and CDD/CDF.

TABLE 2-7. RATIO OF CONTROLLED CDD/CDF TO PARTICULATE EMISSIONS

ISOMER	ANALYTE-TO-PARTICULATE RESULTS[a] (ng analyte per g particulate) Run 2	Run 3	Run 4	Run 5	Average
DIOXINS					
Mono-CDD	ND[b]	ND	ND	ND	ND
Di-CDD	322	595	295	396	402
Tri-CDD	968	1293	694	908	966
2378 TCDD	152	214	84	137	147
Other TCDD	1894	2469	1041	1498	1726
12378 PCDD	268	483	131	288	293
Other PCDD	2932	4034	1111	1910	2497
123478 HxCDD	ND	578	129	289	249
123678 HxCDD	ND	935	202	381	379
123789 HxCDD	ND	ND	39	767	202
Other HxCDD	795	8857	1915	2855	3605
Hepta-CDD	4663	12653	2387	4971	6168
Octa-CDD	2666	9901	2032	4026	4656
TOTAL CDD	14659	42014	10060	18427	21290
FURANS					
Mono-CDF	46	690	234	92	265
Di-CDF	2508	2854	3180	3974	3129
Tri-CDF	8738	20255	8756	10899	12162
2378 TCDF	2491	7133	1748	2727	3525
Other TCDF	7321	16803	6106	7821	9512
12378 PCDF	638	1551	368	703	815
23478 PCDF	1178	3867	609	1288	1735
Other PCDF	3385	10184	2129	3628	4831
123478 HxCDF	ND	6306	832	1705	2211
123678 HxCDF	ND	1721	382	456	640
123789 HxCDF	ND	ND	ND	ND	0
Other HxCDF	408	228	1081	2590	1077
Hepta-CDF	2873	40466	2602	7355	13324
Octa-CDF	518	51347	401	7595	14965
TOTAL CDF	30104	163408	28427	50836	68194
TOTAL CDD/CDF	44762	205422	38488	69263	89484

[a] Only front half particulate data were used.

[b] ND = not detected. Minimum detection limit depends on analyte concentration and particulate concentration.

TABLE 2-8. FLUE GAS AND ASH CDD/CDF ANALYTE-TO-PARTICULATE RATIOS
Averages for Runs 1 to 5

ISOMER	FLUE GAS Uncontrolled[a] (ng/g)[b]	FLUE GAS Controlled (ng/g)[b]	ASH ESP (ng/g ash)	ASH Total Discharge (ng/g ash)
DIOXINS				
Mono-CDD	ND[c]	ND	ND	ND
Di-CDD	1.29	402	0.05	0.05
Tri-CDD	5.31	966	0.54	0.19
2378 TCDD	0.708	147	0.17	0.06
Other TCDD	6.97	1730	2.14	0.32
12378 PCDD	0.570	293	0.70	0.14
Other PCDD	12.9	2500	4.78	0.53
123478 HxCDD	0.697	249	0.99	0.13
123678 HxCDD	1.48	379	0.95	0.16
123789 HxCDD	0.789	202	ND	ND
Other HxCDD	17.8	3610	10.9	1.38
Hepta-CDD	16.8	6170	15.7	1.94
Octa-CDD	13.7	4660	17.7	3.26
TOTAL CDD	79.1	21300	54.6	8.17
FURANS				
Mono-CDF	0.739	265	ND	0.01
Di-CDF	10.3	3130	0.30	0.14
Tri-CDF	30.1	12200	3.86	0.66
2378 TCDF	5.02	3530	1.89	0.23
Other TCDF	15.1	9510	7.99	0.67
12378 PCDF	1.01	815	0.63	0.16
23478 PCDF	1.88	1740	1.33	0.16
Other PCDF	5.49	4830	7.38	0.26
123478 HxCDF	1.84	2210	2.73	0.09
123678 HxCDF	0.786	640	1.30	0.00
123789 HxCDF	0.009	ND	ND	ND
Other HxCDF	2.59	1080	7.09	0.43
Hepta-CDF	4.68	13300	11.0	0.65
Octa-CDF	1.27	15000	2.43	1.88
TOTAL CDF	80.7	68200	47.9	5.31
TOTAL CDD/CDF	160	89500	103	13.5

a The average particulate loading for Runs 7, 8, and 9 and the average CDD/CDF concentration for Runs 2 to 5 were used to calculate the uncontrolled CDD/CDF ratio.

b ng/g = ng CDD/CDF per gram of particulate.

c ND = not detected in the flue gas. Detection limit varies with each congener and is not presented here.

The large difference between the uncontrolled and controlled ratios indicates that the ESP is much better at removing particulate matter than CDD/CDF. This suggests that CDD/CDF exists either mostly in the flue gas vapor phase, or on a fine particulate that is largely unaffected by the ESP.

2.1.5 2378-TCDD Toxic Equivalency

The CDD/CDF results for uncontrolled and controlled emissions are expressed in terms of 2378-TCDD toxicity equivalents (corrected to 12 percent CO_2) in Table 2-9. Each isomer has a 2378-TCDD toxicity equivalency factor[4] (also presented in Table 2-9), which ranks the toxicity of the isomer relative to the toxicity of 2378-TCDD. The equivalency factors were developed by EPA and are used in risk analysis models. In terms of 2378-TCDD toxicity equivalents, the average uncontrolled total CDD/CDF concentration was 4.5 ng/dscm; the average controlled total CDD/CDF 2378-TCDD toxic equivalent concentration was 6.2 ng/dscm.

The ESP ash and total ash discharge CDD/CDF concentrations are expressed in terms of 2378-TCDD toxicity equivalents in Tables 2-10 and 2-11. In terms of 2378-TCDD equivalents, the ESP ash average total CDD/CDF concentration was 1.1 ng/g. The total ash discharge samples showed a 2378-TCDD toxic equivalent concentration of 0.2 ng/g for average total CDD/CDF.

2.1.6 Isomer Distributions

The distributions of CDD/CDF isomers expressed on a mole fraction basis are presented in Table 2-12 for the uncontrolled and controlled flue gas streams, Table 2-13 for the ESP ash samples, and Table 2-14 for the total ash discharge samples. Isomer distributions are also shown graphically in Figures 2-1 and 2-2.

In the uncontrolled flue gas, hexa, hepta, and octa-CDDs were the most prevalent at about 20 mole percent each. The penta-CDDs were also abundant at about 10 mole percent. A similar pattern is also found in the controlled flue gas. The ESP ash and total ash discharge show a small shift from the lower

TABLE 2-9. CDD/CDF CONCENTRATIONS EXPRESSED AS 2378-TCDD TOXIC EQUIVALENTS

		2378-TCDD Toxic Equivalent Concentration (ng/dscm @ 12% CO2)									
	2378 TCDD EQUIV.	Uncontrolled Flue Gas				Controlled Flue Gas					
ISOMER	FACTORS	Run 3	Run 4	Run 5	Average	Run 1	Run 2	Run 3	Run 4	Run 5	Average
DIOXINS											
Mono-CDD	0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Di-CDD	0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tri-CDD	0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2378 TCDD	1.0000	3.75	0.271	0.522	1.51	1.27	1.73	0.628	0.619	0.748	0.998
Other TCDD	0.0100	0.312	0.055	0.080	0.149	0.191	0.216	0.073	0.077	0.082	0.128
12378 PCDD	0.5000	1.03	0.347	0.454	0.609	1.42	1.53	0.711	0.485	0.783	0.987
Other PCDD	0.0050	0.318	0.038	0.058	0.138	0.140	0.167	0.059	0.041	0.052	0.092
123478 HxCDD	0.0400	0.108	0.027	0.044	0.060	0.000	0.000	0.068	0.038	0.063	0.034
123678 HxCDD	0.0400	0.264	0.050	0.065	0.126	0.000	0.000	0.110	0.060	0.083	0.051
123789 HxCDD	0.0400	0.122	0.081	0.000	0.067	0.000	0.000	0.000	0.012	0.168	0.036
Other HxCDD	0.0004	0.034	0.004	0.007	0.015	0.002	0.004	0.010	0.006	0.006	0.006
Hepta-CDD	0.0010	0.069	0.015	0.024	0.036	0.046	0.053	0.037	0.018	0.027	0.036
Octa-CDD	0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TOTAL CDD		6.00	0.887	1.25	2.71	3.07	3.70	1.70	1.35	2.01	2.37
FURANS											
Mono-CDF	0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Di-CDF	0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tri-CDF	0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2378 TCDF	0.1000	1.14	0.902	1.17	1.07	2.34	2.84	2.10	1.29	1.49	2.01
Other TCDF	0.0010	0.036	0.027	0.034	0.032	0.076	0.083	0.049	0.045	0.043	0.059
12378 PCDF	0.1000	0.215	0.193	0.240	0.216	0.702	0.727	0.456	0.272	0.384	0.508
23478 PCDF	0.1000	0.413	0.353	0.440	0.402	1.51	1.34	1.14	0.450	0.703	1.03
Other PCDF	0.0010	0.013	0.009	0.013	0.012	0.065	0.039	0.030	0.016	0.020	0.034
123478 HxCDF	0.0100	0.046	0.029	0.043	0.039	0.000	0.000	0.185	0.061	0.093	0.068
123678 HxCDF	0.0100	0.016	0.010	0.025	0.017	0.000	0.000	0.051	0.028	0.025	0.021
123789 HxCDF	0.0100	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other HxCDF	0.0001	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.001	0.001	0.001
Hepta-CDF	0.0010	0.010	0.008	0.012	0.010	0.035	0.033	0.119	0.019	0.040	0.049
Octa-CDF	0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TOTAL CDF		1.89	1.53	1.98	1.80	4.73	5.07	4.12	2.18	2.80	3.78
TOTAL CDD/CDF		7.89	2.42	3.24	4.51	7.80	8.77	5.82	3.54	4.81	6.15

TABLE 2-10. ESP ASH CDD/CDF RESULTS EXPRESSED AS 2378-TCDD TOXIC EQUIVALENTS

ISOMER	2378-TCDD Toxic Equiv. Factors	2378-TCDD TOXIC EQUIVALENT CONCENTRATION (ng/g or ppb, mass basis) Run 01	Run 02	Run 03	Run 04	Run 5[a]	Average
DIOXINS							
Mono-CDD	0.0000	0.000	0.000	0.000	0.000	0.000	0.000
Di-CDD	0.0000	0.000	0.000	0.000	0.000	0.000	0.000
Tri-CDD	0.0000	0.000	0.000	0.000	0.000	0.000	0.000
2378 TCDD	1.0000	0.350	0.090	0.170	0.110	0.140	0.172
Other TCDD	0.0100	0.043	0.014	0.021	0.012	0.017	0.021
12378 PCDD	0.5000	0.565	0.215	0.410	0.235	0.323	0.350
Other PCDD	0.0050	0.040	0.016	0.026	0.017	0.021	0.024
123478 HxCDD	0.0400	0.072	0.020	0.044	0.026	0.035	0.040
123678 HxCDD	0.0400	0.000	0.032	0.066	0.039	0.053	0.038
123789 HxCDD	0.0400	0.000	0.000	0.000	0.000	0.000	0.000
Other HxCDD	0.0004	0.007	0.002	0.005	0.003	0.004	0.004
Hepta-CDD	0.0010	0.022	0.010	0.018	0.013	0.016	0.016
Octa-CDD	0.0000	0.000	0.000	0.000	0.000	0.000	0.000
TOTAL CDD		1.10	0.400	0.760	0.456	0.608	0.664
FURANS							
Mono-CDF	0.0000	0.000	0.000	0.000	0.000	0.000	0.000
Di-CDF	0.0000	0.000	0.000	0.000	0.000	0.000	0.000
Tri-CDF	0.0000	0.000	0.000	0.000	0.000	0.000	0.000
2378 TCDF	0.1000	0.336	0.132	0.192	0.127	0.160	0.189
Other TCDF	0.0010	0.015	0.005	0.008	0.005	0.006	0.008
12378 PCDF	0.1000	0.122	0.035	0.062	0.042	0.052	0.063
23478 PCDF	0.1000	0.236	0.085	0.138	0.091	0.115	0.133
Other PCDF	0.0010	0.014	0.004	0.007	0.005	0.006	0.007
123478 HxCDF	0.0100	0.054	0.013	0.028	0.019	0.023	0.027
123678 HxDCF	0.0100	0.026	0.007	0.014	0.008	0.011	0.013
123789 HxCDF	0.0100	0.000	0.000	0.000	0.000	0.000	0.000
Other HxCDF	0.0001	0.001	0.000	0.001	0.000	0.001	0.001
Hepta-CDF	0.0010	0.021	0.006	0.011	0.008	0.009	0.011
Octa-CDF	0.0000	0.000	0.000	0.000	0.000	0.000	0.000
TOTAL CDF		0.826	0.287	0.459	0.306	0.382	0.452
TOTAL CDD/CDF		1.93	0.687	1.22	0.761	0.990	1.12

a Average of duplicate analyses for Run 5.

TABLE 2-11. TOTAL ASH DISCHARGE CDD/CDF RESULTS EXPRESSED AS 2378-TCDD TOXIC EQUIVALENTS

ISOMER	2378-TCDD Toxic Equiv. Factors	2378-TCDD TOXIC EQUIVALENT CONCENTRATION (ng/g or ppb, mass basis) Run 01	Run 02	Run 03	Run 04	Run 05	Average
DIOXINS							
Mono-CDD	0.0000	0.000	0.000	0.000	0.000	0.000	0.000
Di-CDD	0.0000	0.000	0.000	0.000	0.000	0.000	0.000
Tri-CDD	0.0000	0.000	0.000	0.000	0.000	0.000	0.000
2378 TCDD	1.0000	0.020	0.080	0.080	0.020	0.100	0.060
Other TCDD	0.0100	0.001	0.005	0.004	0.000	0.006	0.003
12378 PCDD	0.5000	0.030	0.080	0.110	0.020	0.120	0.072
Other PCDD	0.0050	0.001	0.003	0.004	0.001	0.005	0.003
123478 HxCDD	0.0400	0.002	0.006	0.008	0.002	0.009	0.005
123678 HxCDD	0.0400	0.004	0.007	0.010	0.002	0.010	0.006
123789 HxCDD	0.0400	0.000	0.000	0.000	0.000	0.000	0.000
Other HxCDD	0.0004	0.000	0.001	0.001	0.000	0.001	0.001
Hepta-CDD	0.0010	0.001	0.002	0.003	0.001	0.004	0.002
Octa-CDD	0.0000	0.000	0.000	0.000	0.000	0.000	0.000
TOTAL CDD		0.059	0.183	0.218	0.045	0.254	0.152
FURANS							
Mono-CDF	0.0000	0.000	0.000	0.000	0.000	0.000	0.000
Di-CDF	0.0000	0.000	0.000	0.000	0.000	0.000	0.000
Tri-CDF	0.0000	0.000	0.000	0.000	0.000	0.000	0.000
2378 TCDF	0.1000	0.011	0.042	0.004	0.005	0.052	0.023
Other TCDF	0.0010	0.000	0.001	0.001	0.000	0.001	0.001
12378 PCDF	0.1000	0.004	0.017	0.018	0.000	0.034	0.015
23478 PCDF	0.1000	0.007	0.021	0.024	0.000	0.023	0.015
Other PCDF	0.0010	0.000	0.000	0.000	0.000	0.001	0.000
123478 HxCDF	0.0100	0.000	0.000	0.000	0.001	0.004	0.001
123678 HxDCF	0.0100	0.000	0.000	0.000	0.000	0.000	0.000
123789 HxCDF	0.0100	0.000	0.000	0.000	0.000	0.000	0.000
Other HxCDF	0.0001	0.000	0.000	0.000	0.000	0.000	0.000
Hepta-CDF	0.0010	0.000	0.001	0.001	0.000	0.001	0.001
Octa-CDF	0.0000	0.000	0.000	0.000	0.000	0.000	0.000
TOTAL CDF		0.023	0.082	0.048	0.006	0.116	0.055
TOTAL CDD/CDF		0.081	0.265	0.266	0.052	0.370	0.207

