Dioxin/Furan Air Emissions, General Emissions, and Fuel Composition of Duraflame Firelogs and Douglas Fir Cordwood

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1 Introduction

OMNI Environmental Services, Inc in collaboration with Puget Sound Clean Air Agency and Environment Canada has set out to representatively measure firelog air emissions from fireplaces. Fireplaces are very common in the United States and Canada with 35.4 million usable fireplaces in the United States (U.S. Census, 2003). However, emissions testing from fireplaces, particularly emissions from burning firelogs in them, is uncommon. There has been little documentation on dioxin/furans from burning fuel in fireplaces and further general emissions measurements are needed. Two of the most common fireplace fuels in the Northwest region are Duraflame firelogs and Douglas fir cordwood. The following report is designed to show two common fuels compared side by side from the typical usage of household fireplaces.

General Dioxins/Furans

2 Test Program

The first phase of our testing was to measure dioxin/furan ("dioxin") emissions from locally purchased Duraflame firelogs and Douglas fir cordwood in a standard fireplace. Phase two was to conduct general emissions tests on the same two fuels. These general emissions tests include total particles (PM), respirable particles ($PM_{2.5}$), carbon monoxide (CO), nitrogen oxides (NO_x), volatile organic compounds (VOC), polycyclic aromatic hydrocarbons (PAH), benzene and formaldehyde. In addition to the dioxin air emissions and general emissions, the firelogs were characterized by fuel composition tests. These tests include heat, loss on drying, and ash content, as well as, proximate-ultimate analyses, chlorine content, wax content, wax analyses, fiber identification, amount of combustion residue per unit mass of fuel burned, toxic metals content, and heat content of residue.

Emission tests were conducted on each fuel with a burn pattern characteristic of that which would be a typical homeowner. Our composition tests were conducted on both fuels for product documentation purposes. The results of the tests can be used to compare emissions from a commercially available firelog with locally purchased Douglas fir cordwood.

The fuels used were:
Duraflame Xtra Time Firelog, 2.7 kg (6 lb.) Firelog made of wood fiber and wax by Duraflame, Inc., manufactured in Canada.
Douglas Fir Cordwood, locally purchased Portland, Oregon.

Test Fireplace and Dilution Tunnel
All tests were preformed in a standard 36-inch zero clearance radiant fireplace with glass doors open. During the tests an expanded metal grate (10 gauge, 3.2 cm [1.25 in] wide

openings) was placed on top of a standard fireplace grate (about 15cm [6 in] spacing between bars). The use of an expanded grate with close bar spacing or a metal overly minimizes the physical break-up of the firelog allowing for more complete combustion.

A 36 cm (14 in) diameter dilution tunnel was used to cool and dilute the fireplace emissions prior to sample collection. The fireplace chimney was located under the collection hood of the dilution tunnel and the entire exhaust stream was captured and mixed with room air and outdoor air. Dilution tunnels are used for source tests because they permit the sampling of air pollutants in a chemical and physical form similar to that which they will have once they exit the chimney and mix with ambient air. This is particularly important for characterizing emissions from the combustion of biomass fuels because a large fraction of their general emissions are comprised of semi-volatile organic compounds. The relative partitioning of these compounds between the vapor phase and sub-micron particles is primarily dependent on temperature (Broderick, 2005).

Fuels
The Duraflame firelog and Douglas fir cordwood used for comparison represent typical wax/fiber firelogs and cordwood, respectively, that would be burned in the Pacific Northwest.

The firelog test consisted of burning two 4-hour firelogs in succession. Our firelog fuel burning protocol includes two firelogs because firelog emissions tend to be significantly lower than cordwood (Broderick, 2005). Due to low emission rates, some emissions may be undetectable when only one firelog is burned. Therefore, in order to increase the accuracy of the results, two firelogs were burned in succession and larger sample amounts were collected with the appropriate matrix. Furthermore, burning two firelogs in succession is typical usage for a homeowner's fireplace.

