

**WOOD-CHIP FIRED FURNACES TESTING PROJECT  
AIR EMISSIONS TESTING AND  
PUBLIC HEALTH IMPACTS ANALYSIS**

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## EXECUTIVE SUMMARY

Environmental Risk Limited (ERL) was retained by the Coalition of Northeastern Governors (CONEG) Policy Research Center, Inc. to perform an assessment of two wood-chip fired furnaces in Vermont. The objectives of this program were to provide representative air pollutant emissions data on small scale commercial wood-chip fired heating systems and to evaluate associated health risks, if any. In the first phase of this program, emissions data were obtained by testing two boilers located in Vermont in the size range of 0.5 million BTU per hour (MMBtu/hr) to 3.0 MMBtu/hr heat input. In the second phase of this program, the Vermont Department of Health (DOH) performed a preliminary screening assessment of the potential health risk impacts based on the results of the emissions testing. For comparative purposes, screening risk assessments were also performed for similarly sized oil-fired furnaces using site-specific parameters and assumptions.

## KEY FINDINGS

Key findings from this project include:

- Two wood-chip fired furnaces with multiple chamber combustion design were tested for this program, one located at the Green Acres Housing Project in Barre Town and the other located at the Hazen Union High School in Hardwick, VT.
- The scope of the emissions test program included total suspended particulate (TSP), multiple metals, dioxins and furans, polynuclear aromatic hydrocarbons (PAH), formaldehyde, benzene, hexavalent chromium, nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), and oxygen (O<sub>2</sub>).
- Some differences in the design and operation of the two tested systems were observed. The Hazen unit, equipped with a particulate control device, had lower emissions of particulate and metals. The Green Acres unit had higher CO and lower NO<sub>x</sub> emissions, indicative of lower combustion temperature.
- In general, emissions of CO, NO<sub>x</sub>, metals, and some of the organics are comparable to EPA emission factors and other test data on small capacity commercial wood-fired furnaces. Perhaps due to the multiple chamber design, particulate emissions from both tested units were lower than EPA emission factors and other test data.
- The tested units have higher NO<sub>x</sub>, but much less CO, particulate, and organic compound emissions than smaller residential wood burning appliances.
- Compared to similarly sized oil-fired furnaces, the tested units have an order of magnitude higher CO, PAH, and formaldehyde emissions and comparable NO<sub>x</sub>, metals, and benzene emissions.
- With regard to the preliminary screening health risk assessment, no major difference in potential risk due to inhalation exposure to carcinogens was noted between wood and oil fired furnaces at each location.

- The level of concern for adverse noncarcinogenic effects associated with inhalation exposure to emissions from either a wood or oil fired furnace located at the Green Acres Housing Project was estimated to be greater than that for the Hazen Union High School location. A higher level of concern was estimated to be associated with the wood-fired cases at both sites.
- Due to the limited data available for review, the conservativeness of assumptions, and preliminary nature of the assessments, the Vermont DOH cautions against making any general statement regarding the magnitude of the potential risks to public health that may be associated with inhalation exposure to ambient emissions from wood-fired furnaces. For the same reasons, no definitive conclusions can be drawn regarding the relative magnitude of potential risks due to inhalation exposure to emissions from wood-fired units as compared to oil-fired units.

For a fuller discussion of the public health assessment, please see Volume IV in the final report, and pages 7-9 in the Executive Summary.

## **TEST FURNACE DESCRIPTIONS**

Two representative wood-chip fired units were selected for this program, one located at the Green Acres Housing Project in Barre Town, VT and the second located at the Hazen Union High School, Hardwick, VT. Both units are of modern design and differ from more traditional wood-fired stoves and stoker boilers. These units utilize a multiple chamber combustion design in which wood fuel is introduced into one chamber to maintain a standing bed of coals and the resulting off-gases, mainly carbon monoxide (CO) and hydrogen, are burned in subsequent chambers.

The Green Acres Housing Project utilizes a Messersmith Manufacturing, Inc. furnace. The Messersmith wood-chip furnace incorporates a Federal/A.L. Eastwood & Sons, Inc. 60 HP boiler with a heating surface of 397 square feet. The boiler has a heat input rating of 2.2 BTU MMBTU/hr and provides process hot water (~200°F) for heating throughout the housing facility. This boiler is equipped with automatic soot blowers. The furnace consists of a conveyORIZED automatic feeder, primary combustion chamber and a secondary combustion chamber. The feed system is automated by an interlock control which prevents overfeeding. Other than combustion controls, the system does not use additional pollution control equipment. The Messersmith furnace operates basically in one operating mode that has a fixed wood chip feed rate. Heat input during the test program ranged from 1.02 to 1.99 MMBtu/hr.

The Hazen Union High School uses a Chiptec Model 85-90T furnace and boiler. The Chiptec wood-chip furnace incorporates a 63 HP boiler with a 400 square foot heating surface. This boiler has a heat input rating of 2.8 MMBtu/hr and also provides process hot water (~200°F) for heating purposes. The furnace consists of a conveyORIZED automatic feeder, primary combustion chamber, secondary combustion chamber, and a tertiary combustion chamber. The feed system is automated by an interlock control which prevents overfeeding of wood-chips. This boiler is not equipped with soot blowers. Flue gases exit this boiler, enter a mechanical cyclone (for particulate removal), and then are discharged to the atmosphere by a variable speed induced draft fan. The Chiptec furnace operated in two different operating modes for this test program, a pilot mode and a low fire mode. Pilot mode is an idle setting where the fuel feed is reduced to a point just capable of maintaining the coal bed. The low fire mode is used at start-up and normal operation. The pilot

mode used a feed rate of approximately 20 pounds per hour (lb/hr) and the low fire mode operated at a feed rate of 238 to 192 lb/hr. During the first dioxin/furan and PAH tests, a low fire rate of 238 lb/hr was used. This produced an abnormally high mass of coals on the grate and widely fluctuating CO levels. The remaining tests were conducted at a reduced rate of 192 lb/hr. CO levels seemed to stabilize after the feed rate was lowered.

## **SCOPE OF EMISSIONS TEST PROGRAM**

Air pollutant emissions measured at each furnace outlet included total suspended particulate (TSP), multiple metals (arsenic, barium, beryllium, cadmium, total chromium, copper, lead, manganese, nickel, selenium, silver, and zinc), polychlorinated dibenzo-p-dioxins (PCDD), polychlorinated dibenzofurans (PCDF), polynuclear aromatic hydrocarbons (PAH), formaldehyde, benzene, hexavalent chromium, oxides of nitrogen (NO<sub>x</sub>), carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), and oxygen (O<sub>2</sub>). Table 1 summarizes the test matrix and sampling methods used. It should be noted that monitoring of most parameters could not be conducted concurrently due to the small size of the stacks sampled. Therefore, correlations from the results of the tests must be based on average data. The results of the emissions test program are summarized in Tables 2 and 3 in units of lb/MMBtu heat input. The complete test report is organized into eight volumes including results summary, description of test procedures, calculations, raw data, laboratory analyses, and a record of source operating conditions.