TABLE 2-12. UNCONTROLLED AND CONTROLLED ISOMER DISTRIBUTIONS AT NORTH ANDOVER RESCO

ISOMER	MOLE FRACTION									
	UNCONTROLLED				CONTROLLED					
	Run 03	Run 04	Run 05	Average	Run 01	Run 02	Run 03	Run 04	Run 05	Average
DIOXIN										
Mono-CDD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Di-CDD	0.02	0.05	0.03	0.03	0.04	0.03	0.02	0.04	0.03	0.03
Tri-CDD	0.09	0.11	0.09	0.09	0.09	0.09	0.04	0.09	0.07	0.07
2378 TCDD	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Other TCDD	0.11	0.10	0.09	0.10	0.15	0.15	0.07	0.12	0.10	0.12
12378 PCDD	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.02	0.02
Other PCDD	0.20	0.12	0.12	0.15	0.19	0.21	0.11	0.12	0.11	0.15
123478 HxCDD	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.02	0.01
123678 HxCDD	0.02	0.02	0.02	0.02	0.00	0.00	0.02	0.02	0.02	0.01
123789 HxCDD	0.01	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.04	0.01
Other HxCDD	0.25	0.14	0.18	0.19	0.03	0.05	0.21	0.19	0.15	0.13
Hepta-CDD	0.18	0.20	0.21	0.20	0.27	0.28	0.28	0.21	0.25	0.26
Octa-CDD	0.10	0.21	0.24	0.18	0.20	0.15	0.20	0.17	0.18	0.18
FURAN										
Mono-CDF	0.01	0.03	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.01
Di-CDF	0.17	0.20	0.10	0.16	0.14	0.11	0.03	0.14	0.11	0.10
Tri-CDF	0.41	0.39	0.41	0.40	0.29	0.32	0.17	0.34	0.26	0.28
2378 TCDF	0.06	0.05	0.07	0.06	0.06	0.08	0.05	0.06	0.06	0.06
Other TCDF	0.18	0.16	0.20	0.18	0.20	0.24	0.12	0.21	0.16	0.19
12378 PCDF	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01
23478 PCDF	0.02	0.02	0.02	0.02	0.04	0.03	0.03	0.02	0.02	0.03
Other PCDF	0.06	0.05	0.07	0.06	0.16	0.10	0.07	0.07	0.07	0.09
123478 HxCDF	0.02	0.01	0.02	0.02	0.00	0.00	0.04	0.02	0.03	0.02
123678 HxCDF	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01
123789 HxCDF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other HxCDF	0.03	0.02	0.03	0.02	0.01	0.01	0.00	0.03	0.04	0.02
Hepta-CDF	0.04	0.04	0.05	0.04	0.07	0.07	0.22	0.07	0.12	0.11
Octa-CDF	0.01	0.01	0.01	0.01	0.01	0.01	0.26	0.01	0.11	0.08

TABLE 2-13. CDD/CDF ISOMER DISTRIBUTIONS IN THE ESP ASH SAMPLES

ISOMER	MOLE FRACTIONS					
	Run 01	Run 02	Run 03	Run 04	Run 05[a]	Overall Average
DIOXINS						
Mono-CDD	0.00	0.00	0.00	0.00	0.00	0.00
Di-CDD	0.00	0.00	0.00	0.00	0.00	0.00
Tri-CDD	0.02	0.02	0.01	0.01	0.01	0.01
2378 TCDD	0.01	0.00	0.00	0.00	0.00	0.00
Other TCDD	0.06	0.06	0.04	0.04	0.04	0.05
12378 PCDD	0.01	0.02	0.02	0.01	0.01	0.01
Other PCDD	0.11	0.11	0.10	0.09	0.10	0.10
123478 HxCDD	0.02	0.02	0.02	0.02	0.02	0.02
123678 HxCDD	0.00	0.03	0.03	0.02	0.03	0.02
123789 HxCDD	0.00	0.00	0.00	0.00	0.00	0.00
Other HxCDD	0.21	0.20	0.22	0.19	0.21	0.21
Hepta-CDD	0.25	0.29	0.29	0.30	0.29	0.28
Octa-CDD	0.31	0.26	0.26	0.31	0.28	0.29
FURANS						
Mono-CDF	0.00	0.00	0.00	0.00	0.00	0.00
Di-CDF	0.00	0.00	0.02	0.02	0.02	0.01
Tri-CDF	0.08	0.15	0.11	0.12	0.11	0.11
2378 TCDF	0.04	0.05	0.05	0.04	0.04	0.05
Other TCDF	0.19	0.22	0.18	0.18	0.18	0.19
12378 PCDF	0.01	0.01	0.01	0.01	0.01	0.01
23478 PCDF	0.03	0.03	0.03	0.03	0.03	0.03
Other PCDF	0.16	0.16	0.15	0.15	0.15	0.16
123478 HxCDF	0.06	0.04	0.05	0.05	0.05	0.05
123678 HxDCF	0.03	0.02	0.03	0.02	0.03	0.02
123789 HxCDF	0.00	0.00	0.00	0.00	0.00	0.00
Other HxCDF	0.15	0.10	0.14	0.12	0.13	0.13
Hepta-CDF	0.20	0.17	0.19	0.21	0.20	0.19
Octa-CDF	0.04	0.03	0.04	0.04	0.04	0.04

[a]Average of duplicate analyses for Run 05.

TABLE 2-14. CDD/CDF DISTRIBUTION IN THE TOTAL ASH DISCHARGE SAMPLES

ISOMER	MOLE FRACTIONS					
	Run 01	Run 02	Run 03	Run 04	Run 05	Average
DIOXINS						
Mono-CDD	0.00	0.00	0.00	0.00	0.00	0.00
Di-CDD	0.00	0.01	0.00	0.01	0.02	0.01
Tri-CDD	0.01	0.05	0.02	0.02	0.04	0.03
2378 TCDD	0.01	0.01	0.01	0.01	0.01	0.01
Other TCDD	0.02	0.07	0.04	0.02	0.05	0.04
12378 PCDD	0.02	0.02	0.02	0.02	0.02	0.02
Other PCDD	0.06	0.09	0.07	0.07	0.07	0.07
123478 HxCDD	0.02	0.02	0.02	0.02	0.02	0.02
123678 HxCDD	0.03	0.02	0.02	0.03	0.02	0.02
123789 HxCDD	0.00	0.00	0.00	0.00	0.00	0.00
Other HxCDD	0.22	0.16	0.19	0.22	0.16	0.19
Hepta-CDD	0.29	0.23	0.22	0.26	0.22	0.24
Octa-CDD	0.32	0.32	0.38	0.32	0.37	0.34
FURANS						
Mono-CDF	0.00	0.00	0.00	0.25	0.01	0.05
Di-CDF	0.06	0.04	0.01	0.10	0.06	0.05
Tri-CDF	0.17	0.23	0.09	0.07	0.20	0.15
2378 TCDF	0.08	0.09	0.00	0.08	0.07	0.07
Other TCDF	0.17	0.20	0.11	0.08	0.15	0.14
12378 PCDF	0.03	0.03	0.02	0.00	0.04	0.02
23478 PCDF	0.05	0.04	0.02	0.00	0.03	0.03
Other PCDF	0.07	0.06	0.03	0.08	0.07	0.06
123478 HxCDF	0.00	0.00	0.00	0.15	0.04	0.04
123678 HxDCF	0.01	0.00	0.00	0.00	0.00	0.00
123789 HxCDF	0.00	0.00	0.00	0.00	0.00	0.00
Other HxCDF	0.13	0.10	0.06	0.07	0.08	0.09
Hepta-CDF	0.15	0.12	0.06	0.13	0.15	0.12
Octa-CDF	0.09	0.09	0.59	0.00	0.10	0.17

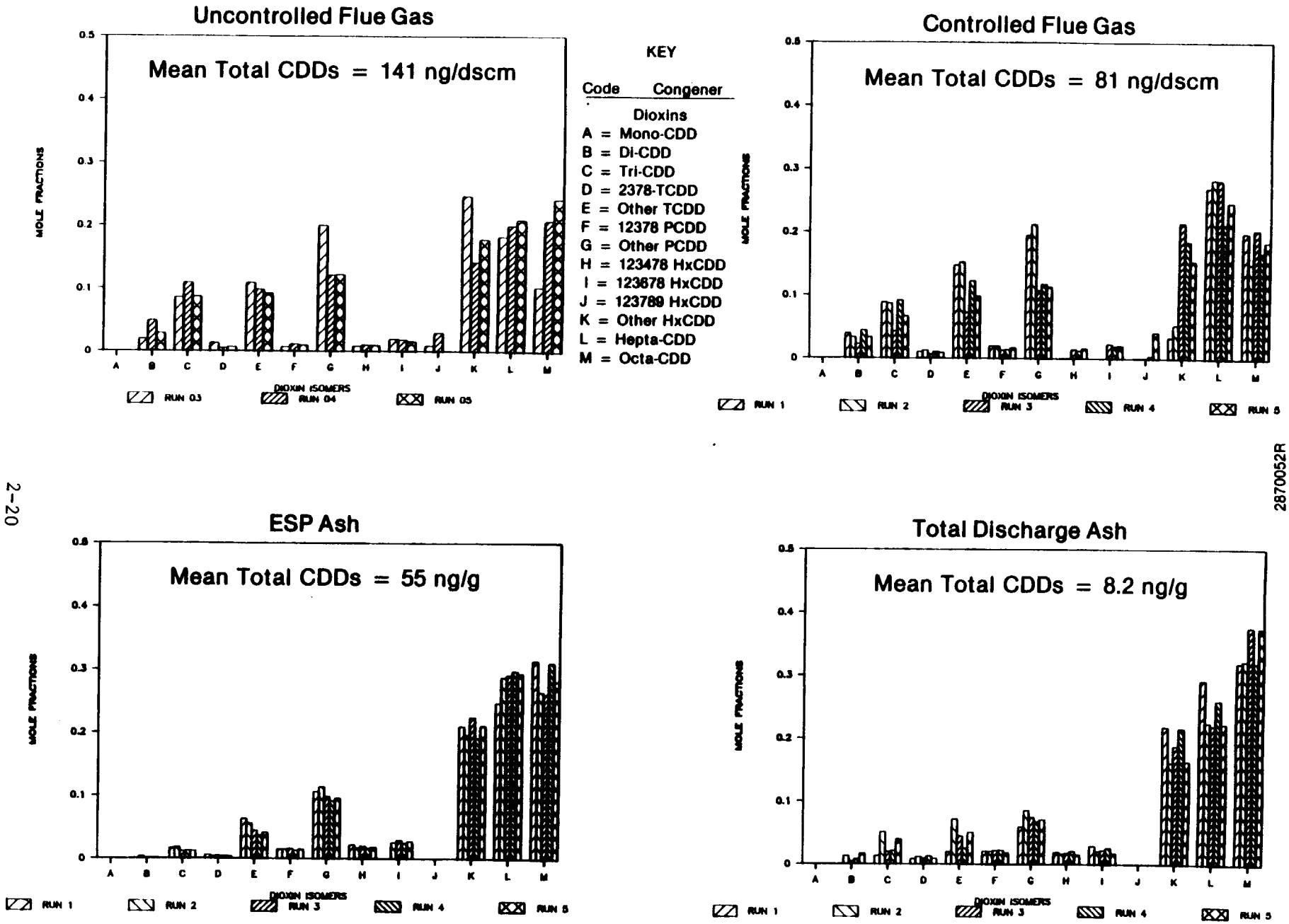

Figure 2-1. Comparison of CDD Isomer Distributions at North Andover RESCO

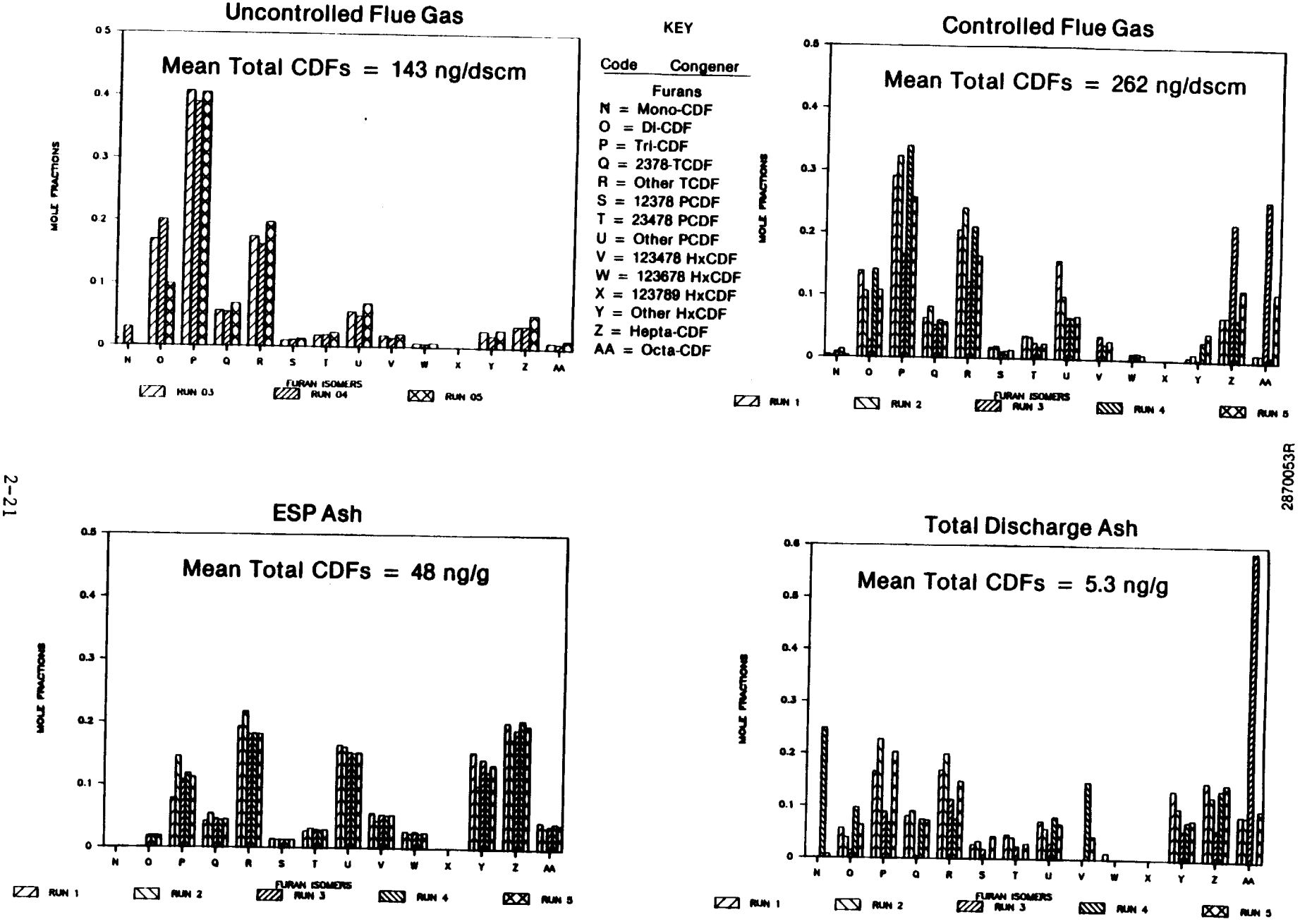

Figure 2-2. Comparison of CDF Isomer Distributions at North Andover RESCO

chlorinated isomers to the more highly chlorinated isomers, as compared with the flue gas isomer distributions.

In the uncontrolled flue gas, tri-CDF was the most prevalent at 40 mole percent, followed by other TCDF at 18 mole percent. The same pattern was found in the controlled flue gas, which showed tri-CDF at 28 mole percent, followed by other TCDF at 19 mole percent. The ESP ash and total discharge ash isomer distributions show a shift from the lower chlorinated furans (di- and tri-) to the higher chlorinated furans (hexa- and hepta-).

Overall, the data indicate that the ESP does not affect the distribution of the isomers in the flue gas. However, since the ESP ash shows a small shift to the more highly chlorinated congeners, these may be more readily condensing or forming on the particulate after removal from the flue gas.

2.2 TOTAL ORGANIC CHLORIDE (TOCL) RESULTS FOR THE CONTROLLED FLUE GAS

The controlled flue gas TOCL sampling trains were operated concurrently with the CDD/CDF flue gas sampling trains. Therefore, the TOCL results represent the concentration of total organic chloride that was in the controlled flue gas during the same time that CDD/CDF sampling was taking place. TOCL sampling followed the CDD/CDF sampling protocol except that hexane was used for sample recovery instead of methylene chloride. The TOCL results are presented in Table 2-15, and are compared with the average controlled 2378-TCDD, total CDD, total CDF, and total CDD/CDF results. No correlation between these values was recognized.

2.3 PARTICULATE RESULTS

The particulate loading was measured at North Andover RESCO at both the ESP inlet and ESP outlet locations. The uncontrolled and controlled results for Runs 7 through 9 are summarized in Table 2-16. Table 2-16 also includes flue gas and process parameters that were measured during testing. The average controlled result does not include Run 7. This result was determined to be a statistical outlier under the condition where extreme observations in either direction are considered rejectable.[5] The Run 7 controlled train

TABLE 2-15. CORRELATION OF TOCL RESULTS TO CDD/CDF RESULTS

Run	Average Controlled (ng/dscm)				
	TOCL	2378-TCDD	Total CDD	Total CDF	Total CDD/CDF
1	10.3	0.99	120.3	287.7	407.9
2	20.4	1.28	123.9	254.5	378.5
3	349.6	0.52	101.9	396.4	498.3
4	156.0	0.49	58.9	166.3	225.2
5	53.5	0.60	81.3	224.4	305.7

TABLE 2-16. SUMMARY OF UNCONTROLLED AND CONTROLLED PARTICULATE EMISSIONS FOR NORTH ANDOVER RESCO

Run No. / Date / Type Emissions	Run 7 07-14-86		Run 8 07-15-86		Run 9 07-16-86		Average[a]	
	Uncontrolled	Controlled	Uncontrolled	Controlled	Uncontrolled	Controlled	Uncontrolled	Controlled
Flue Gas Characteristics[b]								
Volume gas sampled (dscf)	83.8	120.5	85.3	114.9	82.7	119.9	--	--
Flow rate (dscfm)	91,700	98,300	93,500	94,800	92,200	97,300	92,500	96,050
Temperature (^{o}F)	599	579	600	575	609	587	603	581
Moisture (percent by volume)	16.1	15.4	14.3	13.6	14.3	13.7	14.9	13.7
Isokinetics (percent)	101.8	99.7	101.7	98.6	102.1	100.2	101.9	99.4
CO (ppm by volume, dry)[c]	NA	35.9	NA	35.7	NA	27.2	NA	32.9
CO_2 (percent by volume, dry)[c]	d	8.5	10.2	8.6	8.7	9.2	9.5	8.8
O_2 (percent by volume, dry)[c]	d	11.5	9.8	8.3[e]	11.1	10.5	10.5	11.0
Average opacity (percent)	NA	0.31	NA	0.14	NA	0.13	NA	0.19
Process operations								
Steam load (10^3 lbs/hr)		170		168		165		168
Particulate Results[f]								
Front Half Catch) (Probe, cyclone, and filter)								
mg - mass	4866	152.2	3450	23.6	3580	28.5	--	--
gr/dscf	0.8965	0.0195	0.6242	0.0032	0.6682	0.0037	0.7296	0.0035
gr/dscf (corrected to 12% CO_2)	1.148	0.0250	0.7366	0.0044	0.9221	0.0054	0.9356	0.0049
mg/dscm	2,052	44.6	1,429	7.25	1,529	8.39	1,670	7.82
mg/dscm (corrected to 12% CO_2)	2,627	57.1	1,686	10.0	2,100	12.2		
lbs/hr	705	16.4	501	2.58	528	3.06	578	2.82
Kg/hr	320	7.45	277	1.17	240	1.39	262	1.28
Collection Efficiency Percent	97.67		99.49		99.42		99.46	

[a] Values from Run 7 controlled are not included in averages. See Section 2.3 for explanation.