The firelogs were burned one at a time per the package instructions. The first firelog was lit and burned until its visible flame went out. Then the second firelog was placed on the expanded grate and lit. Firelogs were lit with a standard butane lighter. Emissions were sampled until the interior of the chimney cooled to 10ºF (5.6ºC) above room temperature.

The cordwood test consisted of targeting a typical burn pattern of a three-hour fire of seasoned Douglas fir cordwood with 20±5% moisture content. Practice burns were preformed to determine the mass of wood needed for a one hour burn time. The fire was started with 4 pieces of black and white newspaper, kindling and 4 small starter logs. Once started, the fire was maintained with major wood additions of 4.5 kg (10 lbs) every hour for three hours. Each wood addition consisted of adding a pre weighed bundle throughout the hour to maintain a typical burn characteristic of a standard zero-clearance 36-inch fireplace. Our hourly wood addition technique consisted of adding 1-2 logs early in the hour, then adjusting the wood with a poker to maintain a coal bed and adding a log, the adjusting the wood again and adding the final log. After the wood additions there was a 45 minute burn out period for a total test time of around 4.5 hours.

Appendices
Because different analytical laboratories that were contracted to analyze samples and various data summaries have referred to the same samples using different conventions a tabulation of these different conventions is provided as Appendix A to facilitate the review of the data. Appendix B shows photographs of the test-set up and test fires. A summary of the data collected during the dioxin emissions tests can be found in Appendix C and a summary of the general emissions tests in Appendix H. The dioxin laboratory reports can be found in Appendices E and F. Appendix G contains graphs of the temperatures and gas concentrations throughout the tests. The calculated dioxin emission results are in Appendix D and the calculated air emission results are in Appendix H. The general emissions laboratory reports can be found in Appendices J,K, and L. The laboratory reports from fuel characterization can be found in Appendices M, N, O and P.

3 Sampling and Analytical Methods

3.1 Dioxin/Furan Emissions

The dioxin/furan tests consisted of three test runs with Duraflame firelogs and three tests with Douglas fir cordwood and one background test run only sampling laboratory air. Dioxin/furan emission test runs were collected isokinetically by EPA Method 23 from the stack, 8 diameters (64 in) from the top of the fireplace. The sampling was conducted out of the stack (instead of a dilution tunnel) and multiple firelogs were burned in order to obtain adequate sample for analyses. The samples were then sent to the analytical laboratory, which extracted and analyzed using EPA Method 23 for tetra-through-octa chlorinated dioxins and furans. The dioxin/furan laboratory data is provided in Appendix E.

3.2 General emissions

Air emission samples were collected from a dilution tunnel and analyzed following standard sampling and analytical methods.

Particulate samples were collected onto Pall Corporation type A/E glass filters and processed following the protocols specified for wood heaters (40 CFR Pt. 60, App. A, Method 5G) in OMNI's EPA accredited wood heater testing laboratory (certified under 40 CFR Subpart AAA, Pt. 60). The total particulate values are of the mass of material collected on the filter.
The $PM_{2.5}$ samples were collected using an impactor pre-separator developed for the California Air Resources Board. All filters were desiccated to constant weights before and after sampling. Laboratory air and outdoor ambient filter samples were collected using similar sampling rates and were checked for background particulate. There is one qualifier for the total particulate results, particulate samples were calculated based on filter catch only. Filter catch comprises 90% of the total particulate result (Broderick, 2005). Therefore the particulate values are estimated to be 10% low. Appendix H shows particulate data.

Polycyclic aromatic hydrocarbons were sampled with an EPA Method 23 sampling train (often referred to as modified Method 5 or MM5), and analyzed for an extended list of SVOC compounds by method 8270C procedures. The 16 individual polycyclic aromatic hydrocarbons making-up the 16-PAH list are included. (The compounds making up the 7-PAH list were also simultaneously quantified as the 7-PAH list is a subset of the 16-PAH list.) The PAH laboratory data are provided in Appendix J.