Comparing emissions from the two units indicates some differences in the design and operation of the systems. The uncontrolled Green Acres unit has generally higher emissions of particulate than the Hazen unit, which is controlled by a multi-clone particulate control device. The Green Acres unit also has higher emissions of CO and lower emissions of NO<sub>x</sub> than the Hazen unit. The higher CO and lower NO<sub>x</sub> emissions indicate lower combustion temperatures and combustion efficiency than the Hazen unit. CO and NO<sub>x</sub> emissions from combustion sources typically have an inverse relationship. Metals emissions between the facilities were comparable due to the similarities in fuels being burned. PAH emissions were generally higher at the Hazen unit while formaldehyde emissions were lower. Benzene and dioxin/furan emissions were generally below detection limits and comparable for both units.

## **COMPARISON OF EMISSIONS TEST RESULTS WITH OTHER WOOD COMBUSTION AND FOSSIL FUEL-FIRED FURNACES' EMISSIONS**

To put the emissions test results from these two small wood-chip fired units into perspective, Tables 4 and 5 compare the CONEG test results with emissions data from other fuel burning sources. Table 4 is a comparison with residential wood burning appliances including conventional wood stoves, catalytic wood stoves, and stoves designed to fire wood pellet fuel. Table 5 compares the CONEG test boilers with commercial and utility scale wood and fossil fueled boilers. The commercial scale wood and fossil fuel boilers are in the same size range as the tested boilers.

In general, emissions from the Hazen unit are comparable to other smaller commercial wood fired units. Based on higher emissions of CO, formaldehyde and VOCs, the Green Acres plant appears to have a lower combustion efficiency than the other commercial units. Overall both units operated much better than smaller, less efficient residential wood-fired stoves, but have higher emissions than oil and natural gas fired boilers.

### **CONEG Test Boilers Versus AP-42 Emission Factors for Commercial Wood Burners**

- NO<sub>x</sub> and CO emissions from the CONEG tested boilers are similar to EPA AP-42 emissions factors for wood fired spreader stoker boilers and to other small capacity commercial wood boilers.
- The CONEG boilers, only one of which is controlled by a multiclone, have lower particulate emissions than the other commercial scale wood fired boilers, even compared to those units controlled by a multi-clone particulate control device. This is most likely a result of the multiple combustion chamber design of the test units.
- Metals emissions from the CONEG tested units are equivalent to AP-42 emissions factors and generally lower or equivalent to metals emissions from the other wood fired boilers.
- PAH emissions from the Hazen unit are generally higher than those from AP-42 and other similar wood fired units. PAH emissions from the Green Acres unit are more comparable to the AP-42 factors and other small wood fired units. The larger wood fired plants have lower levels of PAH emissions.
- Formaldehyde emissions from both of the CONEG boilers are higher than the AP-42 emission factor. Compared to the other wood fired units, the Hazen facility has similar formaldehyde emissions while the Green Acres unit has higher formaldehyde emissions.
- Benzene and dioxin/furan emissions from the CONEG boilers are generally lower than the AP-42 emission factors.

### **CONEG Test Boilers Versus Residential Wood Burning Appliances**

- The CONEG tested boilers have higher emissions of NO<sub>x</sub> than the smaller residential units, probably due to thermal NO<sub>x</sub> generated at the higher combustion temperatures of the boilers.
- The CONEG tested boilers emit much less CO, particulate, PAH, and benzene than the less efficient smaller units firing normal wood fuel. The units which use pelletized wood fuel have significantly reduced CO and particulate emissions, more comparable to the CONEG tested units.
- Metals emissions rates are equivalent.

### **CONEG Test Boilers Versus Fossil Fuel Boilers**

- The CONEG tested boilers emit slightly more NO<sub>x</sub> than similarly sized commercial fossil fueled boilers, but have a significantly lower NO<sub>x</sub> emission rate than uncontrolled utility boilers.
- CO emissions from the CONEG tested boilers are higher than the fossil fueled units.

- Particulate emissions from the CONEG tested boilers are significantly higher than from distillate oil and natural gas fired boilers while only slightly higher than particulate emissions from residual oil fired boilers.
- Metal emissions from the CONEG tested boilers are comparable to emissions from oil fired units.
- The CONEG tested boilers have higher emissions of PAH compounds than natural gas and oil fired boilers.
- Formaldehyde emissions from the CONEG tested boilers are higher than those from fossil fueled units. Benzene emissions are lower or equivalent to those from fossil fueled units.

## **PUBLIC HEALTH RISK ASSESSMENT**

Screening risk assessments were performed by the Vermont DOH, Division of Environmental Health based on the emissions test results from the two wood-fired furnaces testing program. For comparative purposes, assessments were performed for the wood-fired furnaces and comparably sized oil-fired furnaces at each location using site specific parameters and assumptions. The following assessments were performed:

- Preliminary estimates of the magnitude of the potential excess lifetime carcinogenic risk (ELCR) that may be associated with inhalation exposure to the reported emissions;
- Preliminary estimates of the potential for development of adverse noncarcinogenic health effects that may be associated with inhalation exposure to the reported emissions; and
- Preliminary assessment of the public health risk associated with particulate matter emissions.

The methodology and results of the assessments are detailed in a series of memorandums provided by the Vermont DOH and included within Volume IX of the Final Report. The methodology to assess the potential ELCR and noncarcinogenic health effects involved estimation of ambient concentrations, then calculation of the potential risks using conservative assumptions about the inhalation exposure to hypothetical on-site residents at the Green Acres Housing Project and students and staff at the Hazen Union School. Maximum ambient concentrations corresponding to the wood-fired furnaces were estimated using a screening level computerized dispersion model based on the average results from the emissions test program. Estimated maximum ambient concentrations corresponding to the comparably sized oil-fired furnaces were based on EPA emission factors.

The total estimated potential ELCR derived for each hypothetical potential receptor evaluated in each assessment was greater than  $1 \times 10^{-6}$ . No major difference in potential risk was noted between the two types of fuels examined. Although the preliminary results indicate that the potential ELCR associated with inhalation exposure to emissions from one wood-fired furnace may be greater than the other, due to the lack of site-specific information (e.g., location of maximum exposures), no definite conclusions can be drawn at this time.

For a hypothetical on-site receptor, an increased level of concern for the potential for development of adverse noncarcinogenic effects was estimated to be associated with inhalation exposure to wood-fired emissions from the furnace located at the Green Acres Housing Project. Similar exposure to emissions from a comparable oil-fired unit may also be associated with an increased level of concern for a hypothetical potential young child resident receptor. Overall, a greater level of concern was estimated to be associated with inhalation exposure to emissions from wood or oil fired furnaces similar in size and operation to the one located at the Housing Project. Within each furnace type studied (i.e., Housing Project or School), a higher level of concern was estimated to be associated with inhalation exposure to emissions from the wood-fired version.

Based on the information available for review in the Emissions Test Report, it appears that the Green Acres Housing Project wood-fired furnace has the greater total particulate matter emission rate of the two units examined. It should be noted that the furnace at Hazen Union School has a mechanical cyclone which functions to filter out particulate matter. No information on particle size distribution was presented in the Emissions Test Report. Based on the general information reported in US EPA AP-42, it appears that distillate No. 2 oil-fired commercial/ industrial/residential burners may have even lower total particulate emissions rates and lower PM<sub>10</sub> emission rates than the wood-fired units examined in the Emissions Test Report.