[b] Conversion factors: dscf x 0.028317 = dscm; dscfm x 0.028317 = dscmm; (^{o}F - 32) x 5/9 = ^{o}C
Standard conditions are 68^{o}F (20^{o}C) and 1 atm (1.01325 x 10^5 Pa).

[c] Controlled values are averages of data taken over the sampling period from continuous emission monitors at the ESP outlet location. Uncontrolled values were obtained using EPA Method 3 (Orsat analysis).

[d] The EPA Method 3 bag for Run 7 was contaminated with air for the uncontrolled sample. For Run 7 only, the controlled CEM results were used to adjust the uncontrolled data to a 12 percent CO_2 basis.

[e] This value is not included in the oxygen average and is considered an invalid data point.

[f] Particulate results are adjusted for blank results.

developed a broken liner during sampling in one of the ports. Considering this, the concentration would be expected to be lower than the average unless extraneous glass fragments were recovered in the sample. Instead, the concentration is higher. This could be attributed to the higher opacity during Run 7, except that Run 6 had an even higher average opacity while still having a controlled particulate loading within range of the data, which varied from 0.0013 to 0.0054 grains/dscf normalized to 12 percent CO_2. However, the metal-to-particulate ratios discussed in Section 2.4 are similar for all three runs, which indicates that the ESP may have malfunctioned during Run 7. Opacity data logged every 30 minutes shows a wide variation in opacity during Run 7, indicating that process upsets may have occurred. ESP operating data for Run 7 are not available for review at this time. Therefore, since a broken probe liner developed during Run 7 at the ESP outlet, and a malfunction of the combustor and/or ESP may have occurred, the Run 7 controlled particulate data are not included in the particulate averages presented.

The average uncontrolled particulate concentration normalized to 12 percent CO_2 was 0.9356 grains/dscf and the average controlled concentration was 0.0049 grains/dscf at 12 percent CO_2. The average collection efficiency of the ESP was 99.46 percent.

The controlled particulate loading was measured for all nine runs performed at North Andover RESCO. The results are summarized in Table 2-17. The average controlled particulate loading was 0.0036 grains/dscf normalized to 12 percent CO_2. However, the results from Runs 1, 6, and 7 are not included in the average.

The particulate loading results from Run 1 are considered invalid due to port scrapings that were collected on the filter. After Run 1, the ports were lined with stove pipe to prevent rusty flakes from the port from being drawn into the sampling train.

For Run 6, the combustor was determined by Signal Environmental Systems, Inc., to be operating at abnormal conditions after testing was

TABLE 2-17. SUMMARY OF CONTROLLED PARTICULATE EMISSIONS FOR NORTH ANDOVER RESCO

Run No. Date	Run 1 7-8-86	Run 2 7-9-86	Run 3 7-10-86	Run 4 7-11-86	Run 5 7-12-86	Run 6 7-13-86	Run 7 7-14-86	Run 8 7-15-86	Run 9 7-16-86	Average[a]
Flue Gas Characteristics[b]										
Volume gas sampled (dscf)	54.50	53.4	84.3	107.2	106.5	115.9	120.5	114.9	119.9	--
Flow rate (dscfm)	96,800	95,000	85,800	87,200	86,200	94,300	98,300	94,800	97,300	91,050
Temperature (^{o}F)	582	587	559	567	565	577	579	575	587	573
Moisture (percent by volume)	12.6	13.3	12.8	12.6	13.6	13.0	15.4	13.6	13.7	13.4
Isokinetics (percent)	100.7	100.6	100.0	100.0	100.6	100.0	99.7	98.6	100.2	100.0
CO (ppm by volume, dry)[c]	28.4	37.4	25.4	45.2	25.7	31.1	35.9	35.7	27.2	32.8
CO_2 (percent by volume, dry)[c]	9.0	8.9	8.9	9.6	9.8	9.2	8.5	8.6	9.2	9.2
O_2 (percent by volume, dry)[c]	10.9	10.9	10.5	10.7	10.1	10.8	11.5	8.3[d]	10.5	10.5
Average opacity (percent)	NR	0.10	0.12	0.12	0.13	0.55	0.31	0.14	0.13	0.12
Process operations										
Steam load (10^3 lbs/hr)	166	165	166	166	167	163	170	168	165	166
Particulate Results[e]										
Front Half Catch)										
(Probe, and filter)										
mg - mass	31.8	13.5	5.8	18.7	13.6	29.3	152.2	23.6	28.5	--
gr/dscf	0.0090	0.0039	0.0011	0.0027	0.0020	0.0039	0.0195	0.0032	0.0037	0.0028
gr/dscf (corrected to 12% CO_2)	0.0150	0.0050	0.0013	0.0032	0.0023	0.0048	0.0250	0.0044	0.0054	0.0036
mg/dscm	20.6	8.92	2.43	6.16	4.67	8.93	44.6	7.25	8.39	6.30
mg/dscm (corrected to 12% CO_2)	26.4	11.4	2.94	7.39	5.46	10.9	57.1	10.0	12.2	8.23
lbs/hr	7.47	3.17	0.781	2.01	1.51	3.15	16.4	2.58	3.06	2.19
Kg/hr	3.39	1.44	0.354	0.912	0.684	1.43	7.45	1.17	1.39	0.99

[a] Values from Runs 1, 6, and 7 are not included in the averages. See Section 2.3 for explanation.
[b] Conversion factors: dscf x 0.028317 = dscm; dscfm x 0.028317 = dscmm; (^{o}F - 32) x 5/9 = ^{o}C
Standard conditions are 68^{o}F (20^{o}C) and 1 atm (1.01325 x 10^5 Pa).
[c] These values are averages of data taken over the sampling period from continuous emissions monitors at the ESP outlet location.
[d] This value is not included in the O_2 average and is considered an invalid data point.
[e] Results are adjusted for blank results.
NR = data not recorded by plant.

completed. The combustor had developed a broken grate bar during Run 5 which was manually cleaned until Run 5 was completed. Then, the combustor was shut down overnight and repaired. When Run 6 began the next day, the combustor appeared to be operating normally but Signal later decide that the combustor was still in a start-up operating mode. Run 7 was not included in the average for the reasons discussed previously in this section.

2.4 METALS EMISSIONS RESULTS FOR NORTH ANDOVER RESCO

In order to screen the flue gas for multiple metals, the EPA Method 12 samples collected at the ESP inlet and ESP outlet were analyzed by NAA. The NAA analytical method has not been validated, however, and the results for cadmium, arsenic, total chromium, and nickel should be considered only as screening results. No lead results are reported for these analyses since NAA does not measure lead.

2.4.1 Flue Gas Metals Results

The metals emission results for the selected metals of interest are summarized in Table 2-18. These results should be considered as screening results because the NAA analytical method has not been validated. The average normalized arsenic concentration was 1,008 ug/dscm uncontrolled, and 2.83 ug/dscm controlled. The average ESP collection efficiency for arsenic was 99.74 percent. The average normalized cadmium concentration was 468 ug/dscm uncontrolled, and 16.2 ug/dscm controlled. The average ESP collection efficiency for cadmium was 96.65 percent. For total chromium, the average normalized concentration was 5,169 ug/dscm uncontrolled, and 5.2 ug/dscm controlled. The average ESP collection efficiency for total chromium was 99.87 percent. The average normalized nickel concentration was 487 ug/dscm uncontrolled, and 37.2 ug/dscm controlled. The average ESP collection efficiency for nickel was 81.75 percent.

Total chromium and arsenic demonstrated the highest collection efficiencies, with collection efficiencies in the greater than 99 percent

TABLE 2-1 SUMMARY OF EPA SPECIFIC METALS EMISSIONS FOR NORTH ANDOVER RESCO[a]

Type Emissions	Run 7 07-14-86 Uncontrolled	Run 7 07-14-86 Controlled	Run 8 07-15-86 Uncontrolled	Run 8 07-15-86 Controlled	Run 9 07-16-86 Uncontrolled	Run 9 07-16-86 Controlled	Average Uncontrolled	Average Controlled
Flue Gas Characteristics[b]								
Volume gas sampled (dscf)	83.8	120.5	85.3	114.9	82.7	119.9	--	--
Flow rate (dscfm)	91,700	98,300	93,500	94,800	92,200	97,300	92,500	96,050
Temperature (^{o}F)	599	579	600	575	609	587	603	581
Moisture (percent by volume)	16.1	15.4	14.3	13.6	14.3	13.7	14.9	13.7
Isokinetics (percent)	101.8	99.7	101.7	98.6	102.1	100.2	101.9	99.4
CO (ppm by volume, dry)[c]	NA	35.9	NA	35.7	NA	27.2	NA	32.9
CO_2 (percent by volume, dry)[c]	d	8.5	10.2	8.6	8.7	9.2	9.5	8.8
O_2 (percent by volume, dry)[c]	d	11.5	9.8	8.3[e]	11.1	10.5	10.5	11.0
Average opacity (percent)	NA	0.31	NA	0.14	NA	0.13	NA	0.19
Process operations								
Steam load (10^{3} lbs/hr)		170		168		165		168

Specific Metals Results[f] (Corrected to 12% CO_2) Element	Uncontrolled (ug/dscm)	Controlled (ug/dscm)	CE (%)[g]	Uncontrolled (ug/dscm)	Controlled (ug/dscm)	CE (%)[g]	Uncontrolled (ug/dscm)	Controlled (ug/dscm)	CE (%)[g]	Uncontrolled[h] (ug/dscm)	Controlled[h] (ug/dscm)	CE (%)[h]
Arsenic	786	25.6	96.51	981	2.35	99.79	1,036	3.30	99.68	1,008	2.83	99.74
Cadmium	402	34.6	90.78	470	6.93	98.72	465	25.4	94.57	468	16.2	96.65
Total chromium	2,494	2,291	1.51	3,370	10.4	99.73	6,968	0.00[i]	100.00	5,169	5.2	99.87
Nickel	594	1,357	-145	831	25.6	97.32	143	48.8	66.17	487	37.2	81.75

[a] The metals results are from NAA analysis. This analytical method has not been validated and the results should be considered for screening only. A quality assurance audit was performed for NAA metals analysis.

[b] Conversion factors: dscf x 0.028317 = dscm; dscfm x 0.028317 = dscmm; (^{o}F - 32) x 5/9 = ^{o}C
Standard conditions are 68^{o}F (20^{o}C) and 1 atm (1.01325 x 10^{5} Pa).

[c] Controlled values are averages of data taken over the sampling period from continuous emission monitors. Uncontrolled values were obtained using EPA Method 3 (Orsat analysis).

[d] The EPA Method 3 bag for the Run 7 uncontrolled sample was contaminated with air. For Run 7 only, the controlled CEM results were used to adjust the uncontrolled data to a 12 percent CO_2 basis.

[e] This value is not included in the average and is considered an invalid data point.

[f] These results are for the total train. Beryllium and lead determination not possible by NAA analysis. Values are corrected for blank results.

[g] CE = collection efficiency based on mass rates.

[h] Average concentrations and control efficiencies based on runs 8 and 9 only. Run 7 is not included because the outlet probe liner broke during the run.

[i] When a sample concentration is less than or equal to the blank concentration, the blank-adjusted sample concentration is reported as zero.

range. The ESP was less efficient for collecting cadmium, and was the least efficient for collecting nickel.

The specific metals results contain some outliers. Nickel and chromium in Run 7 have collection efficiencies that are very low or negative caused by a high controlled result. Although the results were adjusted for blanks, precleaned glassware was used, and contact of the train with metal was minimized, contamination may have occurred. The glass probe liner at the ESP outlet broke during this run, which may have been the source of the contamination. Thus, the results for all metals from Run 7 are not included in the averages reported.

2.4.2 ESP Ash Metals Results

The results of the ESP ash metals analyses by NAA are presented in Table 2-19. The most prevalent metals were aluminum, calcium, sodium, zinc, potassium, chlorine, iron, and titanium. These metals had concentrations ranging from 17,000 to 80,000 ppm. Total chromium was detected at 679 ppm, cadmium was detected at 356 ppm, arsenic was detected at 365 ppm, and nickel was detected at 243 ppm. Relatively large amounts of sodium in the sample may cause interference for elements nearby in the spectrum, such as arsenic, cadmium, potassium, bromine, antimony, and samarium. It is important to note here that the NAA analytical method is not an EPA validated method.

TABLE 2-19. SUMMARY OF ESP ASH METALS RESULTS

Element	MICROGRAM OF ELEMENT PER GRAM OF ASH (PPM)[a,b]			
	Run 07	Run 08	Run 09	Average
Aluminum	80208	84888	78073	81056
Calcium	64044	64856	83180	70693
Sodium	42350	46332	43271	43984
Zinc	29631	34904	37267	33934
Potassium	14193	30123	16556	20290
Chlorine	14730	27258	17392	19794
Iron	22791	14642	14928	17453
Titanium	16665	17231	16837	16911
Magnesium	6731	5600	6672	6334
Tin	2390	3813	4099	3434
Bromine	1956	1530	932	1473
Barium	1354	1594	1189	1379
Manganese	1263	1233	1169	1222
Copper	1115	1177	1317	1203
Antimony	1073	1000	973	1015
Chromium[c]	568	441	1029	679
Arsenic	75	465	554	365
Cadmium	274	392	401	356
Nickel	181	448	100	243

[a] When using NAA, sodium in the matrix may interfere with certain metals results.

[b] Results for the remaining metals are presented in Appendix I of Reference 1.

[c] Total chromium results are presented.

3.0 PROCESS DESCRIPTION AND OPERATION

This section contains a description of the combustor process and air pollution control system at the North Andover facility. The combustor operating conditions during testing are summarized in Section 3.3. The ESP operating conditions are not reported since they are considered confidential by the facility. The operating data have been summarized as averages calculated over each test run interval.

3.1 PROCESS DESCRIPTION

The North Andover facility, which began operation in 1985, consists of two identical mass-burn waterwall combustors. Each unit is designed to burn 685 Mg/day (750 ton/day) of municipal waste and produce 93,000 kg/hr (198,000 lb/hr) of steam at 4,130kPa (600 psig) and 400°C (750°F). Steam from both boilers drives a 40-MW turbine-generator. Figure 3-1 presents a diagram of the North Andover process line. Design data for the combustor are summarized in Tables 3-1 and 3-2.

The refuse is neither shredded nor sorted before it is transferred by overhead cranes from an enclosed pit to gravity-fed hoppers. Hydraulic rams, located at the bottom of the feed hoppers, are used to charge the waste onto Martin reciprocating grates.

Underfire and overfire air is drawn from the pit area to fuel the combustion process, which is designed to achieve temperatures in excess of 1370°C (2500°F). Underfire air is supplied through the grates, and overfire air is distributed through nozzles located on the front and rear walls above the flame zone.