Phenol is also part of the 8270C analyte list.

Formaldehyde was collected and analyzed by EPA Method 0011/8315A. Appendix K contains the laboratory data.

Benzene samples were collected in evacuated stainless steel canisters and analyzed by EPA Method TO-14A (GC/MS Scan) for benzene only. The TO-14A data are provided in Appendix L.

Carbon monoxide was measured with a gas filter correlation analyzer following EPA Method 10.

Volatile organic compounds (VOC) were measured with a flame ionization detector analyzer following EPA Method 25A. Propane was used as a calibration gas and data was collected as ppmv propane. Values were previously reported (Broderick, 2005) as carbon, therefore the ppmv values were corrected (multiplied by 3) to account for the instrument analyzing VOC's as propane. Values are reported as ppmv (as carbon).

Nitrogen oxides (NO_x) concentrations were measured with a chemiluminescent gas analyzer by EPA Method 6C. Nitrogen oxide was used as a calibration gas. The instrument converted NO_2 to NO and recorded a total NO_x value as a ppmv. Final NO_x values are reported in NO_2 as a convention. One qualifier for the NO_x values, due to an oversight in the testing set-up, moisture was not constantly removed from the gas clean-up line and NO_2 may have been removed from the sample stream, therefore total NO_x values are estimated to be 10% low. All gas analyzers were calibrated with standard calibration gas tanks and data logged every minute. Data for the gas analyzers can be found in Appendices H.

Gas flow within the dilution tunnel was measured with a P-type pitot tube. Chimney, dilution tunnel, and laboratory temperatures were measured with type-K thermocouples and data logged every minute.

3.3 Fuel Composition Tests

Unburned firelogs were characterized by (1) conducting standard fuel analysis (heat, moisture, carbon, hydrogen, nitrogen, sulfur, oxygen, and ash contents), (2) determining the fraction of wax and fiber by hexane extraction, (3) conducting fiber analysis, and (4) conducting standardized wax analyses (needle penetration, oil content, and carbon number distribution). In order to be consistant with OMNI Environmental Services, Inc previous firelog report (Broderick, 2005) the firelog percent moisture for calculating emissions factors was set at two percent based on firelog literature (Ref. 5-7).

The mass of combustion residue produced per unit mass of each firelog burnt was determined gravimetrically by the weight of the logs before the tests and by the weight of the residue left in the fireplace after the tests. Combustion residue is the material remaining after combustion, generally and imprecisely referred to as “ash”. Combustion residue is made up of both char, which is unburned organic material and elemental carbon, and ash, which is composed of inorganic compounds.

The chloride content of the firelog combustion residues was determined by EPA Method 300.0 on unburned firelog. Chloride analysis was conducted due to the corrosive nature of chloride salts, which can damage fireplaces and their chimneys, and due to the toxic and recalcitrant nature of many chlorinated organic compounds.

Analyses for 26 metals were conducted. These included traditional “toxic” transition and heavy metals and common crustal metals. Standard fuel analysis was also conducted on the residue. The fuel analysis included the heat, moisture, carbon, hydrogen, nitrogen, sulfur, oxygen, and ash contents. Metals analysis of the combustion residue was first prepared with EPA method 3050 digestion procedure which solubilizes most transitional metal oxides (see residue metals lab report Appendix M). The combustion residue was then analyzed for metals by EPA Method 6010B except for mercury which was analyzed by EPA Method 7471A. Appendix M contains the chloride and metal laboratory data.

The heat content (higher heating value, HHV) ASTM D5865, as well as, moisture, ash, carbon, hydrogen, oxygen, nitrogen, and sulfur contents of both the firelog and their combustion residues were determined by proximate/ultimate analyses. Firelog samples were taken from a variety of places by breaking the log apart and pulling off pieces. Samples were then mixed together and ground at the laboratory prior to analysis. Cordwood sawdust samples were collected using a handsaw and cutting across the grain. (Modified ASTM 5373, ASTM D4239 Sec. 3.3, D3174, ASTM D3175 (sparking) ASTM D2015/ASTM D240) Laboratory results are in Appendix N.