Given the limited data available for review; the fact that only those compounds with US EPA approved inhalation toxicity values were evaluated; the many conservative assumptions employed in each assessment; and the preliminary nature of these investigations, caution should be exerted in the interpretation and extrapolation of these results. *It would be premature to make any general statement regarding the magnitude of the potential risks to public health that may be associated with inhalation exposure to ambient emissions from wood-fired furnaces. For these same reasons, no definitive conclusions can be drawn regarding the relative magnitude of potential risks to public health that may be associated with inhalation exposure to emissions from wood-fired units as compared to those from oil-fired units.*

**TABLE 1  
TEST MATRIX  
WOOD-CHIP FIRED FURNACES  
AIR EMISSIONS TEST PROGRAM  
Green Acres Housing Project  
Hazen Union High School**

Sampling Location	Sample/Type Pollutant	No. of Runs	Sampling Method	Sampling Organization	Sample Run Time (min.)	Analytical Method	Analytical Laboratory
Outlet stack	PAH	3	M23	ERL	240	HRGC/HRMS (M8270)	TLI
Outlet stack	PCDD/PCDF	3	M23	ERL	240	HRGC/HRMS (M23)	TLI
Outlet stack	TSP/MM	3	M5/M29	ERL	180	Gravimetric AA, GFAA	TLI
Outlet stack	Formaldehyde	3	CM430	ERL	120	HPLC	TLI
Outlet stack	Hex Chrome	3	CM425	ERL	120	IC/SPEC	TLI/RTI
Outlet stack	Benzene	3	M18	ERL	120	GC/FID	TLI
Outlet stack	NO <sub>x</sub> , CO, O <sub>2</sub>	3	M7E, M10, M3A	ERL	240	CEM	ERL
Outlet stack	O <sub>2</sub> , CO <sub>2</sub>	3	M3 (bag)	ERL	120	Orsat	ERL

ERL = Environmental Risk Limited

TLI = Triangle Laboratories, Inc.

RTI = Research Triangle Institute

HRGC/HRMS = High resolution gas chromatography/high resolution mass spectrometry

CM430 = California Air Resources Board (CARB) Method 430

IC/SPEC = Ion Chromatography/spectrophotometer

M23 = EPA Method 23

HPLC = High Performance Liquid Chromatography

CG/FID = Gas Chromatography/Flame Ionization Detection

## **1.0 INTRODUCTION**

### **1.1 Summary of Test Program**

Environmental Risk Limited (ERL) was retained by the Coalition of Northeastern Governors (CONEG) Policy Research Center, Inc. to conduct an emission measurement test program on two wood-chip fired furnaces. This test program was conducted to determine the air emissions produced by small wood-chip fired furnaces and to determine whether any associated health risks exist. This test program was coordinated by CONEG through its Vermont representative, the Vermont Department of Public Service (VDPS), with the assistance of the Vermont Air Pollution Control Division (VAPCD) of the Vermont Agency of Natural Resources.

Pollutants measured at each furnace outlet sampling location included total suspended particulate (TSP), multiple metals (arsenic, barium, beryllium, cadmium, total chromium, copper, lead, manganese, nickel, selenium, silver and zinc), polychlorinated dibenzo-p-dioxins (CDD), polychlorinated dibenzofurans (CDF), polynuclear aromatic hydrocarbons (PAH), formaldehyde, benzene, hexavalent chromium, oxides of nitrogen (NO<sub>x</sub>), carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), and oxygen (O<sub>2</sub>).

The tests were carried out in conformance with the VAPCD Source Emission Testing Guidelines and the State of Vermont Air Pollution Control Regulations.

### **1.2 Key Personnel**

The following is a listing of the test program organization with names and phone numbers of responsible individuals.

Mr. Norm Hudson, VDPS	(802) 828-2393
Mr. Chris Jones, VAPCD	(802) 241-3851
Mr. David Manning, VAPCD	(802) 241-3855
Dr. Bill Bress, VDH	(802) 863-7220
Mr. Steve Morgan, CCC	(617) 423-9700
Mr. Rick Handley, CONEG	(202) 624-8450
Mr. Michael Holzman, ERL	(203) 242-9933
Mr. Leigh Gammie, ERL	(203) 242-9933

## **2.0 SOURCE AND SAMPLING LOCATION DESCRIPTIONS**

### **2.1 Process Description**

#### **2.1.1 Green Acres Housing Project**

Green Acres Housing Project utilizes a Messersmith Manufacturing, Inc. furnace. The Messersmith wood-chip furnace incorporates a Federal/A.L. Eastwood & Sons, Inc. 60 HP boiler with a heating surface of 397 square feet. The boiler has a heat input rating of 2.2 million BTU per hour (MMBTU/hr) and provides process hot water (~200°F) for heating throughout the housing facility. This boiler is equipped with automatic soot blowers. The furnace consists of a conveyerized automatic feeder, primary combustion

chamber and a secondary combustion chamber. The feed system is automated by an interlock control which prevents overfeeding. Other than combustion controls, the system does not use additional pollution control equipment. The Messersmith furnace operates basically in one operating mode that has a fixed wood chip feed rate. Fuel usage rates can be found in Appendix I-B.

### **2.1.2 Hazen Union High School**

The Hazen Union High School uses a Chiptec Model 85-90T furnace and boiler. The Chiptec wood-chip furnace incorporates a 63 HP boiler with a 400 square foot heating surface. This boiler has a heat input rating of 2.8 MMBtu/hr and also provides process hot water (~200°F) for heating purposes. The furnace consists of a conveyORIZED automatic feeder, primary combustion chamber, secondary combustion chamber, and a tertiary combustion chamber. The feed system is automated by an interlock control which prevents overfeeding of wood-chips. This boiler is not equipped with soot blowers. Flue gases exit this boiler, enter a mechanical cyclone (for particulate removal), and then are discharged to the atmosphere by a variable speed induced draft fan.

The Chiptec furnace operated in two different operating modes for this test program. The pilot mode used a feed rate of approximately 20 pounds per hour (lb/hr) and the low fire mode operated at a feed rate of 192 lb/hr. Frequency of operating mode along with fuel usage rates can be found in Appendix II-B.

Both facilities have limited automated process monitoring features. For this program, manual monitoring was conducted every thirty minutes. The data was collected by a VDPS representative (Mr. Ron Wells). The monitored parameters were as follows:

Wood-chip feed rate	lb/hr
Ambient temperature	°F
Feed water temperature	°F
Boiler discharge water temperature	°F

All process monitoring and field data sheets are contained in Appendix B.

For this test program both furnaces operated below their heat rate capacities due to the "shoulder season" ambient temperatures (30-45°F). Heating demand therefore remained consistent with these ambient conditions.

## **2.2 Flue Gas Sampling Locations**

### **2.2.1 Green Acres Housing Project**

The boiler outlet sampling location at the Green Acres Housing Project was located in a galvanized metal stack extension with an inside diameter (ID) of 23.5 inches. A schematic of the sampling location is shown in Appendix FI. Two sampling ports, spaced 90° apart on a horizontal plane gave access to the flue gas stream. The sampling ports were located 170" (7.2 duct diameters) downstream from the breaching entrance to the chimney flue and 24" (1.0 duct diameters) upstream to the top of the stack extension. EPA Method 1 required the use of 24 total sampling points (12 per port). The individual traverse point locations are shown below.