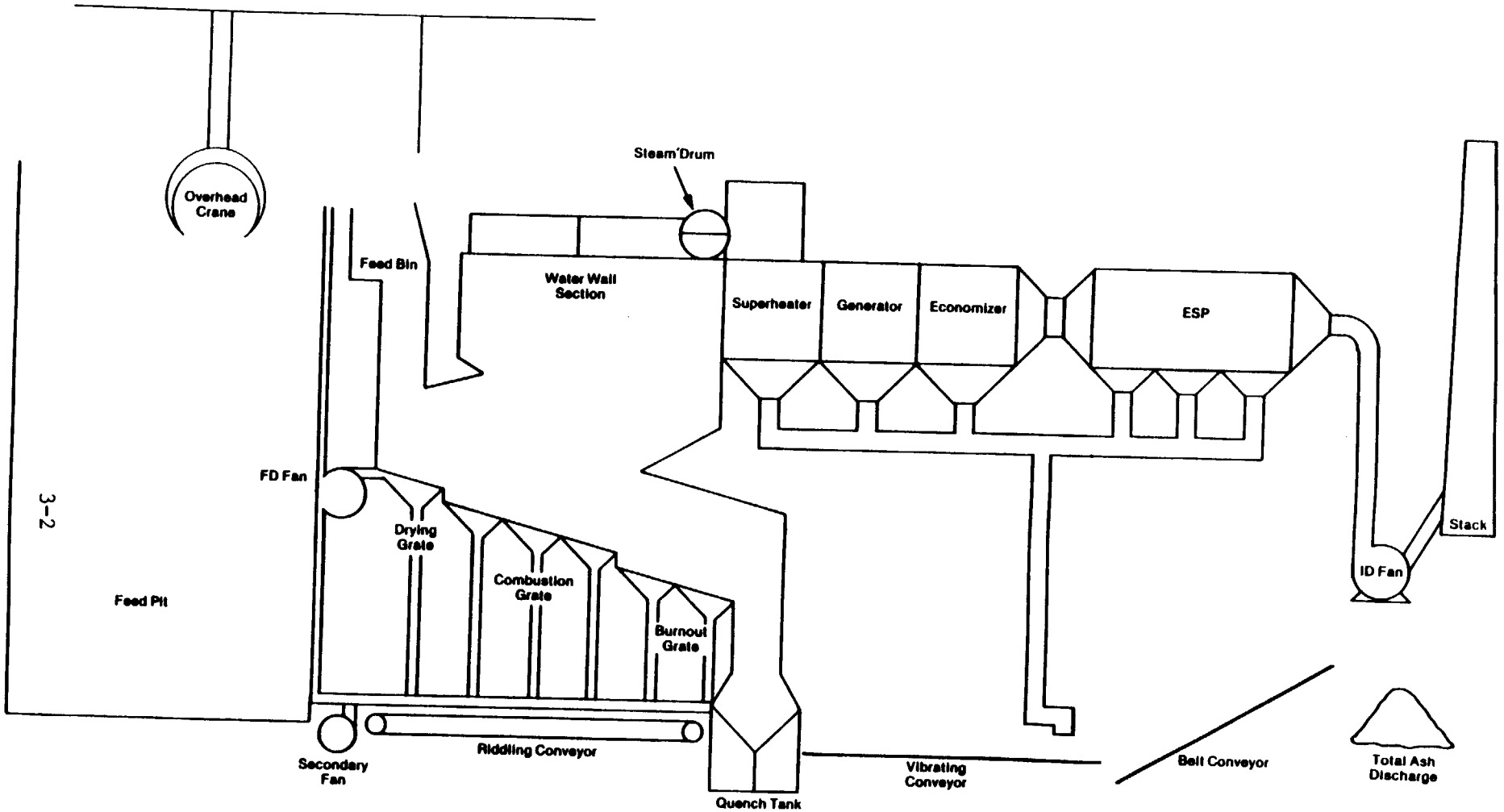

Figure 3 - 1. North Andover RESCO Process Line

TABLE 3-1. NORTH ANDOVER FACILITY STRUCTURAL DESIGN DATA

Chamber configuration				Heat transfer area		Grate data			
Primary chamber		Secondary chamber							
Geometric configuration	Volume, ft^3	Geometric configuration	Volume, ft^3	Radiative ft^2	Convective, ft^2	Type	No. of sections	Pressure drop	Capacity, tons/d
Rectangular	29,000	NA		2,700	50,700	Martin reciprocating			

TABLE 3-2. NORTH ANDOVER FACILITY AIRFLOW DESIGN DATA

Underfire air							Overfire air				
			Flow distribution, percent							Nozzle data	
No. of plenums	No. of controlled flows	Flow rate, acfm	Feed	Dry	Combustion	Burnout	Location	Flow direction	No.	Type	Velocity
		50,000					Front wall	Horizontal	30	2 3/4" diameter	
							Back wall	Inclined	31	2 3/4" diameter	

Each combustor has a volume of 820 m^3 (29,000 ft^3), and each combustor/boiler has 4,900 m^2 (53,000 ft^2) of heat transfer area. Bottom ash is quenched before being combined with the boiler fly ash and ESP ash.

Each unit is equipped with an in-situ CEM system for measuring carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), oxides of nitrogen (NO_x), sulfur dioxide (SO_2), and opacity. The CEM units are located just downstream of the ESP outlet sampling location.

3.2 AIR POLLUTION CONTROL SYSTEM

The air pollution control systems consists of two identical ESPs designed to reduce the particulate matter to a level of 115 mg/Nm^3 (0.05 grains/dscf) at 12 percent CO_2, which corresponds to about 98 percent collection efficiency. (Design data for the ESP's are considered confidential by the ESP manufacturer.)

3.3 EVALUATION OF INCINERATOR OPERATION DURING TESTING

Combustor and ESP operating conditions were monitored by plant personnel in the control room. The following combustor process parameters were recorded every 30 minutes: steam flow; steam drum pressure; superheater (SH) outlet temperature and pressure; economizer inlet feedwater (FW) temperature; economizer outlet FW temperature (east and west); gas temperature entering SH; gas temperature exiting economizer; percent oxygen exiting economizer; primary air temperature, pressure, and flow; forced draft (FD) fan percent damper opening; secondary air temperature, pressure (front and rear walls), flow, fan percent damper opening; and opacity.

The qualitative evaluation of the combustor operation during the sampling intervals was accomplished by plotting the process parameters against time. The plant operating data and the Radian CEM data sets were used. The combustor operating data, which were recorded manually every 30 minutes during testing, were entered into Lotus 1-2-3 spreadsheets to generate the plots. The Radian CEM data were recorded as one-minute averages. The data were imported into Lotus 1-2-3 spreadsheets to generate the plots.

Thirteen process parameters were included in the evaluation: oxygen, carbon monoxide and carbon dioxide measured at the ESP outlet sampling location; oxygen concentration at the economizer outlet; opacity upstream of the outlet sampling location; flue gas temperatures at the superheater inlet, superheater outlet and economizer outlet; steam load; primary air temperature and flow rate; forced draft fan damper opening; and grapple count.

The average values of process data recorded by the plant are presented in Tables 3-3 and 3-4. The individual data points are plotted in Figures 3-2 to 3-17. Each set of variables is shown on two consecutive figures. Runs 1-4 are on the first figure and Runs 5, 7, 8 and 9 are on the second figure. Run 6 data are not included in these figures and the following discussion because Signal determined that the process was operating abnormally during this run. Emissions data for Run 6 are not included in this report either.

3.3.1 Fixed Gases Evaluation (O_2, CO, CO_2) and THC

The fixed gases data shown in Figures 3-2 and 3-3 show that the oxygen concentration in the flue gas varied within a two percent range and was normal during the test period. Carbon monoxide rarely exceeded 50 ppm and showed the widest variation during Run 2 where it varied by 20 ppm. Carbon monoxide was at its highest during Run 4 when CO_2 was about 2 percent lower than the other runs. Overall, however, none of these parameters were significantly out of the normal operating ranges seen during the test program. The full-size plots of the carbon monoxide data are included in Figures 3-4 to 3-11.

Total hydrocarbons varied at most between 0.5 to 2 ppmv, on a dry basis as propane, during Runs 2-5. The average THC concentration was 0.9 ppm.

3.3.2 Flue Gas and Steam Temperature Evaluation

The superheater inlet temperature, superheater outlet temperature and economizer outlet temperature are plotted in Figures 3-12 and 3-13. For Runs 1-5, the flue gas temperatures at the superhater inlet and economizer were maintained at similar and constant levels. The steam exiting the

TABLE 3-3. AVERAGE PROCESS DATA FOR NORTH ANDOVER INCINERATOR TESTS
July 9 through 16, 1986

Date	Run	Steam load, lb/h x 10^3	Steam drum pressure, psig	S.H. out		Econ. in FW temp., ^oF	Econ. out FW temp., ^oF	Gas temp,	
				Temp., ^oF	Pressure, psig			In S.H., ^oF	Out econ., ^oF
07/08/86	1	166	NR[a]	760	600	225	498	1,233	569
07/09/86	2	165	670	759	600	225	498	1,281	570
07/10/86	3	166	674	751	600	226	498	1,245	547
07/11/86	4	166	680	755	600	226	498	1,257	562
07/12/86	5	166	680	757	NR	226	498	1,267	562
07/13/86	6	163	667	745	600	225	498	1,090	587
07/14/86	7	170	680	745	600	227	498	1,217	585
07/15/86	8	168	680	748	600	226	498	1,262	578
07/16/86	9	165	680	750	600	226	498	1,126	586

[a]NR = Not recorded by plant personnel.

TABLE 3-4. AVERAGE PROCESS DATA FOR NORTH ANDOVER INCINERATOR TESTS
July 9 through 16, 1986

Date	Run	Primary air			Secondary					FD fan damp open, percent	Buckets/ hour
		Temp., °F	Pressure in w.c.	Flow, 10^3 ft^3/min	Pressure, in w.c.		Flow, 10^3 ft^3/min		Fan damp opening, percent		
					Front	Back	Front	Back			
07/08/86	1	250	16.00	NR[a]	17.4	15.0	NR	NR	NR	NR	12
07/09/86	2	179.5	16.00	43.9	16.5	15.0	NR	NR	35.3	18.5	12
07/10/86	3	187.3	16.46	38.3	16.5	15.0	NR	NR	NR	15.0	12
07/11/86	4	184.6	16.00	38.8	16.3	15.0	NR	NR	NR	15.3	12
07/12/86	5	148.8	16.00	36.8	16.0	15.0	NR	NR	NR	15.5	13
07/13/86	6	82.8	16.00	43.9[b]	16.4	15.4	62.4[b]	41.3[b]	31.9	17.6	12
07/14/86	7	94.3	16.00	44.5[b]	16.1	15.3	66.5[b]	41.4[b]	31.9	17.3	NR
07/15/86	8	94.8	16.00	44.7[b]	16.1	15.0	69.3[b]	40.2[b]	33.6	18.9	15
07/16/86	9	100.3	16.00	45.9[b]	16.5	15.0	69.1[b]	40.1[b]	34.7	18.9	14

[a] NR = Not recorded by plant personnel.

[b] The air flow rates presented appear to be unrealistic because they would indicate that the combustor was operating at 70 percent overfire air. We believe that the data may have been incorrectly interpreted from the plant gauges or incorrectly recorded. Additional information was requested from facility personnel, but none was provided.

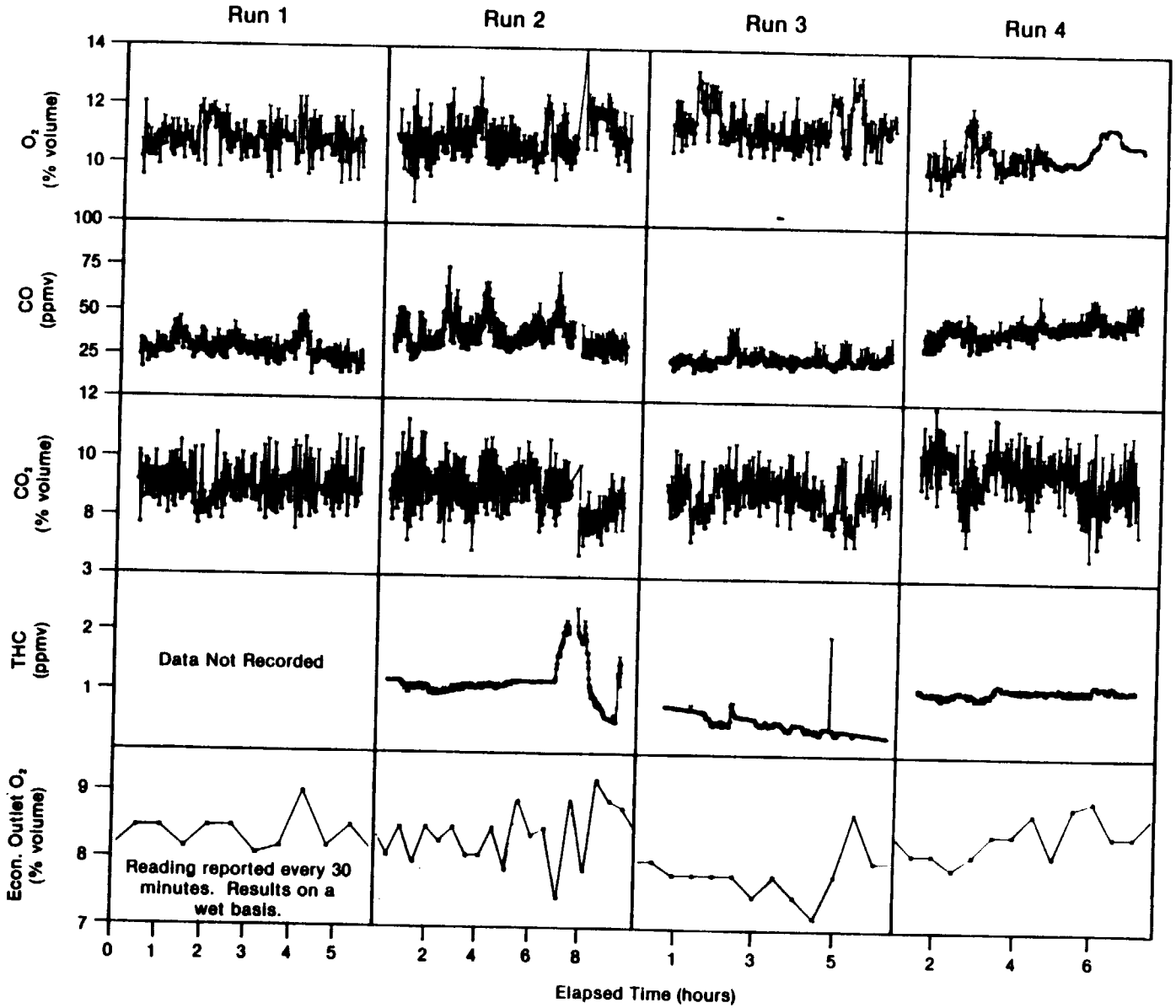

Figure 3-2. Variability of Fixed Gas Concentrations for Runs 1-4 at North Andover RESCO

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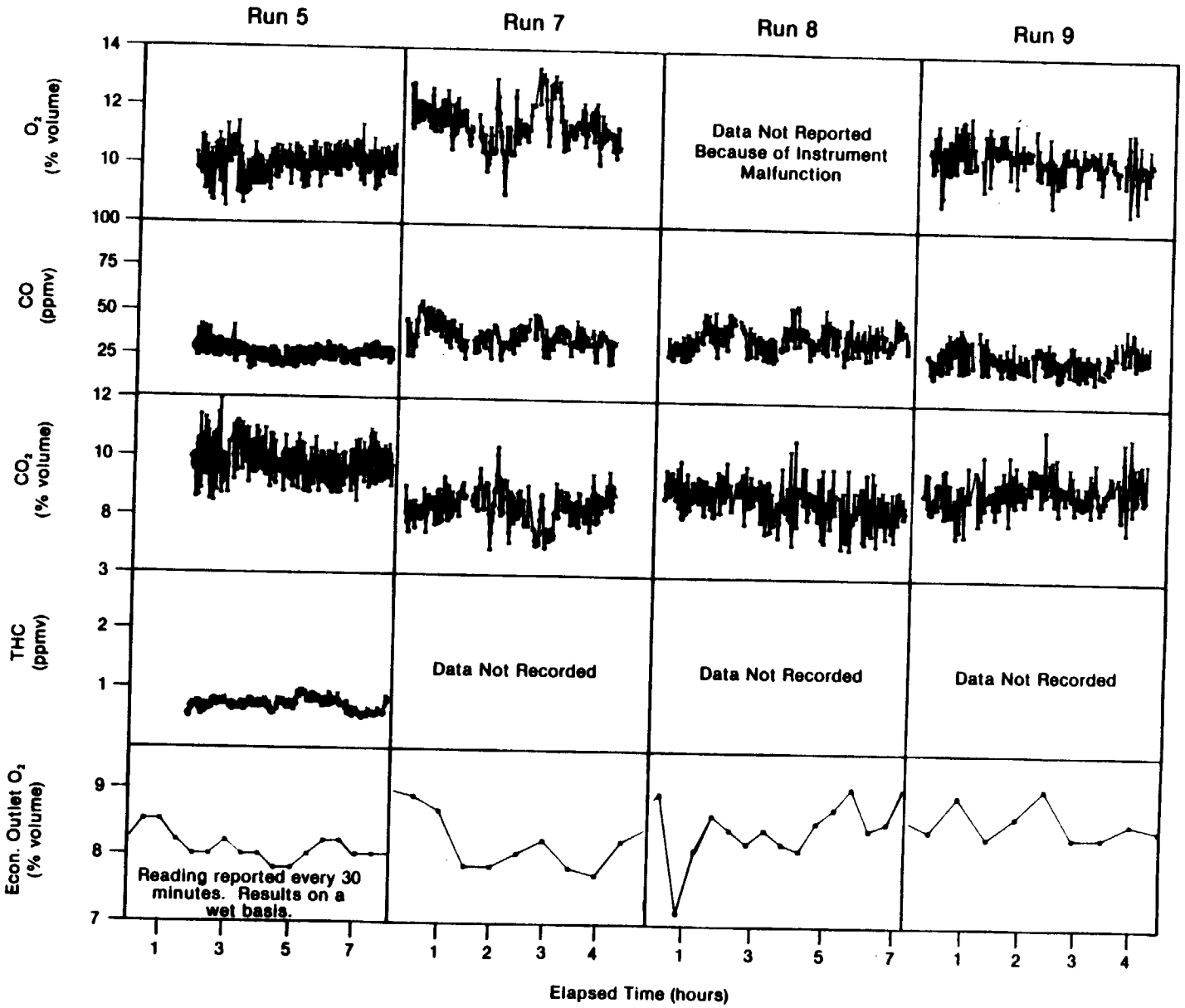