Wax content was determined gravimetrically by weighing the fiber after hexane extractions to separate the fiber and the wax. Three separate samples were extracted and after factoring out moisture, the average percentage was reported as fiber. The difference between the initial firelog sample weight and the fiber weight was reported as the wax percentage. After separation, a wood fiber sample was sent to the USDA Forest Services' Forest Products Laboratory for tree species identification and a wax sample was characterized by measuring the percent oil (ASTM Standard D721), carbon count (ASTM Standard D5442), and by needle penetration (ASTM Standard D1321). Appendix L contains the wax analysis laboratory data and Appendix M contains the notes from the Forest Service regarding the tree species identification.

4 Results

4.1 Dioxin/furan AirEmissions

Table 1 and 2 contain the results for each individual test run, as well as a mean and standard deviation, for firelogs and cordwood. The results are reported with the TEQ method, as emission factors (ng-TEQ/kg) and emission rates (ng-TEQ/hr). Toxic Equivalents or TEQ's, are used to report the toxicity-weighted masses of mixtures of dioxins to give a more meaningful measure of the compound where toxicity information is offered (Van den Berg, 1988.).

4.2 Comments on dioxin/furan samples

Sample collection was optimized for measuring any dioxin/furan emissions; sampling from the stack with a Method 23 sample train and collecting as much sample as the train would allow. The amount of dioxin/furan collected by OMNI Environmental Services, Inc and detected by the environmental laboratory had almost no effect on the overall emissions value once the TEQ method was applied. The most significant factor in the emissions values are the environmental laboratory detection limits. These limits can vary depending on the sample. Since none of the most toxic congeners were detected the use of ½ the laboratory detection limit for all the non detects comprised the most significant part of the dioxin/furan emissions.

4.3 General emissions

Table 3 contains the air emission factors (mass of pollutant/mass fuel on a dry basis) for Duraflame firelogs and Douglas fir cordwood.

Table 4 contains the air emission rates (mass of pollutant/hour of fireplace operation) for each fuel.

Table 5 and 6 contain the emission factors and emission rates for each of the individual PAH compounds that make up the 16-PAH list. When the amount of a PAH compound was below detection limits for PAH compounds, one-half the detection limit was used in the calculation of 7-PAH and 16-PAH emission rates and emission factors.

The calculation of emission rates requires fire duration to be defined by a reproducible metric. There is no standardized definition of end time for fireplace emissions tests. The convention used in this study was to divide the total mass of pollutant emitted during the entire sampling period (the total time from the first firelog being lit until the interior chimney temperature had cooled to 10ºF [5.6ºC] above the laboratory room temperature) by the time that there was a visible flame (the time from the first firelog being lit until the second firelog's flame went out). By using this approach it can be assumed that virtually all pollutants associated with using the firelog are captured/measured and a "standardized," realistic, and easily determined end point is used to characterize the burning duration. The emission rates being calculated in this manner also makes it easier to apply them to the time a home operator burns their fireplace based on visible flame and for comparing the actual burn duration to packaging claims. It should be noted that only a small fraction of the total mass of pollutants are emitted between the time when the last visible flame goes out and when the interior chimney temperature cools to 5.6ºC (10ºF) above room temperature. Combustion is nearly completed when the last flame goes out.

Cordwood burn duration was determined by when the last flame goes out, and the end of sampling was after 4.5 hours or when the interior chimney temperature cools to 10ºF (5.6ºC) above room temperature.

Details of the emission testing, intermediate calculations, and supporting laboratory data are provided in Appendices B, C, D, E, G, H, and I. In all tests the background filters had insignificant amounts to effect particulate results.