<u>Traverse Point No.</u>	<u>Traverse Point Location From Stack Wall (Inches)</u>
1	0.5
2	1.6
3	2.8
4	4.2
5	5.9
6	8.4
7	15.1
8	17.6
9	19.3
10	20.7
11	21.9
12	23.0

The CEM test location was in the boiler breaching, between the boiler outlet and brick chimney flue. One 3/8" hole served as the CEM sample port. This sample port was located in the center of the 20" length of rectangular duct.

### **2.2.2 Hazen Union High School**

The Hazen Union High School boiler outlet sampling location was in a galvanized metal stack extension that measured 16" x 16". The stack extension was approximately 32 inches in length. A schematic of the sampling location is shown in Appendix FII. Three sampling ports, equidistantly spaced on a horizontal plane, gave access to the flue gas stream. The sampling ports were located 94" (5.9 duct diameters) downstream from the breaching entrance to the chimney flue and 16" (1.0 duct diameters) upstream to the top of the stack extension. EPA Method 1 required the use of 16 total sampling points (8 per port). The individual traverse point locations were as follows:

<u>Traverse Point No.</u>	<u>Traverse Point Location From Stack Wall (Inches)</u>
1	1.0
2	3.0
3	5.0
4	7.0
5	9.0
6	11.0
7	13.0
8	15.0

The CEM test location was located in the cyclone discharge duct, between the cyclone exit and brick chimney flue. One 3/8" hole served as the CEM sample port. This sample port was located in the center of the 16" length of circular duct.

### **2.2.3 Wood Chip Process Sampling Location**

Both facilities have similar wood-chip feeding systems. One 4 ounce grab sample of wood-chips was taken every 30 minutes during each test run. The wood-chip samples were collected from the discharge of the screw conveyor just prior to the interlock control. Each sample was placed in a precleaned plastic drum which held all of the collected grab samples from the test program.

### **3.0 SUMMARY AND DISCUSSION OF RESULTS**

#### **3.1 Objectives and Test Matrix**

The purpose of this test program was to develop air emission factors from two small wood-chip fired furnaces and to determine if any potential health risks exist. The specific objectives for the program were to:

- Measure the emissions of PAH compounds from each boiler outlet location.
- Measure the CDD/CDF emissions from each boiler outlet location.
- Measure the emissions of total particulate and multiple metals from each boiler outlet location.
- Measure the formaldehyde, benzene and hexavalent chromium emissions from each boiler outlet location.
- Record process operating data including wood-chip feed rate, water temperature and water pressure during each test period for each boiler.
- Measure the NO<sub>x</sub>, CO, CO<sub>2</sub>, and O<sub>2</sub> emissions simultaneously with each CDD/CDF test.

Table 3-1 presents the sampling and analytical matrix. Tables 3-2 and 3-3 present all emissions test results for the Green Acres Housing Project and Hazen Union High School, respectively.

#### **3.2 Field Test Changes**

##### **3.2.1 Green Acres Housing Project**

The hexavalent chromium sampling train required a filter change for test runs C425-2 and C425-3. Moisture/condensation developed on the unheated filter and would have created a pressure drop too great for proper isokinetic sampling. Before and after the filter change, the sampling train was leak checked. Sampling resumed once a second filter was installed. Sample recovery procedures included both filters (where applicable) and the hexavalent chromium analysis included both filters from each respective test run.

The dioxin/furan sampling occurred from one single traverse port. The other traverse port was not accessible due to the scaffolding configuration. For each dioxin/furan test run the single port was traversed twice. During the sample analysis of the dioxin/furan tests the toluene rinse was inadvertently added to the acetone/methylene chloride rinse for each of the three test runs. For Green Acres the toluene analysis report is not reported.

**TABLE 3-1  
TEST MATRIX  
WOOD-CHIP FIRED FURNACES  
AIR EMISSIONS TEST PROGRAM  
Green Acres Housing Project  
Hazen Union High School**

Sampling Location	Sample/Type Pollutant	No. of Runs	Sampling Method	Sampling Organization	Sample Run Time (min.)	Analytical Method	Analytical Laboratory
Outlet stack	PAH	3	M23	ERL	240	HRGC/HRMS (M8270)	TLI
Outlet stack	PCDD/PCDF	3	M23	ERL	240	HRGC/HRMS (M23)	TLI
Outlet stack	TSP/MM	3	M5/M29	ERL	180	Gravimetric AA, GFAA	TLI
Outlet stack	Formaldehyde	3	CM430	ERL	120	HPLC	TLI
Outlet stack	Hex Chrome	3	CM425	ERL	120	IC/SPEC	TLI/RTI
Outlet stack	Benzene	3	M18	ERL	120	GC/FID	TLI
Outlet stack	NO <sub>x</sub> , CO, O <sub>2</sub>	3	M7E, M10, M3A	ERL	240	CEM	ERL
Outlet stack	O <sub>2</sub> , CO <sub>2</sub>	3	M3 (bag)	ERL	120	Orsat	ERL

ERL = Environmental Risk Limited

TLI = Triangle Laboratories, Inc.