Figure 3-3. Variability of Fixed Gas Concentrations for Runs 5, 7, 8, and 9 at North Andover RESCO

2870855R

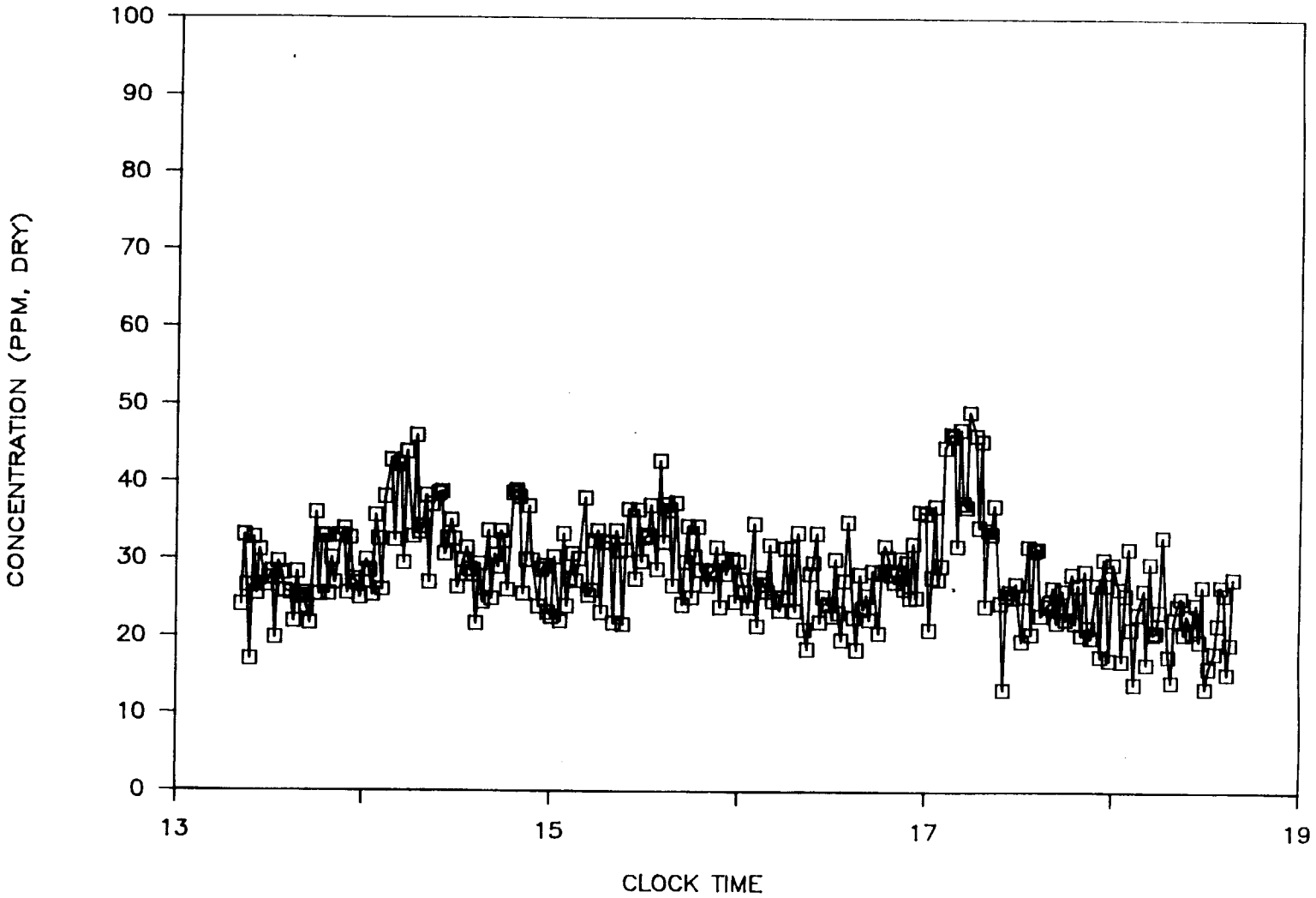

Figure 3-4. Carbon Monoxide Concentration History Run 1 for North Andover RESCO

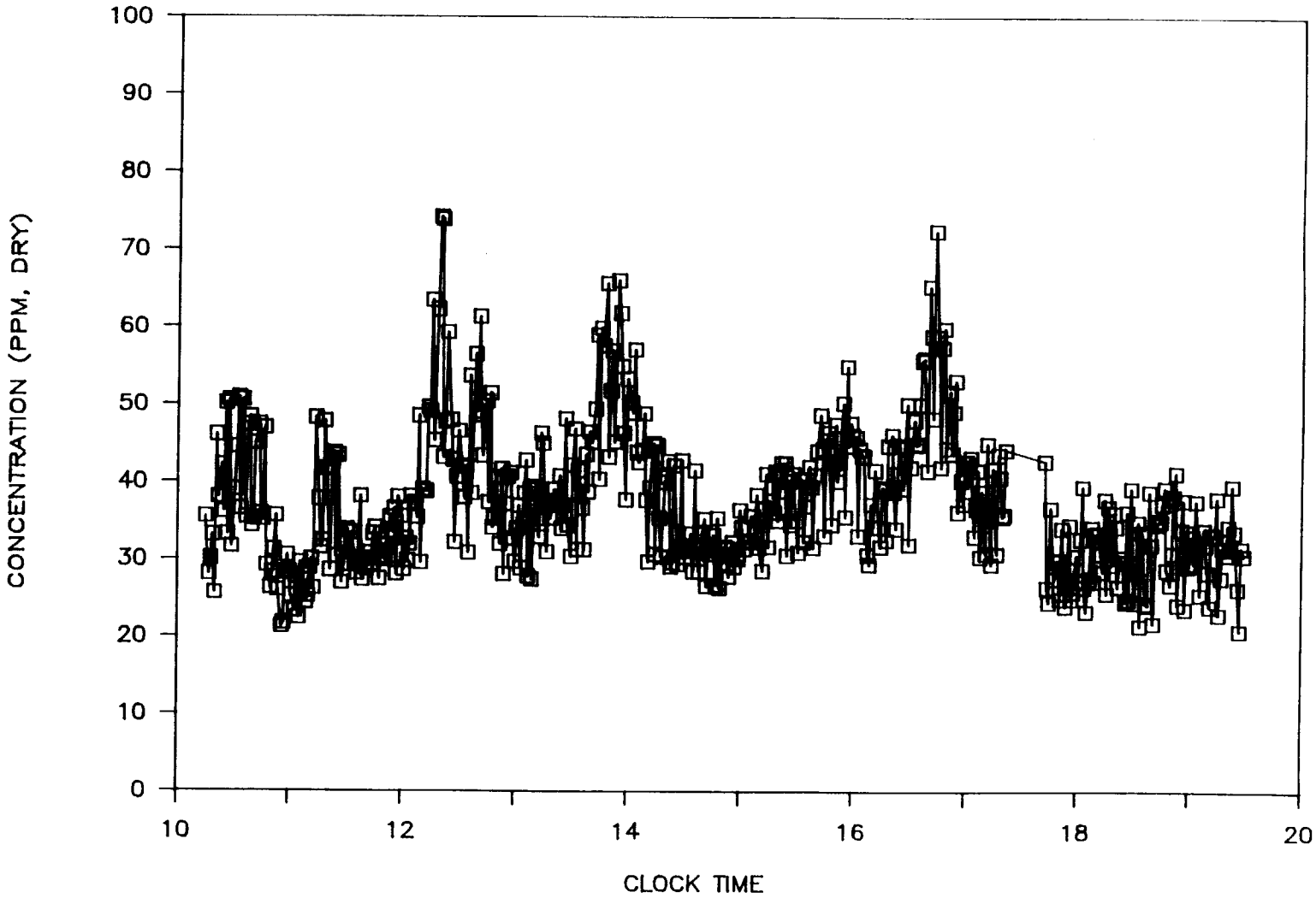

Figure 3-5. Carbon Monoxide Concentration History
Run 2 for North Andover RESCO

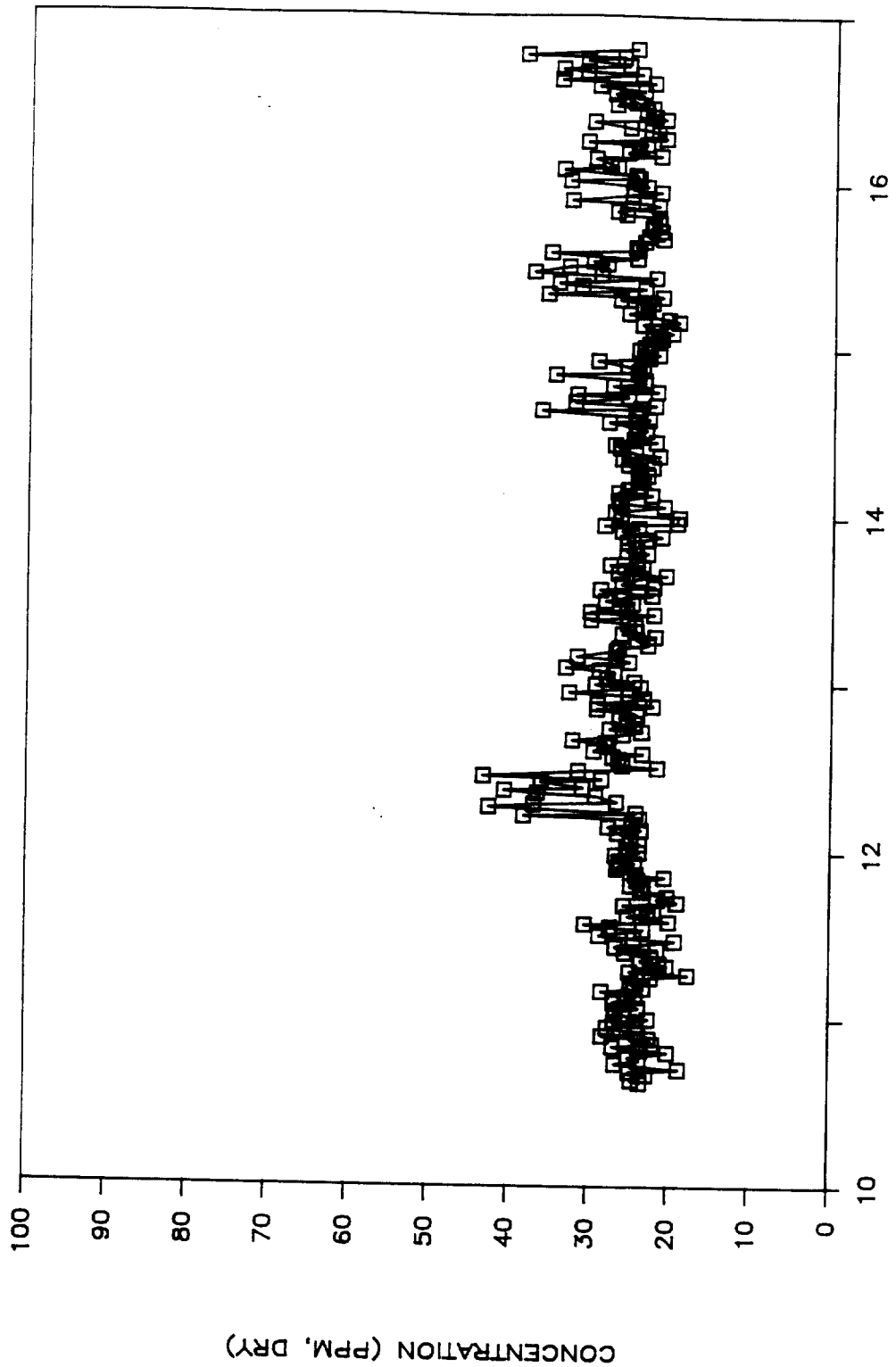

Figure 3-6. Carbon Monoxide Concentration History Run 3 for North Andover RESCO

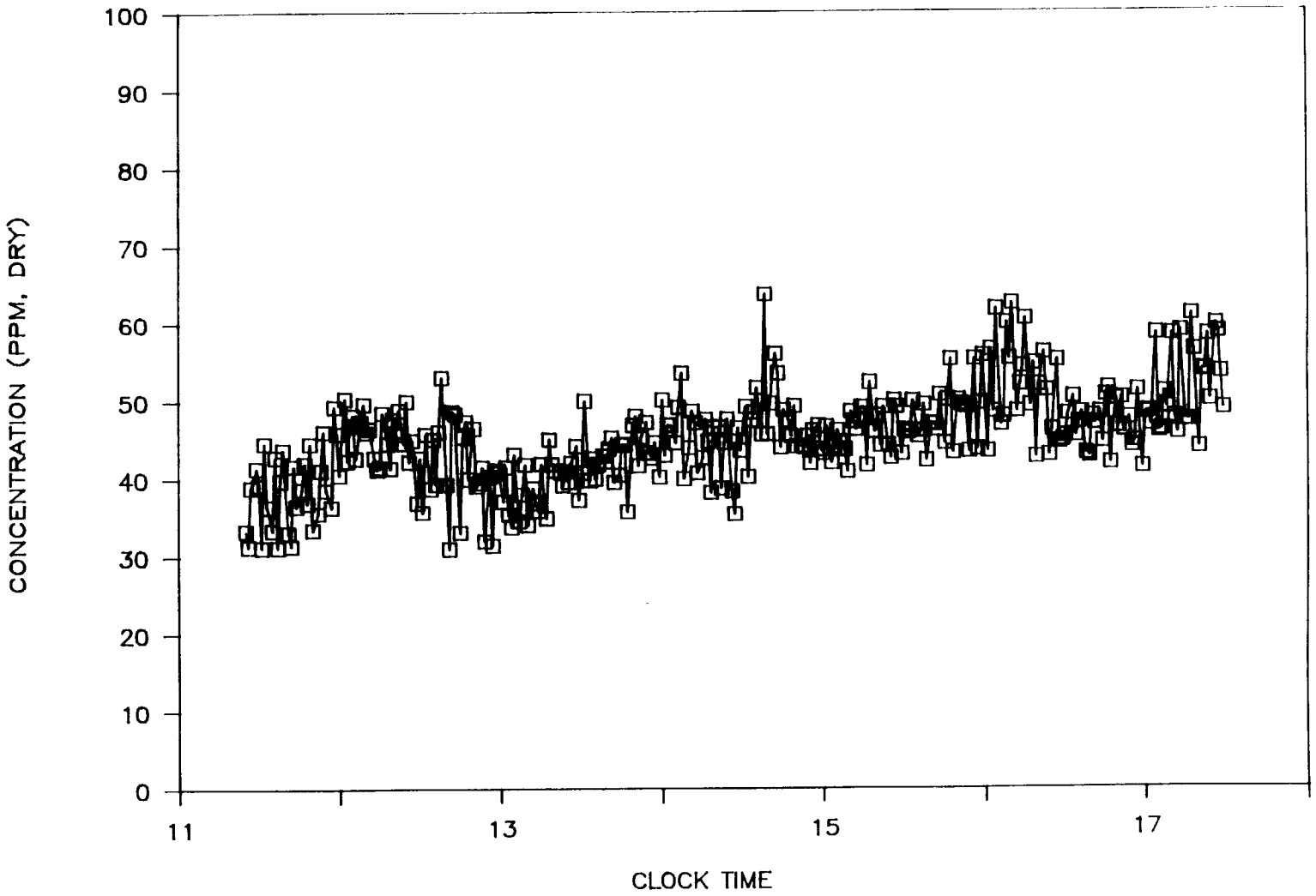

Figure 3-7. Carbon Monoxide Concentration History Run 4 for North Andover RESCO