4.4 Fuel composition tests

The mass of residue per mass of fuel (dry basis) remaining after burning the firelog in a normal fashion on an expanded metal overlay on a standard grate in a fireplace is provided in Table 7. The mass of residue per mass of fuel (dry basis) remaining after burning Douglas fir cordwood on a standard fireplace grate is also provided in Table 7.

The results of analysis of the residue for each fuel are provided in Table 8. Supporting laboratory data are contained in Appendices M and N.

The results of fuel analysis, wax/fiber proportioning and fiber identification are presented in Table 9. Appendices M, N, O and P contain the supporting laboratory data. The results of the wax analysis are provided in Table 10. Supporting laboratory data are provided in Appendix L. It should be noted that while "wax" analyses were used, other materials could be added to wax/fiber logs. These have included molasses, various plant and petroleum oils, and stearic acid (Broderick, 2005).

4.5 Testing Properties

The characteristic burning properties of each fuel during the dioxin tests were documented and the data are shown in Tables 11. The duration of the fire (burn duration) was determined by when the last flame goes out, and the end of sampling was when the interior chimney temperature cools to 10ºF (5.6ºC) above room temperature. The data is shown in Table 9. There is one qualifier for the burn duration in all the dioxin cordwood tests. The last flame out for Douglas fir cordwood was estimated by reviewing the data for the cordwood general emissions test run. When the last flame went out during the general emissions test run the interior chimney temperature was 120ºF (50ºC) and the CO readings in the tunnel were 70 ppmv. The burn durations for the dioxin cordwood tests are reasonable and comparable to the firelog test runs.

The mean and maximum interior chimney temperatures compared to laboratory room air during the dioxin emissions tests are shown in Table 12. The chimney temperatures are measured 30 cm (1 ft) above the fireplace and the room air is measured at 4 ft in front of the fireplace.

Characteristic burning properties for each fuel during the general emissions tests are in table 13. The burn duration is important because it is a factor in calculating the emission rates.

The mean and maximum interior chimney temperatures compared to laboratory room air during the general emissions tests are shown in Table 14.

5 Conclusions

5.1 Dioxin/furan Emissions

After conducting three tests on each fuel and a background test. We can conclude from our results that the average dioxin/furan emission rates (ng TEQ/hr, dry fuel) from burning Duraflame firelogs (0.220) in a fireplace is lower than burning Douglas Fir cordwood (0.832). As has been described in previous studies, due to the differences in heat content and burn rates, emission rates rather than emission factors have been used to describe emissions from firelogs. These trends are reasonably consistent with other studies, in terms of dioxin/furan emission factors from cordwood 0.197 ng TEQ/kg. One study done on oak and pine cordwood in a 42-inch fireplace had emission factors of 0.35 and 1.4 ng TEQ/kg respectively (Gullet, 2001). A background test was conducted for dioxin/furan measurements and both test runs produced dioxin emissions above background air levels.

5.2 General Emissions

The emission rates (g/hr) of nitrogen oxides, volatile organic compounds, carbon monoxide, respirable particles, total particles, 7-PAH's, 16-PAHs, benzene, and formaldehyde were higher from burning Douglas fir cordwood than from burning Duraflame firelogs. All general emissions for the Duraflame firelogs and Douglas fir cordwood were within the standard deviation of the mean compared to other studies (Houck and Crouch, 2002) with the exception of low firelog benzene emisions. The benzene firelog emissions are significantly lower than the mean of other firelog emissions (Houck and Crouch, 2002). All testing calculations and laboratory protocol were reviewed and it is unknown why the benzene emissions were found to be low in the Duraflme firelogs.

5.3 Fuel Composition Tests

Firelog Relevant Toxic Metals

No elevated levels of nickel, vanadium, zinc or copper were found in the combustion residue of the firelogs. The nickel values for the Duraflame firelogs were significantly lower (25.6 mg/kg vs. 10,000+ mg/kg) than in previous reports (Broderick, 2005). These variability's may be due to different wax binders used in manufacturing of the firelogs.