RTI = Research Triangle Institute

HRGC/HRMS = High resolution gas chromatography/high resolution mass spectrometry

CM430 = California Air Resources Board (CARB) Method 430

IC/SPEC = Ion Chromatography/spectrophotometer

M23 = EPA Method 23

HPLC = High Performance Liquid Chromatography

CG/FID = Gas Chromatography/Flame Ionization Detection

**Table 3-2**  
**Summary of Emission Test Results**  
**CONEG/Green Acres Housing**  
**Barretown, Vermont**

Method/Component	Units	Run 1	Run 2	Run 3	Average
Method 3A – O <sub>2</sub>	%	13.1	11.8	13.1	12.7
Method 3A – CO <sub>2</sub>	%	8.0	9.1	7.3	8.1
Method 7E – NO <sub>x</sub>	lb/MMBtu	0.156	0.142	0.139	0.146
Method 10 – CO	lb/MMBtu	1.989	2.114	2.267	2.123
Method 5 – Particulate	lb/MMBtu	1.151E-01	1.444E-01	1.005E-01	1.200E-01
Method 29 – Multiple Metals	lb/MMBtu				
Silver		2.97E-06	< 1.96E-06	3.12E-06	< 2.68E-06
Barium		1.25E-04	1.12E-04	8.40E-05	1.07E-04
Beryllium		< 3.77E-07	2.59E-07	< 1.17E-07	< 2.51E-07
Cadmium		< 3.02E-05	< 1.23E-05	< 1.09E-05	< 1.78E-05
Chromium		3.61E-05	< 2.49E-05	1.81E-05	< 2.64E-05
Copper		9.36E-05	4.83E-05	4.96E-05	6.39E-05
Manganese		5.19E-04	7.25E-04	4.28E-04	5.57E-04
Zinc		5.92E-04	7.49E-04	4.98E-04	6.13E-04
Arsenic		< 2.28E-06	< 3.27E-06	< 2.42E-06	< 2.66E-06
Nickel		3.02E-05	1.49E-05	1.83E-05	2.11E-05
Lead		6.73E-05	4.76E-05	4.00E-05	5.16E-05
Selenium		5.07E-06	< 1.15E-06	< 3.14E-06	< 3.12E-06
Method 425 – Hex Chrome	lb/MMBtu	1.362E-06	1.988E-06	5.815E-07	1.311E-06
Method 429 – PAH	lb/MMBtu				
Naphthalene		1.36E-04	1.15E-04	1.27E-04	1.26E-04
2-Methylnaphthalene		1.23E-05	1.21E-05	1.52E-05	1.32E-05
Acenaphthene		7.85E-07	4.68E-07	1.01E-06	7.53E-07
2-Chloronaphthalene		5.71E-09	3.93E-09	5.91E-09	5.18E-09
Acenaphthylene		2.61E-05	4.20E-05	3.17E-05	3.33E-05
Fluorene		6.24E-07	3.93E-07	8.51E-07	6.22E-07
Phenanthrene		2.10E-05	2.97E-05	2.94E-05	2.67E-05
Anthracene		1.31E-06	3.23E-06	2.78E-06	2.44E-06
Fluoranthene		8.04E-06	1.41E-05	1.03E-05	1.08E-05
Pyrene		7.06E-06	1.22E-05	8.90E-06	9.38E-06
Benzo(A)anthracene		7.43E-07	2.77E-06	1.09E-06	1.54E-06
Chrysene		2.53E-06	3.74E-06	3.18E-06	3.15E-06
Perylene		6.94E-08	3.79E-07	1.77E-07	2.08E-07
Benzo(B)fluoranthene		2.59E-06	4.68E-06	3.70E-06	3.66E-06
Benzo(K)fluoranthene		5.89E-07	8.69E-07	8.79E-07	7.79E-07
Benzo(A)pyrene		4.63E-07	1.78E-06	7.27E-07	9.91E-07
Benzo(E)pyrene		1.53E-06	3.16E-06	2.45E-06	2.38E-06
Benzo(g,h,i)perylene		8.48E-07	2.65E-06	2.29E-06	1.93E-06
Indeno(1,2,3,cd)pyrene		6.38E-07	1.62E-06	1.57E-06	1.28E-06
Dibenz(a,h)anthracene		6.94E-08	1.74E-07	1.55E-07	1.33E-07
Method 430 – Formaldehyde	lb/MMBtu	9.449E-03	1.204E-02	9.915E-03	1.047E-02
Method 18 – Benzene	lb/MMBtu	1.287E-04	< 3.037E-06	< 3.037E-06	< 4.494E-05
Method 23 – Total Dioxin/Furan	lb/MMBtu	< 2.16E-11	< 8.10E-12	< 4.15E-12	< 1.13E-11
Method 2 – Volumetric Flow	dscfm	619	640	621	627
Method 4 – Moisture	%	7.29	8.35	7.77	7.80
Method 19 – F-Factor	dscf/MMBtu	9891	9891	9891	9891

**Table 3-3**  
**Summary of Emission Test Results**  
**CONEG/Hazen Union School**  
**Hardwick, Vermont**

Method/Component	Units	Run 1	Run 2	Run 3	Average
Method 3A - O <sub>2</sub>	%	8.3	8.0	8.6	8.3
Method 3 - CO <sub>2</sub>	%	11.9	7.0	8.6	9.2
Method 7E - NO <sub>x</sub>	lb/MMBtu	0.210	0.210	0.213	0.211
Method 10 - CO	lb/MMBtu	1.425	0.847	0.435	0.902
Method 5 - Particulate	lb/MMBtu	1.062E-01	9.106E-02	9.605E-02	9.777E-02
Method 29 - Multiple Metals	lb/MMBtu				
Silver		< 1.54E-06	< 1.38E-06	1.62E-06	< 1.51E-06
Barium		4.02E-05	3.55E-05	3.62E-05	3.73E-05
Beryllium		< 1.35E-07	< 1.07E-07	< 2.68E-07	< 1.70E-07
Cadmium		< 3.75E-06	< 4.00E-06	< 4.03E-06	< 3.93E-06
Chromium		8.64E-06	< 3.91E-06	< 6.97E-06	< 6.51E-06
Copper		5.28E-05	4.99E-05	4.40E-05	4.89E-05
Manganese		9.21E-05	8.86E-05	8.64E-05	8.91E-05
Zinc		1.07E-03	7.80E-04	8.79E-04	9.10E-04
Arsenic		< 6.88E-07	< 5.29E-07	< 4.95E-07	< 5.71E-07
Nickel		5.02E-06	2.65E-06	3.04E-06	3.57E-06
Lead		2.66E-05	2.08E-05	2.27E-05	2.34E-05
Selenium		< 6.17E-07	< 5.53E-07	< 6.46E-07	< 6.05E-07
Method 425 - Hex Chrome	lb/MMBtu	8.034E-07	8.246E-07	8.833E-07	8.371E-07
Method 429 - PAH	lb/MMBtu				
Naphthalene		3.05E-05	8.82E-05	1.05E-04	7.47E-05
2-Methylnaphthalene		9.54E-06	2.72E-05	2.88E-06	1.32E-05
Acenaphthene		2.43E-07	9.46E-07	2.06E-07	4.65E-07
2-Chloronaphthalene		2.35E-08	4.12E-08	1.25E-08	2.57E-08
Acenaphthylene		2.47E-05	5.55E-04	3.10E-05	2.04E-04
Fluorene		1.11E-06	6.35E-06	1.24E-06	2.90E-06
Phenanthrene		1.15E-04	5.47E-04	1.31E-04	2.64E-04
Anthracene		1.53E-06	3.76E-05	3.62E-06	1.42E-05
Fluoranthene		4.61E-05	1.72E-04	6.70E-05	9.51E-05
Pyrene		3.85E-05	1.47E-04	5.76E-05	8.12E-05
Benzo(A)anthracene		1.73E-06	4.26E-05	4.48E-06	1.63E-05
Chrysene		8.62E-06	4.92E-05	1.49E-05	2.43E-05
Perylene		1.28E-07	7.81E-06	4.89E-07	2.81E-06
Benzo(B)fluoranthene		4.96E-06	5.72E-05	1.31E-05	2.51E-05
Benzo(K)fluoranthene		1.04E-06	8.84E-06	2.57E-06	4.15E-06
Benzo(A)pyrene		8.54E-07	3.57E-05	3.74E-06	1.34E-05
Benzo(E)pyrene		3.38E-06	3.48E-05	8.95E-06	1.57E-05
Benzo(g,h,i)perylene		9.69E-07	3.85E-05	3.79E-06	1.44E-05
Indeno(1,2,3.cd)pyrene		7.70E-07	4.57E-06	2.96E-06	2.77E-06
Dibenz(a,h)anthracene		6.18E-08	2.06E-05	2.65E-07	6.97E-06
Method 430 - Formaldehyde	lb/MMBtu	3.572E-03	4.160E-04	1.589E-04	1.382E-03
Method 18 - Benzene	lb/MMBtu	1.698E-04	< 2.122E-06	< 2.122E-06	< 5.800E-05
Method 23 - Total Dioxin/Furan	lb/MMBtu	< 1.13E-11	< 1.18E-11	< 6.48E-12	< 9.86E-12
Method 2 - Volumetric Flow	dscfm	360	318	309	329
Method 4 - Moisture	%	14.26	13.02	13.84	13.71
Method 19 - F-Factor	dscf/MMBtu	9416	9416	9416	9416

### **3.2.2 Hazen Union High School**

With the experience gained from the Green Acres hexavalent chromium tests, filter changes were conducted for each of the three Hazen Union test runs.