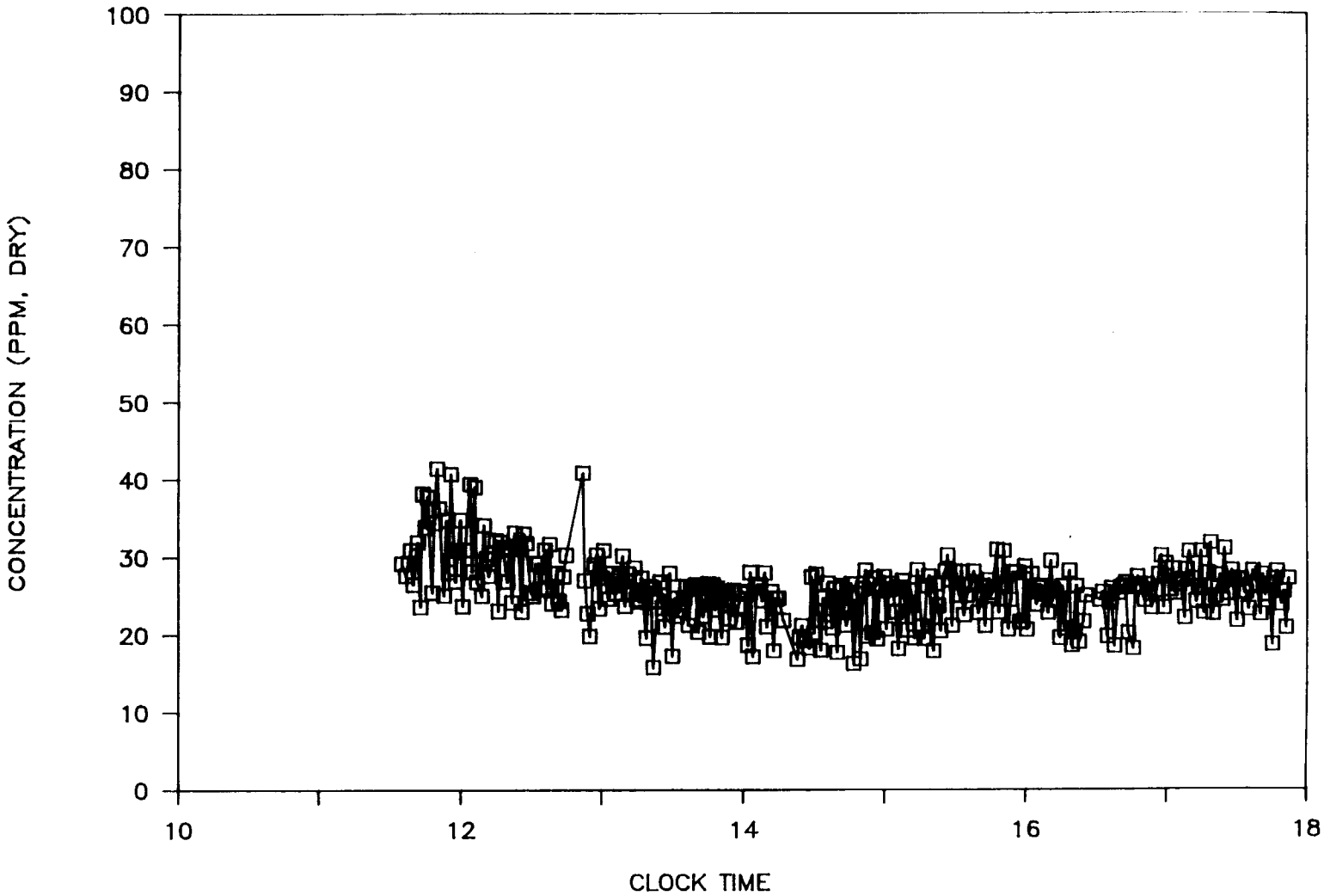

Figure 3-8. Carbon Monoxide Concentration History
Run 5 for North Andover RESCO

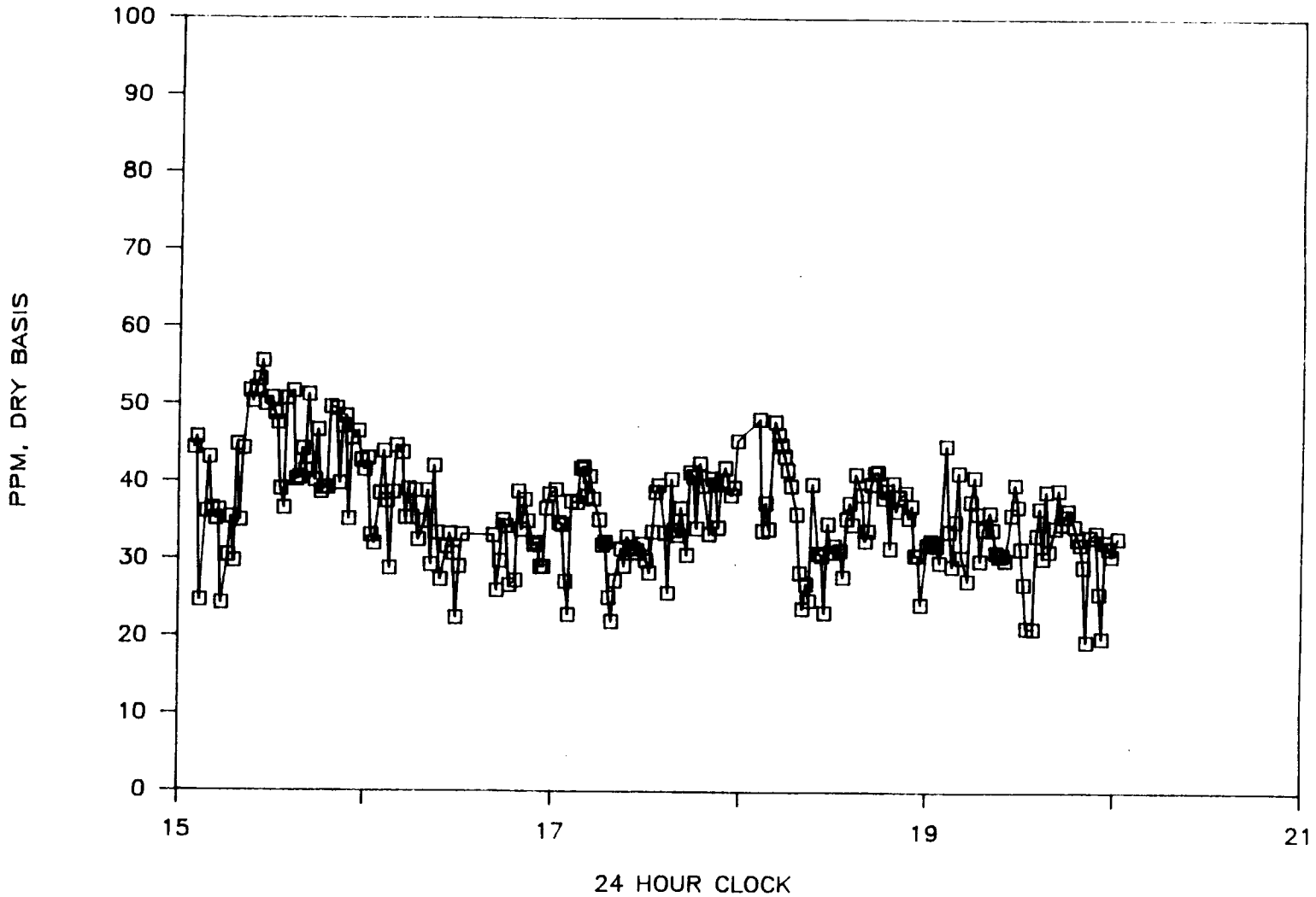

Figure 3-9. Carbon Monoxide Concentration History Run 7 for North Andover RESCO

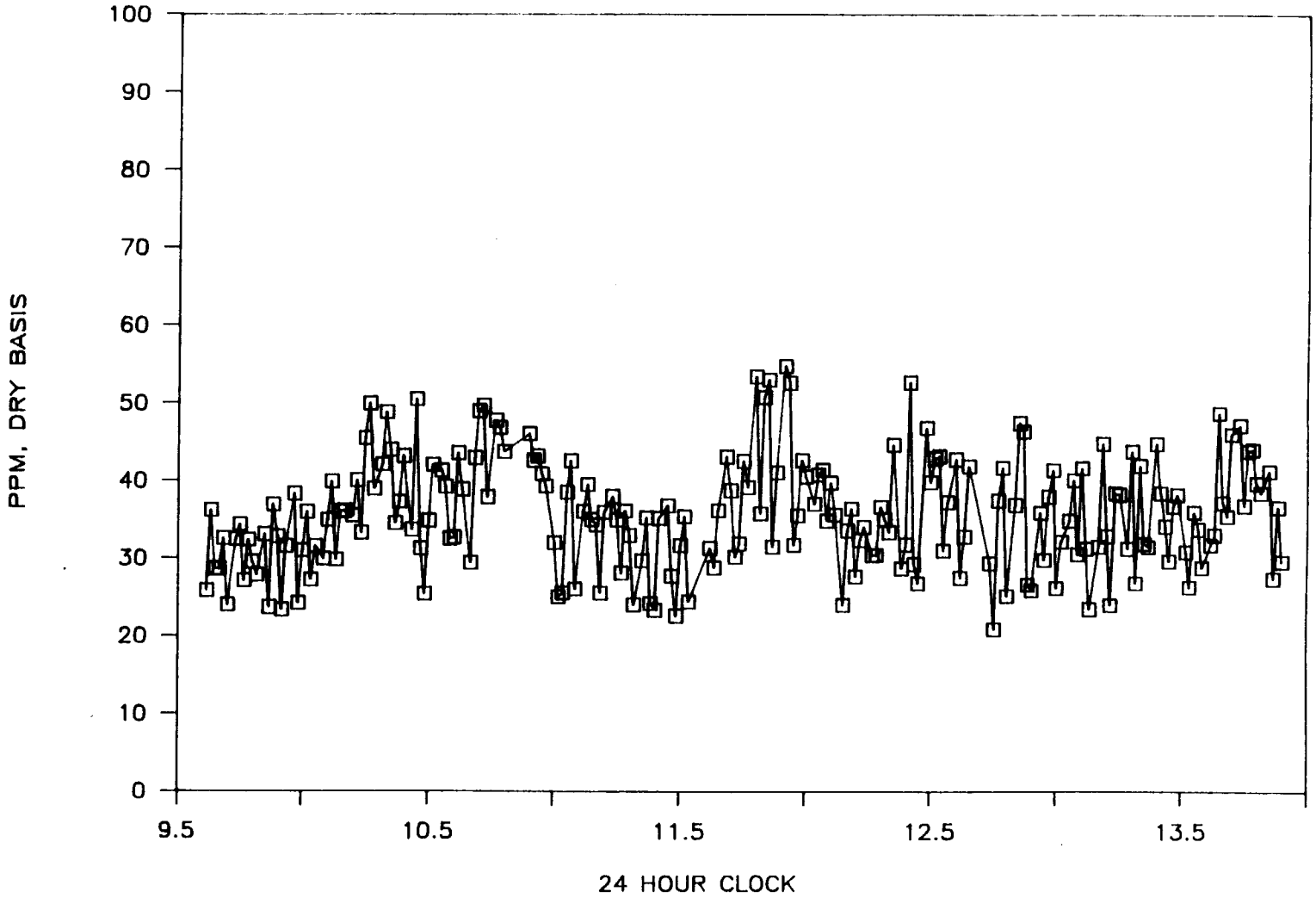

Figure 3-10. Carbon Monoxide Concentration History
Run 8 for North Andover RESCO

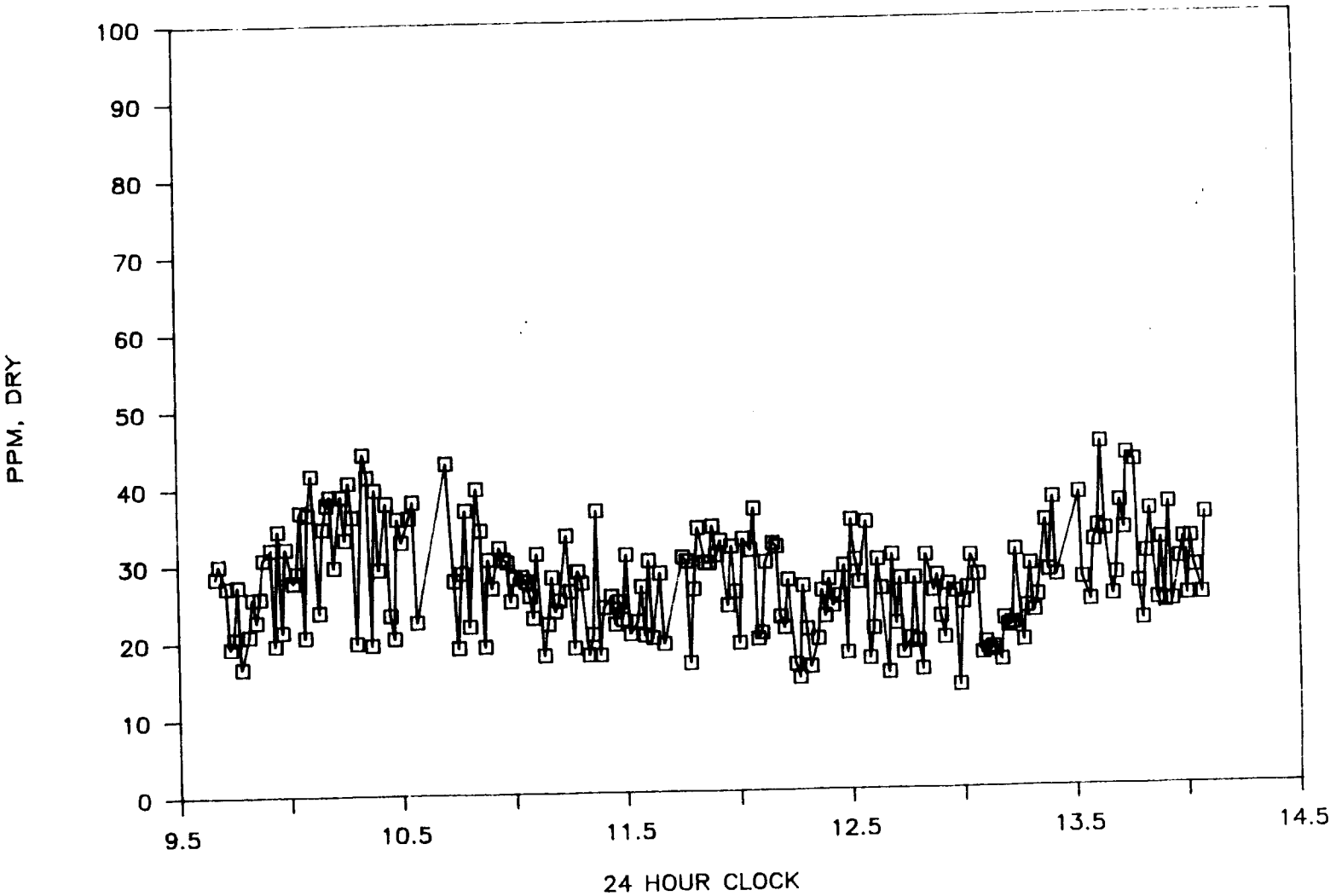

Figure 3-11. Carbon Monoxide Concentration History
Run 9 for North Andover RESCO

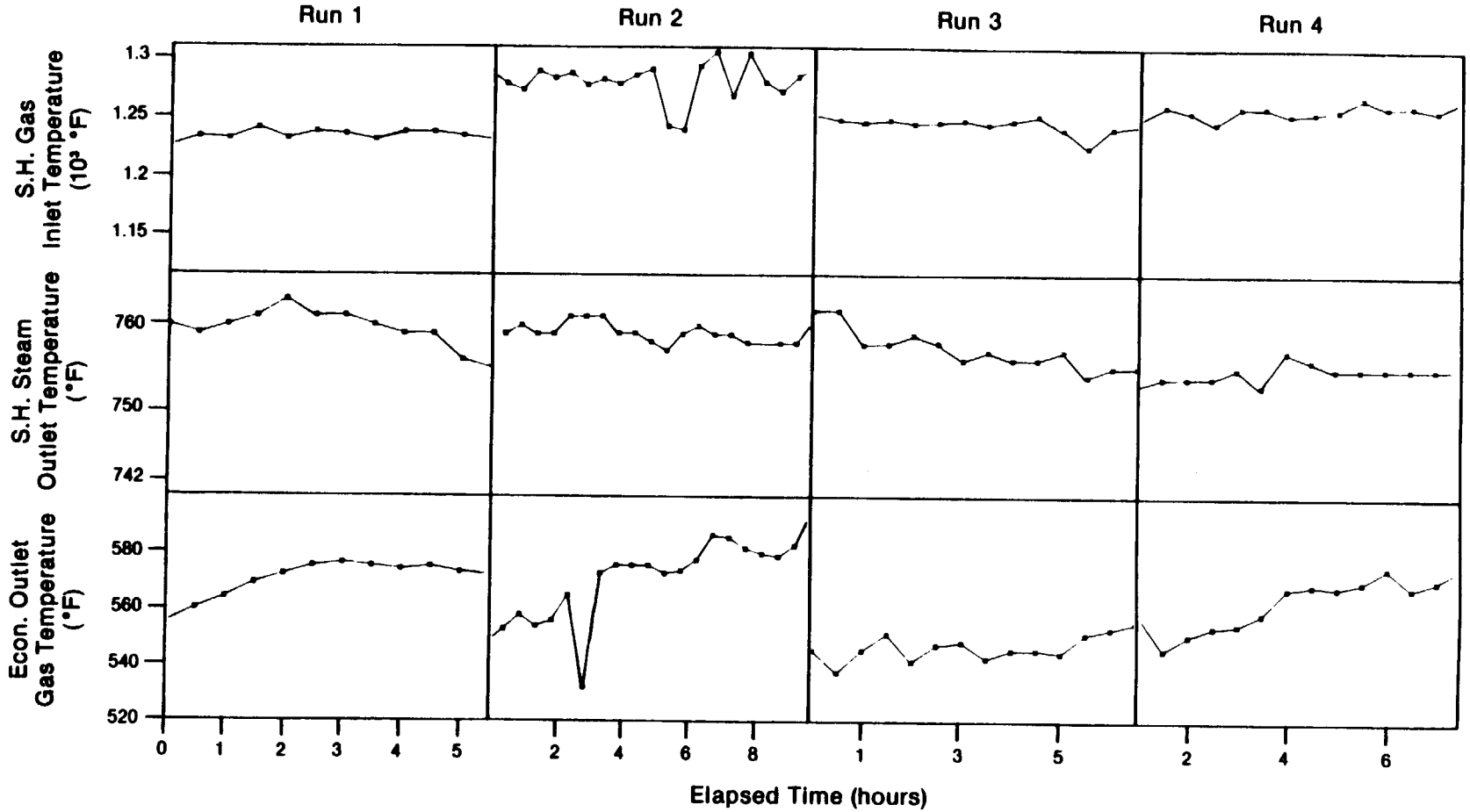

Figure 3-12. Variability of Various Flue Gas and Steam Temperatures for Runs 1-4 at North Andover RESCO