Proximate/Ultimate Fuel and Residue

The analysis of the fuel and combustion residue was typical of firelogs and cordwood.

Firelog Wax Analysis
On comparasion to the OMNI 2005 firelog report the needle penetration for the Duraflame firelog was average, while the oil content fell below the average and the waxes seemed to be comprised of slightly higher molecular weights than the mean.

5.4 Testing Properties
The firelogs lit easily and had visible flames for approximately the burning time indicated on the packaging. The Douglas fir burned consistently with a typical soft cordwood fire. The combustion times and temperatures are representative of a typical usage of a household fireplace.

5.5 Summary
In summary, the dioxin/furan emissions (g/hr) from burning Duraflame firelogs in a fireplace are significantly less than burning Douglas fir cordwood. However, the amount of dioxins detected for either fuel was extremely low. The general emissions rate (g/hr) for burning Duraflame firelogs were significantly less than cordwood. Finally, the fuel composition tests showed Duraflame firelogs were generally consistent with typical firelogs and the Douglas fir was consistent with soft cordwood.

6 References

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Table 1
Dioxin/Furan Emissions Duraflame Firelogs and Background

Emission Test	Units	Background**	Run 1	Run 2	Run 3	Mean ± Standard Deviation
Emissions Factor	ng TEQ/kg	N/A	0.271	0.324	0.321	0.305±0.030
Emissions Rate	ng TEQ/hr	0.100	0.173	0.252	0.235	0.220±0.042

*Value includes ½ of the detection limit of the dioxin compounds that were not detected
** Background measurements were conducted sampling laboratory air out of the fireplace test stack

Table 2
Dioxin/Furan Emissions Douglas Fir Cordwood

Emission Test	Units	Run 1	Run 2	Run 3	Mean ± Standard Deviation
Emissions Factor	ng TEQ/kg	0.195	0.196	0.201	0.197±0.003
Emissions Rate	ng TEQ/hr	0.804	0.848	0.844	0.832±0.024

*Value includes ½ of the detection limit of the dioxin compounds that were not detected

Table 3
General Air Emission Factors

Pollutant	Units	Duraflame Xtra Time Firelog	Douglas Fir Cordwood
Carbon Monoxide (CO)	g/kg fuel, db	66.5	61.7
Nitrogen Oxides (NO_x)*	g/kg fuel, db	1.5	0.83
Volatile Organic Compounds (VOC)**	g/kg fuel, db	28.0	10.1
Respirable Particles ($PM_{2.5}$)	g/kg fuel, db	12.3	8.04
Total Particles (PM)	g/kg fuel, db	17.8	8.85
7-PAH***	mg/kg fuel, db	0.85	0.40
16-PAH	mg/kg fuel, db	56.8	20.9
Benzene	g/kg fuel, db	0.044	0.165
Formaldehyde	g/kg fuel, db	0.963	1.09

* NOx reported as nitrous dioxide
**VOC's reported as carbon
***½ of the detection limit value was used for the calculation of 7-PAH and 16-PAH values for compounds that were below detection limits.

Table 4
General Air Emission Rates

Pollutant	Units	Duraflame Firelog	Douglas Fir Cordwood
Nitrogen Oxides (NO_x)*	g/hr	0.82	2.8
Volatile Organic Compounds (VOC)**	g/hr	15.4	33.6
Carbon Monoxide (CO)	g/hr	36.5	204
Respirable Particles ($PM_{2.5}$)	g/hr	6.79	26.7
Total Particles (PM)	g/hr	9.72	29.4
7-PAH***	mg/hr	0.47	1.3
16-PAH***	mg/hr	31.1	69.4
Benzene	g/hr	0.024	0.549
Formaldehyde	g/hr	0.528	3.62

Note: The g/hr values were calculated by measuring the total grams of pollutant emitted during the entire test and by dividing it by the time that the logs had visible flames.
* NOx reported as nitrous dioxide
**VOC's reported as carbon
***1/2 of the detection limit value was used for the calculation of 7-PAH and 16-PAH values for compounds that were below detection limits.