Test run and sample identifications for Hazen Union used the letter "H" as an identifier. For example, the first dioxin/furan test run from Hazen Union was identified as "M23-1H".

At the completion of the first dioxin/furan test run, adjustments to the wood chip feed rate were made, reducing the low fire mode rate from 238 pounds per hour (lb/hr) to 192 lb/hr. A visual inspection revealed an abnormally high mass of coals had built up on the ash grate. This may have been caused by over feeding, thus the feed rate was reduced.

Carbon monoxide (CO) levels during the three dioxin/furan tests spiked above the 1000 part per million (ppm) range of the CO analyzer. As a result of this the CO range was increased to the 0-10,000 ppm range to accommodate the higher spikes. CO levels seemed to stabilize once the lower feed rate was implemented for the low fire mode.

During the third formaldehyde test run (C430-3H) the Teflon sample line became dislodged from the sample port. This was exposed to ambient conditions for approximately 2-3 minutes. A depleted supply of DNPH solution prevented a possible fourth run from occurring. The results from this third test run have been reported.

## **3.3 Emissions Summary of Results**

### **3.3.1 Green Acres Housing Project**

Results of all measured emissions data are shown in Table 3-2. Each individual test run is presented along with the 3-run average. Additional data summaries expressed in different units of measure are contained in Appendix I-A.

### **3.3.2 Hazen Union High School**

Test results from Hazen Union High School are summarized in Table 3-3. Additional data summaries are contained in Appendix II-A.

## **4.0 SAMPLING AND ANALYTICAL PROCEDURES**

### **4.1 Total Particulate and Multiple Metals Tests**

Total particulate matter and multiple metals sampling and analysis was performed by EPA Method 29, as described in the Code of Federal Regulations (CFR), Title 40, Part 60, Appendix A. The sampling train is shown schematically in Appendix F and consisted of a glass nozzle, heated probe, heated quartz fiber filter, five impingers, vacuum pump, dry gas meter and an orifice flowmeter.

A glass nozzle was attached to a stainless steel, glass-lined probe which was heated to prevent condensation (248°±25°F). A heated quartz fiber filter, maintained at 248°±25°F, was attached to the back end of the probe. An ice bath containing five impingers was connected to the back end of the filter via a flexible Teflon line. The first impinger was an optional knockout, the second and third impingers contained 100 milliliters (ml) of a 5% HNO<sub>3</sub>/10% H<sub>2</sub>O<sub>2</sub> solution, the fourth was empty and the fifth impinger contained 250 grams (g) of silica gel to remove any remaining moisture.

Flexible tubing, vacuum gauge, needle valve, leakless vacuum pump, bypass valve, dry gas meter, calibrated orifice and inclined manometer completed the sampling train. The stack velocity pressure was measured using a pitot tube and inclined manometer. The stack temperature was monitored by a thermocouple that was attached to the pitot and connected to a potentiometer. A check valve was not used in the ERL sampling train due to malfunctions in cold weather.

A nomograph was used to quickly determine the orifice pressure drop required for any pitot velocity pressure and stack temperature to maintain isokinetic sampling conditions. Sample flow was adjusted by means of the bypass valve.

Before and after each test run the sampling train was leak checked. Prior to testing, a preliminary velocity traverse covering all sampling points was performed to check for cyclonic flow. Test data was recorded on field data sheets shown in Appendices I-B and II-B. At the end of each test the sampling train was first recovered for the particulate portion using the following sequence:

- Container 1 - Filter
- Container 2 - Acetone wash of nozzle, probe and front half of the filter holder. The probe and nozzle were washed and brushed three times.
- Container 3 - Silica gel from the fifth impinger.

Upon completion of the particulate recovery, the multiple metals portion was recovered following the scheme shown in Appendices I-C and II-C. The particulate samples (Containers 1 and 2) were transported to the laboratory and the following analyses performed.

- Container 1 - Transfer the filter and any loose particulate matter from the sample container to a tared glass weighing dish, desiccate and dry to constant weight. Report results to the nearest 0.1 mg. Upon completion of the gravimetric analysis, the filter is combined with the contents of Container 2 for metals analysis as shown in Appendix C.
- Container 2 - Transfer the acetone washings to a tared beaker and evaporate to dryness at ambient temperature and pressure. Desiccate and dry to a constant weight. Report results to the nearest 0.1 mg. The dry residue is then put back into solution with nitric acid and combined with the contents of Container 1 for metals analysis as shown in Appendix C.

Analysis of multiple metals was conducted for arsenic, barium, beryllium, cadmium, total chromium, copper, lead, manganese, nickel, selenium, silver and zinc. Mercury was not sampled or analyzed for; please

disregard mention of this in the sample recovery and analysis flow charts shown in Appendices I-C and II-C. Sample analysis was performed by Triangle Laboratories, Inc.

#### **4.2 Polychlorinated Dibenzo-p-dioxins, Polychlorinated Dibenzofurans, and PAH Tests**

Polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans (CDD/CDF), and polynuclear aromatic hydrocarbons (PAH) sampling and analysis was accomplished by EPA Method 23. A schematic diagram of the sampling system is shown in Appendix F. The train consisted of a glass nozzle, glass lined probe, heated glass fiber filter, heated Teflon sample line, spiral tube condenser, XAD-2 sorbent module, followed by three impingers, silica gel drying cartridge, leakless pump, and dry gas meter.

Prior to use in the field, the glass fiber filters (EMB2000) were pre-cleaned and checked for contamination. During this procedure, a total of up to 50 filters from the same lot were extracted simultaneously with toluene in a soxhlet extractor for a period of 24 hours. Triangle Laboratories, Inc. analyzed the filter extract by gas chromatography/mass spectrometry (GC/MS) to verify that the filters were free of contamination. The pre-cleaned filters were used in the field for sample collection. To prevent contamination of the filters, they were kept in a pre-cleaned petri dish and sealed with Teflon tape.

Methylene chloride was used as the final solvent for preparation of the XAD-2 resin. The fluidized bed technique was used to dry the resin. The final solvent rinses were analyzed for residuals prior to packing the traps. Care was taken to ensure that the resin was kept at temperatures below 120°F before and after sample collection to prevent resin decomposition. The sorbent tube was charged with 25 to 30 grams of the pre-cleaned resin. The period of time between resin pre-cleaning and use in the field was minimized and not allowed to exceed 14 days.

All glass components of the sampling train, including the sorbent tube, were pre-cleaned prior to sampling according to the procedures listed below. Cleaned glassware was sealed with pre-cleaned foil until sample train assembly. Assembly of the sample trains was conducted in a designated clean up area.

##### CDD/CDF/PAH GLASSWARE PRE-CLEANING PROCEDURES

1. Glassware soaked in hot soapy water (Alconox) 50°C or more.
2. Tap water rinsed (three times).
3. DI water rinsed (three times).
4. Baked at 450°F for two hours.
5. Rinsed with pesticide grade acetone (three times).
6. Rinsed with pesticide grade methylene chloride (three times).
7. Glassware capped with methylene chloride rinsed aluminum foil.

Assembly of the sample train was conducted in the on-site mobile laboratory. Following sample recovery, the glassware was reused at the same sampling location.