2870852R

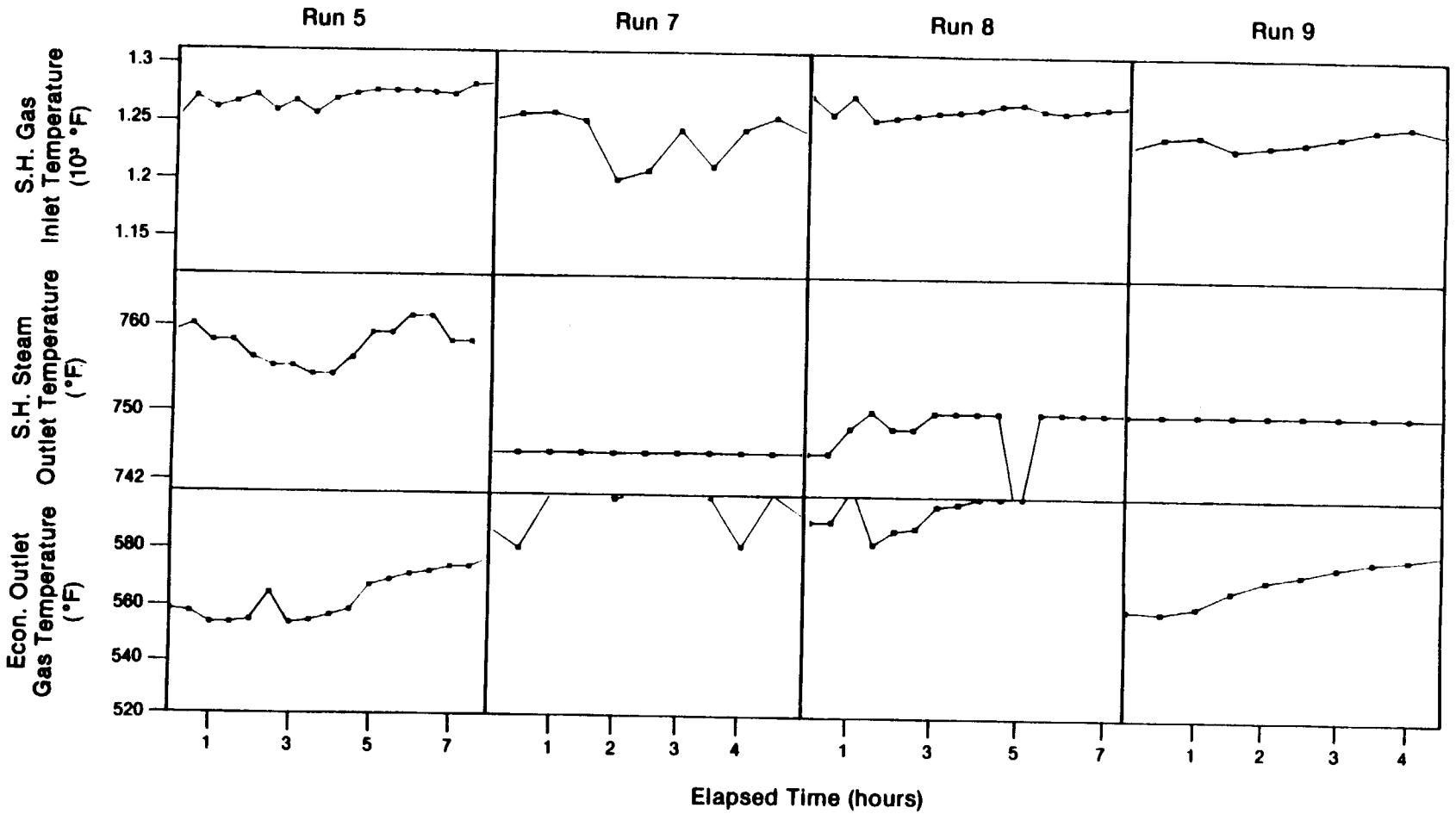

Figure 3-13. Variability of Various Flue Gas and Steam Temperatures for Runs 5, 7, 8, and 9 at North Andover RESCO

2870853R

superheater also was maintained at a near constant temperature. The economizer outlet temperature varied the most over a 20°F range. During Runs 7 and 8, the superheater flue gas inlet temperature was back to normal, but the superheater steam outlet temperature was still low. The economizer temperature was 20°F higher. During Run 9, the temperatures at the superheater flue gas inlet and steam outlet were significantly lower than the previous runs. The economizer outlet temperature was not affected.

Overall, the combustor was operating significantly differently during Runs 7-9, than during Runs 1-5.

3.3.3 Load and Opacity Evaluation

The fluctuations in steam load, grapple count and opacity are shown in Figures 3-14 and 3-15. Steam load was maintained at a normal rate during all the runs varying up to 5,000 lb/hr. The grapple count varied from 8 to 14 buckets per hour to maintain the steam load. These parameters appear to be operating normally during all the runs.

Opacity showed significant increases during Run 6 and Run 7, with an occasional peak during Runs 5 and 8. The opacity during Runs 1-5 had typically been maintained under 10 percent, but during Run 7 peaked over 50 percent. Atypical operation definitely occurred during Run 7.

3.3.4 Primary Air Evaluation

The fluctuations of the forced draft (FD) fan, primary air temperature, and primary air flow rate are shown in Figures 3-16 and 3-17. During Run 1, the FD fan damper position was at 55 percent, significantly higher than the rest of the runs where it was set at 15 percent. The primary air temperature was at 250°F during Run 1, dropped to approximately 180°F for Runs 2-4, and dropped midway through Run 5 to 80°F for Runs 5-9. The primary air flow was at 44,000 cfm during Run 2, dropped to 30,000 cfm during Runs 3-5, and went back up to 44,000 during Runs 7-9. These operating data indicate that there was some significant differences in operation between Runs 1, Runs 2-5, and Runs 7-9.

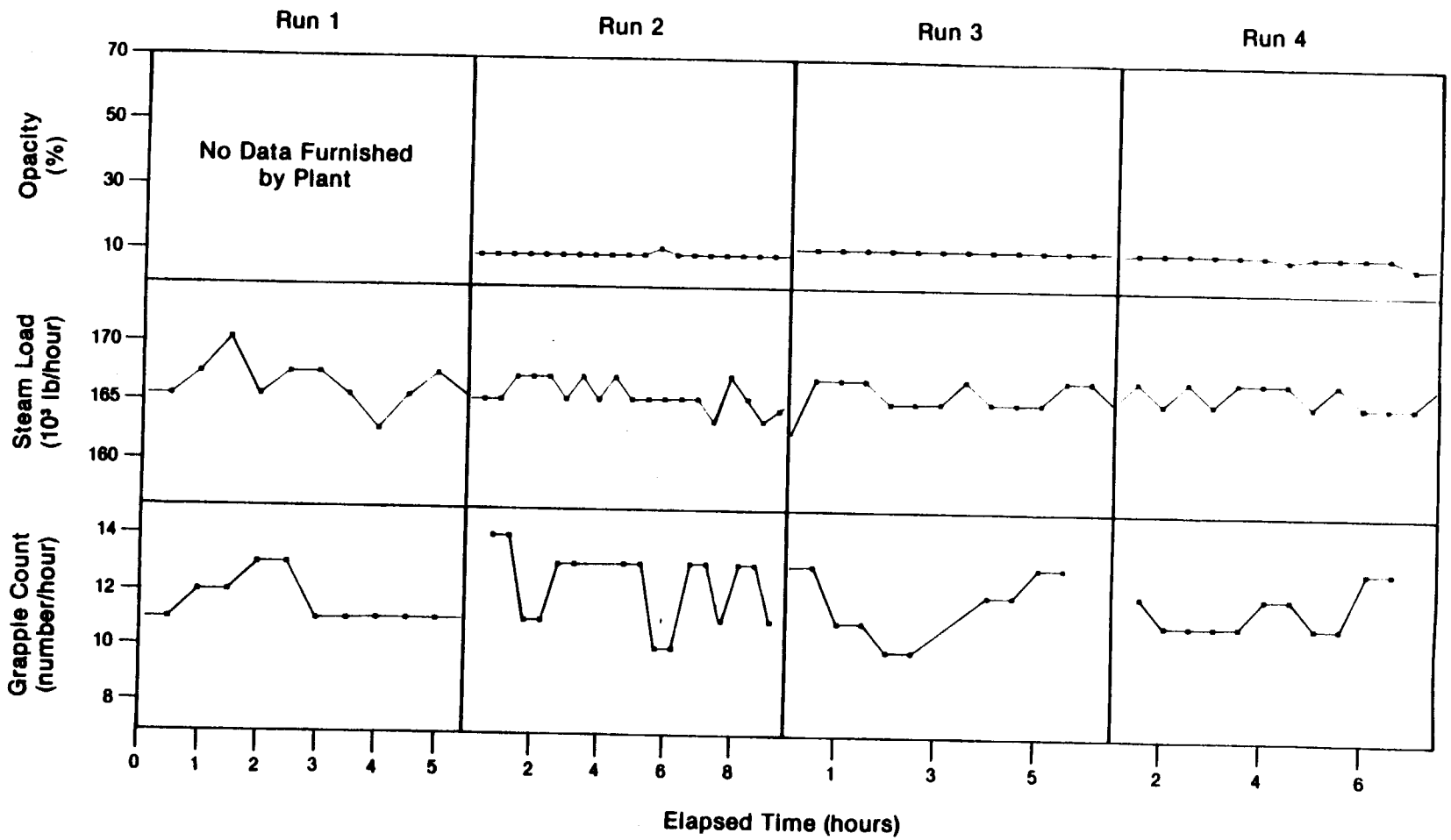

Figure 3-14. Variability of Opacity, Steam Load, and Grapple Count for Runs 1-4 at North Andover RESCO

2870850R

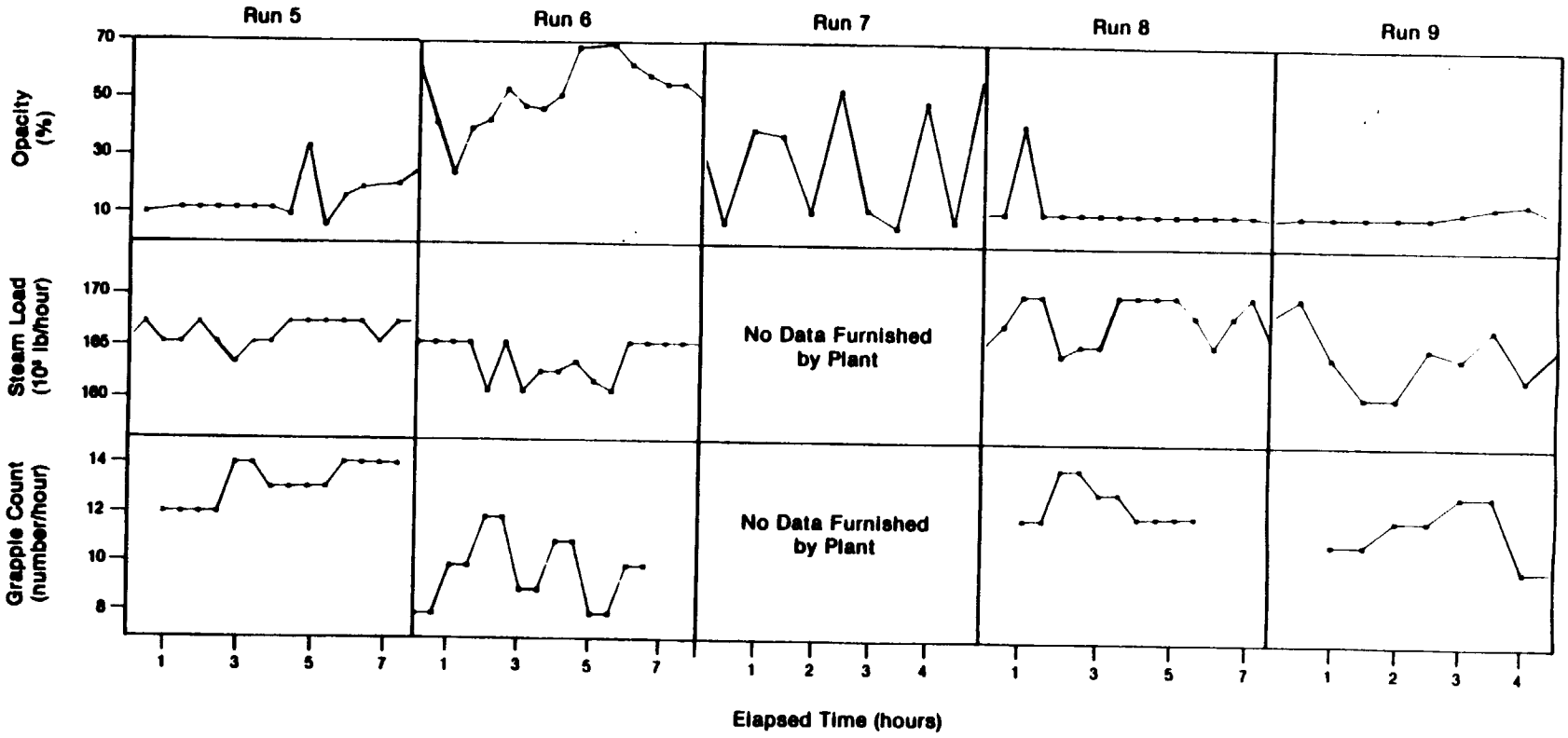

Figure 3-15. Variability of Opacity, Steam Load, and Grapple Count for Runs 5, 6, 7, 8, and 9 at North Andover RESCO