Flue gas was sampled isokinetically through a glass nozzle and heated glass lined probe. Particulate matter was removed from the gas stream by means of a glass fiber filter housed in a glass holder maintained at 248°F±25°F. The filter holder contained a Teflon frit to support the filter. The gases passed through a spiral tube condenser and into a sorbent trap for removal of organic constituents. A chilled impinger train

was used to remove water from the flue gas, and a dry gas meter was used to measure the volume of sampled gas.

Sample recovery was conducted in a sterile environment located in the on-site mobile laboratory. Access to this area was limited to those individuals involved in the sample recovery process. The sample recovery, sample extraction, sample cleanup/fractionation, and analysis schemes are shown in Appendices I-C and II-C.

The CDD/CDF samples were extracted and analyzed according to the procedures described in EPA Method 23 and the Triangle Lab User Manual. A laboratory method blank was prepared along with each batch of three samples.

EPA Method 23 requires the toluene rinse procedure where the glassware components in the CDD/CDF sampling train are rinsed with toluene as a QA/QC field blank check. The "toluene rinse" was extracted as follows:

1. 100 µl of the internal standard solution was added to the contents of the container.
2. The sample was concentrated to a volume of about 1-5 ml using a rotary evaporator at a temperature of less than 37°C.
3. The sample container was rinsed three times with small portions of toluene at a temperature of less than 37°C and added to the concentrated sample.
4. The sample was further concentrated to near dryness.

Analysis of the extract was identical to the CDD/CDF procedures except for the sample concentration procedure. The solution was concentrated in a rotary evaporator apparatus rather than a nitrogen evaporator concentrator.

Analysis of the PAH samples was performed in accordance with EPA Method 8270. Prior to extraction, the XAD-2 traps, filters, and rinses were spiked. These portions of the sampling train were soxhlet extracted with methylene chloride for 16 hours. The extract was concentrated to 5 milliliters (ml) and then split, with 50 percent saved. The remaining semi-volatile extract was concentrated to 1.0 ml prior to analysis by HRGC/HRMS.

#### **4.3 Formaldehyde Tests**

Gaseous formaldehyde was withdrawn at a constant rate (200 cubic centimeters/minute) from the source and collected in aqueous acidic 2,4-dinitrophenyl-hydrazine (DNPH) absorbing solution. Three samples were collected at the boiler outlet sampling location according to CARB Method 430.

Formaldehyde present in the emissions reacted with the DNPH to form the formaldehyde dinitrophenyl-hydrazone derivative. The DNPH derivative was extracted, solvent exchanged, concentrated, and then analyzed by high performance liquid chromatography.

A schematic of the sampling train is shown in Appendix F. This sampling train consisted of the following components:

- Heated Teflon Sample Probe
- Differential Pressure Gauge
- Metering System
- Barometer
- Gas Density Determination Equipment

The formaldehyde emissions were collected in two impingers, each containing 10 ml of the DNPH solution. Each impinger was recovered separately into its own vial. At the laboratory, the samples from each individual test run were combined and then analyzed by high performance liquid chromatography (HPLC).

CARB Method 430 was selected for its ability to effectively sample and analyze levels of formaldehyde from this combustion source. The main differences between CARB 430 and Method 0011 (M0011) are as follows: CARB Method 430 is a single point constant velocity sampling procedure where as M0011 is an isokinetic procedure. Both methods use DNPH as the collection media, however, CARB 430 uses approximately 40 milliliters (ml) of total solution (including rinses) compared to 300 ml of solution with M0011. Analytical sensitivity based on the small total volume of 40 ml is greatly increased. Sample recovery procedures associated with CARB 430 are simpler and do not require the use of methylene chloride as a clean up solvent as specified in M0011.

Laboratory analysis was provided by Triangle Laboratories, Inc (TLI). All necessary reagents were provided by TLI. This included absorbing reagents and their respective quality assurance. The formaldehyde sample recovery process and analytical flowcharts are shown in Appendices I-C and II-C.

#### **4.4 Benzene Tests**

Gaseous benzene was withdrawn at a constant rate (approximately 150 cubic centimeters/minute) from the boiler exhaust and collected in a 25.0 liter Tedlar bag. Three samples were collected consecutively at the outlet sampling location. Each test was performed according to EPA Method 18. Samples were collected using the "bag-in-a-box" sampling system, shown in Appendices I-F and II-F. A short stainless steel probe was connected to a Teflon sample line. This sample line passed through the wall of a rigid container and connected to the sample bag, creating a vacuum seal. The bags were filled at a constant rate over a 120-minute sampling period by slowly evacuating the air within the container. The resulting vacuum inflated the bag with the extracted flue gas sample. Each sample/line bag pair was filled, purged, and filled again to condition the sampling train and minimize any wall absorption effects.

Collection of the benzene samples occurred simultaneously with the formaldehyde tests. At the completion of sample collection, the bag samples were analyzed within 18 hours by gas chromatography/flame ionization detection (GC/FID) at Quanterra Environmental Services.

#### **4.5 Hexavalent Chromium Tests**

Hexavalent chromium (hex chrome) sampling and analysis was accomplished by CARB Method 425. The sampling train was identical to the EPA Method 5/29 train previously described, with the following exceptions:

- 0.1N NaOH in the first two impingers
- Teflon coated glass fiber filter after the second impinger
- silica gel moisture trap after the filter

The hex chrome sampling train is shown in Appendices I-F and II-F. Each impinger contained 50 ml of 0.1N NaOH absorbing solution. Isokinetic sampling occurred in the same manner as described for the TSP/MM tests. At the completion of sampling, the train was recovered as follows:

Container 1 -	The probe was rinsed three times with 0.1N NaOH, total rinse volume exceeded 100 ml.
Container 2 -	Contents of the first two impingers, and a 10 ml rinse with 0.1N NaOH of each impinger.
Container 3 -	Filters.

The above containers were sealed, liquid levels marked, prepared for shipment and delivered to the laboratory for analysis. Containers 1, 2 and 3 were combined, extracted, and analyzed by ion chromatography (IC) spectrophotometry. The samples were not split for total chromium analysis as directed in the method. Total chromium was determined from the multiple metals tests.

Ion chromatography coupled with the spectrophotometer offered a superior analytical approach based on better sensitivity and lower detection limits. Sample interface was by direct injection and no sample manipulation was required to counteract interferences.

#### **4.6 Continuous Emission Monitoring**

ERL conducted the outlet flue gas measurements for NO<sub>x</sub>, CO and diluent O<sub>2</sub> using EPA Reference Methods 7E, 10, and 3A, respectively. A schematic diagram of the sampling system is shown in Appendices I-F and II-F. The continuous emission monitoring system (CEMS) drew flue gas in through a 2-foot stainless steel heated probe with in-stack and/or heated out-of-stack filtration systems. The gas sample was drawn through the probe and filter(s) by a heated Teflon lined diaphragm vacuum pump. From the pump, the sample was sent through a heated Teflon sample line. At the end of the sample line, the extracted flue gas was sent through a refrigerator-type condenser, into a manifold, and finally to the NO/NO<sub>x</sub>, O<sub>2</sub>, and CO analyzers. Analyzer outputs were recorded by a data acquisition system (DAS) at fifteen (15) or thirty (30) second intervals.