2870851R

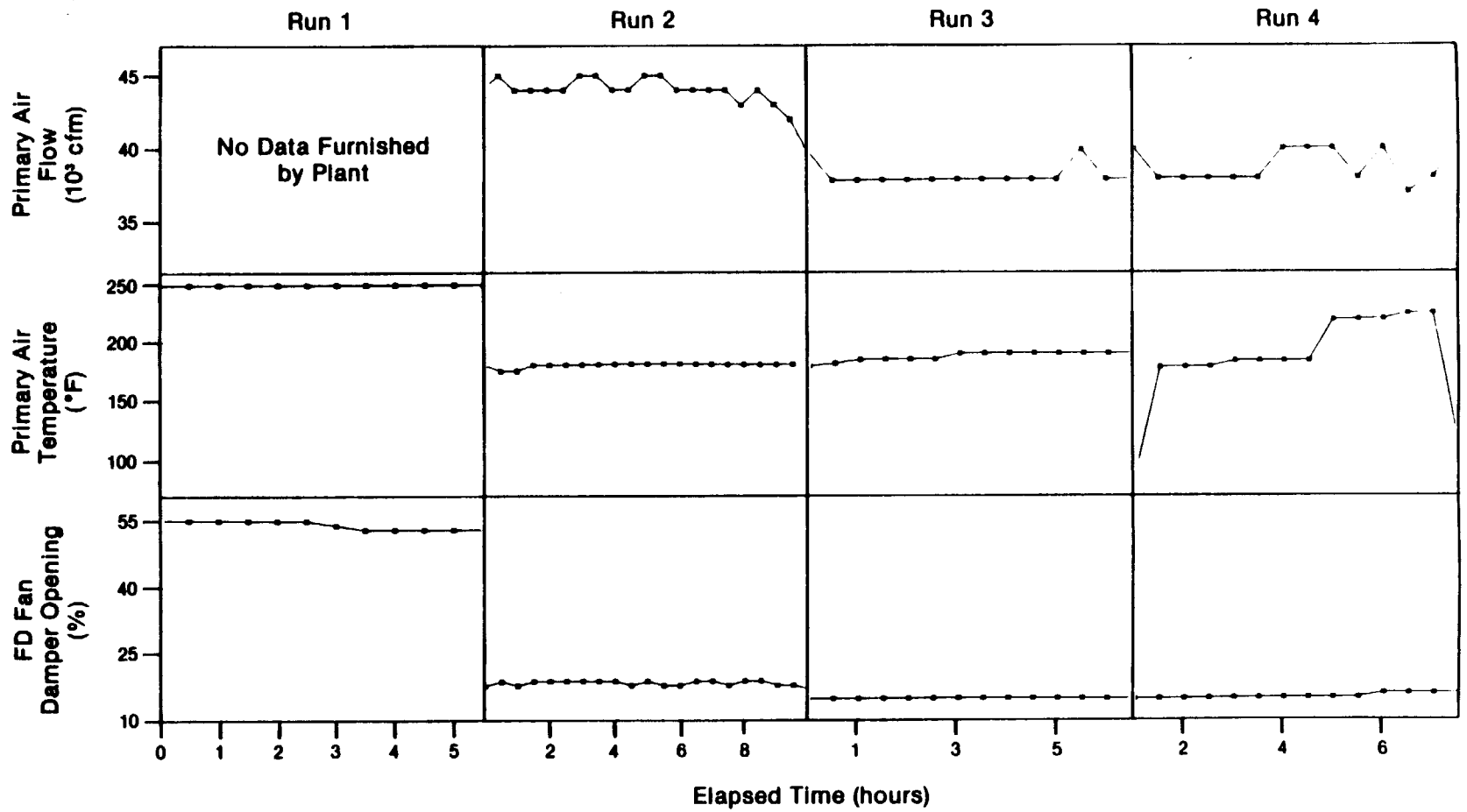

Figure 3-16. Variability of Air Flow Rate for Runs 1-4 at North Andover RESCO

2870848R

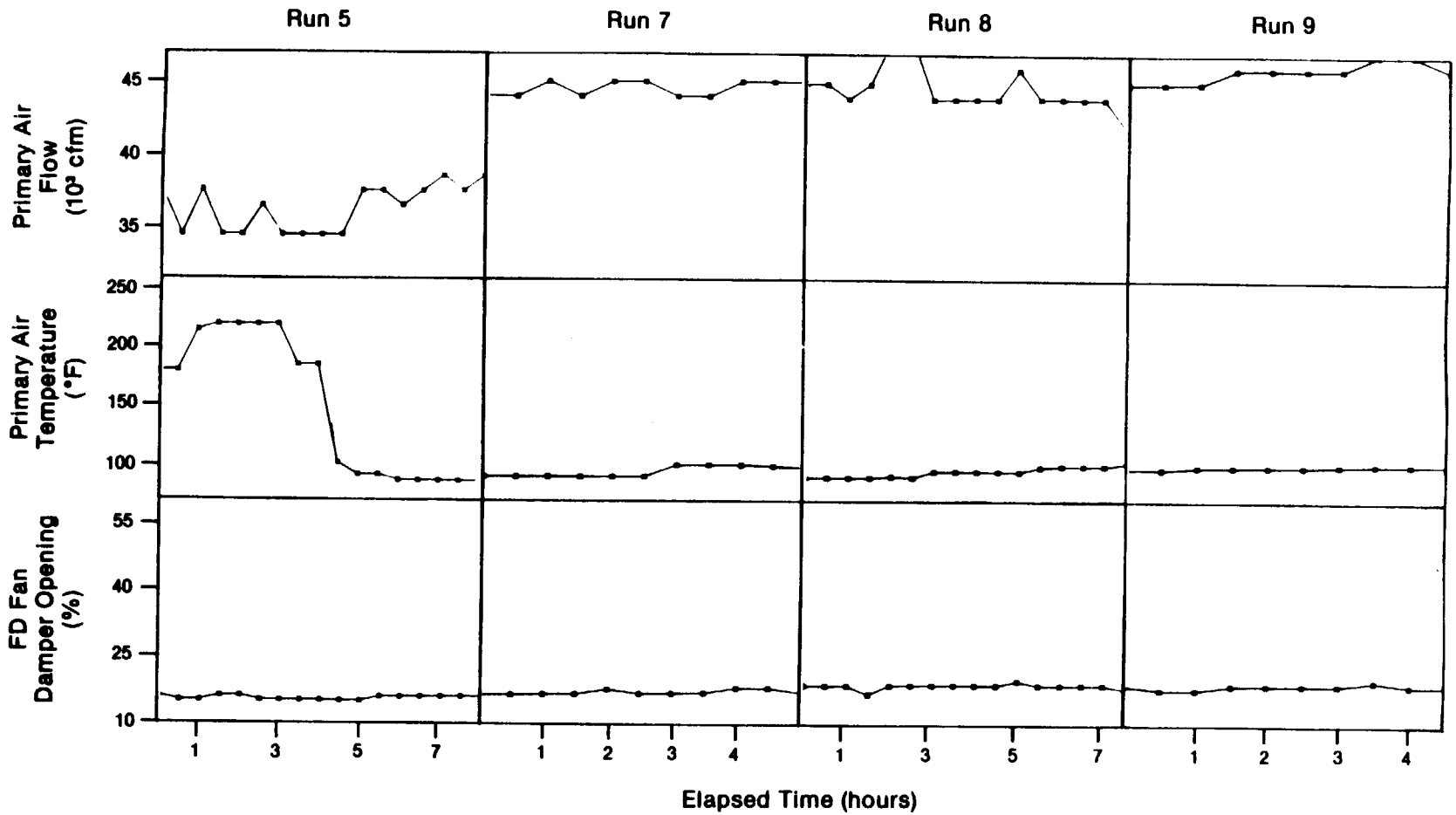

Figure 3-17. Variability of Air Flow Rate for Runs 5, 7, 8, and 9 at North Andover RESCO

2870849R

Table 3-5 presents the average CEM data from the plant's instrumentation. Also shown in Table 3-5 are the results from Radian's CEMs. The instruments used by the plant are in-situ analyzers which give results on a wet basis. The results have been corrected to a dry basis for equivalent comparison to the Radian CEM results. The difference in the results can be attributed to the different sampling and analytical systems used.

TABLE 3-5. AVERAGE CEM DATA FOR NORTH ANDOVER TESTS[a,b]
July 9 through 16, 1986

Run	Date	O_2 (vol %)		CO (ppmv)		CO_2 (vol %)		Plant SO_2 (ppmv)	Plant NO_x (ppmv)	Plant Opacity (Percent)	Radian THC (ppm, as propane)
		Plant	Radian	Plant	Radian	Plant	Radian				
1	7/08/86	NC (8.4)	10.9	NR	28.4	NR	9.0	NR	NR	NR	--[c]
2	7/09/86	9.7 (8.4)	10.9	51 (44)	37.4	10.5 (9.1)	8.9	21 (18)	174 (151)	0.10	1.2
3	7/10/86	9.0 (7.8)	10.5	41 (36)	25.7	12.2 (10.6)	8.9	37 (32)	186 (162)	0.12	0.5
4	7/11/86	9.8 (8.5)	10.7	29 (25)	45.2	12.0 (10.5)	9.6	46 (40)	191 (167)	0.12	1.1
5	7/12/86	9.4 (8.1)	10.1	13 (11)	25.7	12.0 (10.4)	9.8	43 (37)	213 (184)	0.13	0.7
6[d]	7/13/86	9.9 (8.6)	NR	32 (28)	NR	11.4 (9.9)	NR	48 (42)	186 (162)	0.55	NC
7	7/14/86	9.9 (8.3)	11.5	57 (48)	35	10.3 (8.7)	8.5	54 (46)	203 (172)	0.31	NC
8	7/15/86	9.8 (8.4)	--[e]	53 (46)	36	10.5 (9.1)	8.6	31 (27)	219 (189)	0.14	NC
9	7/16/86	10.0 (8.6)	10.5	NR	27	NR	9.2	NR	NR	0.13	NC

[a]Plant CEMs except for the O_2 analyzer were located about 10 ft downstream of the ESP outlet sampling locations. The O_2 analyzer was located at the economizer outlet. The plant used in-situ infrared analyzers. Radian CEMs were located at the ESP outlet sampling location. Radian did not measure SO_2, NO_x, or opacity. Radian used an extractive system.

[b]Plant CEM measurements are presented on both dry basis and a wet basis. The results on a wet basis are reported in parentheses below the dry basis values. The plant CEM results were originally recorded on a wet basis and converted to a dry basis using the moisture content of the flue gas determined by EPA Method 4.

[c]THC data not recorded due to data logger malfunction during Run 1.

[d]Data not reported by Radian because Run 6 was considered abnormal by Signal.

[e]Value considered invalid due to an instrument malfunction.

NR = not reported.
NC = sample not collected.

4.0 SAMPLING AND ANALYTICAL PROCEDURES

The sampling and analytical procedures used at North Andover RESCO were the most recent versions of the published methods. In some cases, the methods were modified to incorporate the most recent developments which have been accepted by the sampling community. In this section brief descriptions of each sampling and analytical method summarized in Table 4-1 are provided. A more detailed explanation of the sampling methods can be found in the test reports.[7,8]

4.1 CDD/CDF SAMPLING AND ANALYSIS

CDD/CDF sampling followed the December 1984 draft protocol for the determination of chlorinated organic compounds in stack emissions. The protocol was developed by the Environmental Standards Workshop sponsored by the American Society of Mechanical Engineers (ASME) and EPA.

The method is based on EPA Reference Method 5. Basically, the ASME/EPA protocol modifies the EPA Method 5 train to include a section to trap chlorinated organics before the gas sample enters the impingers.

The CDD/CDF analysis for the flue gas and ash samples followed the ASME/EPA analytical procedures to assay stack effluent samples and residual combustion products for CDD and CDF dated December 1984. The protocol includes organic solvent extraction, silica gel column gas chromatographic separation, and high resolution gas chromatography and high resolution mass spectrometry analysis.

4.2 TOCL SAMPLING AND ANALYSIS

The TOCL flue gas samples were collected using the same protocol as the CDD/CDF samples except the protocol used hexane for sample recovery purposes. The samples were analyzed by the Nulton method, which uses a short

TABLE 4-1. SUMMARY OF SAMPLING METHODS AND ANALYTICAL PROCEDURES USED DURING THE NORTH ANDOVER RESCO TEST PROGRAM

Parameters	Sampling Method	Analytical Method
CDD/CDF	Environmental Standards Workshop (Dec. 1984)	High resolution GC/MS
TOCL	Environmental Standards Workshop (Dec. 1984)	Nulton Method (short column GC with Hall detector)
Particulates	EPA Method 5	Gravimetric
Metals	EPA Method 12 (alternate)	Neutron Activation Analysis
O_2, CO_2, CO, THC	Extraction	Methods 3A, 10, and 25A (CEM)
Molecular weight	EPA Method 3	Orsat apparatus
Moisture	EPA Method 4	Gravimetric
Velocity	EPA Method 2	--
Temperature	Type K thermocouple	--
ESP Ash and total ash discharge	Composite grab sample	CDD/CDF: Environmental Standards Workshop Protocol (Dec. 1984) Metals: Neutron Activation Analysis (ESP ash only)

column gas chromatograph and a Hall detector. The method actually quantified total organic halogens, but the halogens detected were assumed to be chlorine (based on the feed). The levels are quantified by comparing the area response of the sample chromatogram with that of the external standard, hexachlorobenzene.

4.3 FLUE GAS PARTICULATE SAMPLING AND ANALYSIS

Particulate sampling and analysis was performed according to EPA Method 5. The flue gas sample was withdrawn isokinetically and particulates were collected on a glass fiber filter which was maintained at 120 $\pm 14^{\circ}C$ (248 $\pm 25^{\circ}F$). After sampling was completed, the probe was rinsed with acetone. The acetone washes and filters were dessicated. The particulate mass was determined gravimetrically.

4.4 METALS SAMPLING AND ANALYSIS

Metals sampling followed EPA Alternate Reference Method 12 where both particulate matter and metals samples were collected using the same train. The EPA Method 12 train has been demonstrated specifically for lead and cadmium only. However for this test program, the method was used as a screening analysis for additional metals.

The analytical method was modified by using NAA as the analysis method rather than Atomic Absorption. The ESP ash was also analyzed by NAA. NAA can be used to analyze for all the specific metals except lead and beryllium. Also, the method does not differentiate between different valence states or compounds of a metal such as Cr(+III) or Cr(+VI).

4.5 CEM SAMPLING AND ANALYSIS

The CEM system was an extractive system where the flue gas was withdrawn from the stack as a single point and then transferred through a heat-traced teflon line to a gas conditioner which removed moisture by cooling the gas.

The flue gas was split and sent to each type of analyzer. At North Andover RESCO, nondispersive infrared analyzers were used to measure CO and CO_2 and a paramagnetic analyzer was used to measure O_2. THC was measured by a flame ionization detector on a propane basis. The analyzers were calibrated daily with commercially prepared and certified zero and span gases.

4.6 ESP ASH AND TOTAL ASH DISCHARGE SAMPLING

Full-belt cuts of the ESP ash and total ash discharge were collected every 30 minutes starting 45 minutes after the start of the flue gas sampling. The delay allowed for the hold-up time in the ash handling systems. At the end of testing, the samples were composited, riffled, coned and quartered. For CDD/CDF analysis, about 10 grams of ash were analyzed. For metals analysis by NAA, ESP ash samples of about 50 ml were analyzed.

5.0 QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC)

In order to ensure and quantify the acceptability and reliability of the data generated, a QA/QC program was included in the emissions test program at North Andover RESCO. QA/QC procedures were included in all the phases of data generation: equipment and sampling preparation, sampling operations, sample recovery, sample analysis, and data reduction. This section summarizes the procedures used during this test program. The detailed procedures and results of the QA/QC program can be found in the emission test reports.

The estimated and achieved precision, accuracy, and completeness for this test program are summarized in Table 5-1. Precision and accuracy for the CDD/CDF analyses were all better than expected values.

5.1 EQUIPMENT AND SAMPLING PREPARATION

Sampling equipment was cleaned, checked, and calibrated before use in the field. Table 5-2 summarizes the equipment that was calibrated for each for each method. Calibration data were recorded on data sheets which are included in the appendices of the emission test reports.

Following the cleaning procedure specified by each method, the sampling train and recovery glassware was cleaned and capped prior to shipment to the field. Once in the field, a lab proof blank was collected for each set of sampling glassware. One set was analyzed. The purpose of the lab proof blank is to quantify background contamination in the cleaned glassware. Sets of sampling glassware were dedicated to each method to prevent cross-contamination.

For CDD/CDF sampling additional preparation quality control steps included cleaning and blanking the XAD resin and filters. The final rinses of the solvents were analyzed for total chromatographable organics by gas chromatography/flame ionization detection.

TABLE 5-1. SUMMARY OF ESTIMATED AND ACHIEVED PRECISION, ACCURACY AND COMPLETENESS

Parameter	Precision (± %)		Accuracy (± %)		Completeness	
	Estimated	Achieved	Estimated	Achieved	Estimated	Achieved
CDD						
Flue gas	50	12[a]	50	4[b]	100	100
Ash	50	27[c]	50	NA	100	100
CDF						
Flue gas	50	9[a]	50	20[b]	100	100
Ash	50	15[c]	50	NA	100	100
NAA Metals	NA	10	NA	5	100	100
CEMs[d]	10	NE	10	NE	100	99
Volumetric flowrate	6	NE	10	NE	100	100
Fixed gases/ molecular weight	10	NE	20	NE	100	99
Temperature	± 2°F	NE	± 5°F	NE	100	100

[a]Value reported is the largest percent difference calculated for any congener from outlet-Run 5-BH duplicate analyses.

[b]Based on the analysis of audit samples; a spiked XAD and a spiked water sample.

[c]Value reported is the largest percent difference calculated for any congener from ESP ash-Run 5 duplicate analyses.

[d]Precision of CEMs is expressed as the % coefficient of variation (CV) determined from daily analyses of a QC standard, where

% CV = (standard deviation/mean) x 100

NE = not evaluated.

TABLE 5-2. SUMMARY OF EQUIPMENT USED IN PERFORMING SAMPLING

Parameter	Method	Calibrated Equipment Used to Measure Parameters						
		Type "S" Pitot Tube	Manometer	Temperature Measuring Device	Orsat	Nozzles	Balances	Dry Gas Meter
Volumetric Flue Gas Flow Rate	EPA 1 & 2	X	X	X				
Gas Phase Composition								
Moisture	EPA 4	X	X	X			X	X
Molecular Weight	EPA 3				X			
CDD/CDF	ASME/EPA Protocol	X	X	X	X	X	X	X
TOCL/Particulate	ASME/EPA Protocol (modified)	X	X	X	X	X	X	X
Metals/Particulate	Alternate EPA Method 12	X	X	X	X	X	X	X

5.2 SAMPLING OPERATIONS

QA/QC procedures for sampling operations included leakchecks before and after each port, following detailed checklists during sampling to ensure each step was properly completed, and having qualified personnel performing the sampling operations. Data were recorded on the data forms which are included in the appendices of the emissions test reports.

5.3 SAMPLE RECOVERY

A recovery efficiency blank was collected for each method to quantify the efficiency of the recovery procedure and any contamination that may have occurred during recovery. Sample recovery procedures were carried out in a controlled-atmosphere, enclosed trailer in order to minimize contamination.

Each sample bottle was assigned a unique alphanumeric identification code which was recorded in a logbook and on the sample label. Chain-of-custody sheets were filled out and packed with the samples as they were packed into coolers for shipment.

5.4 SAMPLE ANALYSIS

The sample analyses were performed by laboratories familiar with the analytical procedures. The accuracy of the analyses was evaluated by submitting blind audit samples prepared by independent laboratories along with the field samples. Precision was evaluated by performing duplicate analyses of selected samples in each batch. For the CDD/CDF analyses, internal standard and surrogate recoveries were determined in addition to the other QA/QC procedures.

5.5 DATA REDUCTION

QA/QC procedures for data reduction included using computer programs to generate data. This reduces the human calculational error. Data input files

and equations were double checked by an independent person and tables of results were spot checked by hand. In addition, any data points that appeared to be outliers were double checked.

6.0 REFERENCES

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5. Natrella, Mary Gibbons, Experimental Statistics. National Bureau of Standards Handbook. 1963. pp. 17-2 to 17-3.

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7. Reference 1.

8. Reference 2.