A total of three 240-minute CEM test runs were performed simultaneously with the CDD/CDF/ PAH tests. A zero and mid-range calibration check was performed between each test run. In addition, a full range calibration and linearity check was performed on each reference method analyzer at the beginning of each test day. Emissions are being reported in parts per million (ppm), pounds per hour (lb/hr), and pounds per million Btu (lb/MMBtu).

All field data reporting and calculations were conducted in accordance with the guidelines presented in EPA Reference Method 6C. Copies of the field data sheets are included in Appendices I-B and II-B.

#### 4.6.1 Instrumentation

The NO<sub>x</sub> instrument was a Rosemount Model 955 NO/NO<sub>x</sub> analyzer. This instrument utilizes the principle of chemiluminescence, whereby NO in the sample gas reacts with ozone (O<sub>3</sub>) at a specific wavelength to produce NO<sub>2</sub>. The NO<sub>2</sub> is then disassociated by a converter to produce NO, which is the combination of the original NO and the disassociated NO<sub>2</sub> in the sample stream. This total NO is proportional to the original NO<sub>x</sub> (NO and NO<sub>2</sub>) concentration.

The O<sub>2</sub> instrument was a Rosemount Model 755 analyzer, which measures O<sub>2</sub> concentration by means of the paramagnetic susceptibility of the sample gas using a proven magneto-type measuring cell. Oxygen molecules are attracted more strongly by the magnetic field than are molecules of other gases, and their concentrations can thereby be measured.

The CO instrument was a TECO Model 48 analyzer which measures CO concentration by means of non-dispersive infrared radiation (NDIR). The infrared radiation is produced by the analyzer and is, in turn, absorbed by the continuous flow of sample gas through the analyzer. The percentage of infrared radiation thus absorbed is proportional to the concentration of CO in the gas stream.

#### 4.6.2 Analyzer Calibrations

For the field tests, the analyzers were calibrated and linearized at three or four points along their measurement ranges at the beginning of each test day. EPA Protocol 1 gases were introduced to each analyzer. The system bias and drift tests were conducted with appropriate mid-level calibration gases based on the source emissions. These system calibrations were repeated after each 240-minute test run. The gases passed through all components of the sampling system except the sampling probe.

#### 4.6.3 CEM Data Reduction

The system calibrations were performed to document any instrument drift. Using Equation 6C-1 (CFR, Title 40, Part 60, Appendix A), the ppm and percent values were corrected to account for the zero and span values and any instrument drift as follows:

$$C_{gas} = (\bar{C} - C_o) \times \frac{C_{ma}}{C_m - C_o}$$

where:

$C_{gas}$  = emissions concentration (ppm or %)

$\bar{C}$  = average emissions reading (ppm or %)

$C_o$  = average zero reading (ppm or %)

$C_m$  = average span reading (ppm or %)

$C_{ma}$  = span gas concentration (ppm or %)

The corrected ppm and % averages were then used to calculate emission rates in the appropriate standard units.

#### **4.7 Wood Chip Fuel Tests**

During the course of each individual test run, a 4-ounce wood-chip sample was collected from the automatic auger. The wood-chips were placed in a precleaned plastic drum and stored over the six-day test period. At the completion of the six-day test period (at each facility), the contents of the plastic drum was thoroughly mixed. From this container, three 5-pound samples were collected and placed in sealed plastic bags for analysis and archiving. One sample per test location was given to ERL for ASTM analysis. One sample was given to the VDPS representative and one sample to the VAPCD representative for archiving or future analyses. The wood-chip samples were analyzed for percent moisture, hydrogen, nitrogen, oxygen, sulfur, carbon, ash and BTU per pound (BTU/lb). Fuel analysis was performed by Commercial Testing and Engineering Co. in South Holland, Illinois.

#### **4.8 Flue Gas Analysis**

The composition of the gas stream at the boiler outlet sampling location was analyzed for oxygen and carbon dioxide during each test run in accordance with EPA Method 3. In order to make accurate assessment of the flue gas composition, redundant Orsat analyses were conducted. During each particulate test run, at least one multi-point integrated sample of flue gas was taken for Orsat analysis. The integrated gas sampling train and grab sampling train used for EPA Method 3 is shown in Appendices I-F and II-F.

#### **4.9 Sample Identification and Custody**

The ERL project manager ensured that all samples were accounted for and that proper custody procedures were followed. For this entire test program the project manager conducted all sample recovery, sample logging, sample preparation for shipping, and chain-of-custody tasks.

Green Acres sampling identification consisted of the following example sequence (M23-1, M29-1, M18-1, C425-1, C430-1, and M3-1). The Hazen Union sample identification consisted of the following nomenclature (M23-1H, M29-1H, M18-1H, C425-1H, C430-1H, and M3-1H).

### **5.0 QA/QC ACTIVITIES**

#### **5.1 QC Procedures**

Specific quality control (QC) procedures were followed to ensure the continuous production of useful and valid data throughout the course of this test program. The QC checks and procedures described in this

section represent an integral part of the overall sampling and analytical scheme. Strict adherence to prescribed procedures is quite often the most applicable QC check. A discussion of both the sampling and analytical QC checks that were utilized during this program is presented below.

### **5.2 Post-Test Equipment Calibrations**

Post-test equipment calibrations were conducted on each CEM analyzer and dry gas meter used at both test sites. All calibrations met their acceptance criteria and no adjustments were needed to correct emissions data.

### **5.3 Particulate/Multiple Metals QC Procedures**

One outlet field blank was submitted for analysis during this two source test program. A complete sampling train was set up, leak checked at the outlet sampling location, and recovered in an identical manner as an actual test run. The recovered samples were labeled as the field blank and submitted with the other samples for analysis.

### **5.4 Formaldehyde QC Procedures**

One outlet field blank from each test site was submitted for analysis during this two source test program. A complete outlet sampling train was set up, leak checked and recovered in an identical manner as an actual test run. The recovered samples were labeled as the field blanks and submitted with the other samples for analysis. Results for only the formaldehyde tests have been blank corrected.

### **5.5 Hexavalent Chromium QC Procedures**

One outlet field blank was submitted for analysis during this two source test program. A complete outlet sampling train was set up, leak checked and recovered in an identical manner as an actual test run. The recovered samples were labeled as the field blank and submitted with the other samples for analysis. A reagent blank was not submitted during this test program. The remaining 0.1N NaOH solution was used for the preparation of the blank train leaving a depleted supply.

### **5.6 QA Audits**

One dioxin/furan (CDD/CDF) quality assurance (QA) audit was obtained from the United States Environmental Protection Agency (USEPA). The results of this audit are presented in Appendix I-C.

### **5.7 QA/QC Checks of Data Reduction**

The project manager ran an independent check (using a validated computer program) of the calculations with predetermined data before the field test. This ensured that calculations done in the field were accurate. The project manager also conducted a spot check on-site to assure that data was being recorded accurately. After the test, the QA/QC manager checked the data input to assure that the raw data had been transferred to the computer accurately.

The  $F_o$  factors from Method 3 were used to validate the  $CO_2/O_2$  data. The outlet volumetric flow rates were compared daily. Agreement within tests were  $\pm 10$  percent (based on steady operations).

During the operation of the CEM system comparisons were made between the CEM  $O_2$  and Orsat  $O_2$  concentration.

## REFERENCES

United States Environmental Protection Agency, Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition, January 1995.

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