Table 5
Polycyclic Aromatic Hydrocarbon (PAH) Emission Factors

PAH Compound	Units	Duraflame Xtra-time Firelog	Douglas Fir Cordwood
Naphthalene	mg/kg fuel, db	41.8	12.0
Acenaphthene	mg/kg fuel, db	2.43	3.62
Acenaphthalene	mg/kg fuel, db	0.63	0.27
Fluorine	mg/kg fuel, db	2.04	1.18
Phenanthrene	mg/kg fuel, db	5.84	2.95
Anthracene	mg/kg fuel, db	0.63	0.32
Fluoranthene	mg/kg fuel, db	1.41	0.06*
Pyrene	mg/kg fuel, db	0.97	0.06*
Benzo(ghi)perylene	mg/kg fuel, db	0.12*	0.06*
Benzo(a)anthracene	mg/kg fuel, db	0.12*	0.06*
Chrysene	mg/kg fuel, db	0.12*	0.06*
Benzo(b)fluoranthene	mg/kg fuel, db	0.12*	0.06*
Benzo(k)fluoranthene	mg/kg fuel, db	0.12*	0.06*
Benzo(a)pyrene	mg/kg fuel, db	0.12*	0.06*
Dibenzo(a,h)anthracene	mg/kg fuel, db	0.12*	0.06*
Indeno(1,2,3-c,d)pyrene	mg/kg fuel, db	0.12*	0.06*

db, dry basis
*1/2 the detection limit

Table 6
Polycyclic Aromatic Hydrocarbon (PAH) Emission Rates

PAH Compound	Units	Duraflame Xtra Time Firelog	Douglas Fir Cordwood
Naphthalene	mg/hr	22.3	39.9
Acenaphthene	mg/hr	1.33	12.0
Acenaphthalene	mg/hr	0.35	0.90
Fluorine	mg/hr	1.12	3.90
Phenanthrene	mg/hr	3.20	9.75
Anthracene	mg/hr	0.35	1.05
Fluoranthene	mg/hr	0.77	0.19*
Pyrene	mg/hr	0.53	0.19*
Benzo(ghi)perylene	mg/hr	0.07*	0.19*
Benzo(a)anthracene	mg/hr	0.07*	0.19*
Chrysene	mg/hr	0.07*	0.19*
Benzo(b)fluoranthene	mg/hr	0.07*	0.19*
Benzo(k)fluoranthene	mg/hr	0.07*	0.19*
Benzo(a)pyrene	mg/hr	0.07*	0.19*
Dibenzo(a,h)anthracene	mg/hr	0.07*	0.19*
Indeno(1,2,3-c,d)pyrene	mg/hr	0.07*	0.19*

*1/2 the detection limit

Table 7
Residue Produced in a Fireplace

	Units	Duraflame Xtra Time Firelog	Douglas Fir Cordwood
Residue	g/kg fuel, dry	14.9	18.0

*Residue is the material remaining after combustion, generally referred to as "ash." Residue is made up of both char, which is unburned organic material and elemental carbon, and ash, which is composed of inorganic compounds.

Table 8
Residue Analysis

Analysis	Units	Xtra Time Firelog	Douglas Fir Cordwood
Aluminum	mg/kg residue, dry	5070	5160
Antimony	mg/kg residue, dry	<10	<10
Barium	mg/kg residue, dry	167	406
Beryllium	mg/kg residue, dry	<1.0	<1.0
Boron	mg/kg residue, dry	216	108
Cadmium	mg/kg residue, dry	<1.0	<1.0
Calcium	mg/kg residue, dry	36,800	30,600
Chromium	mg/kg residue, dry	7.0	6.3
Cobalt	mg/kg residue, dry	2.7	2.4
Copper	mg/kg residue, dry	49.0	88.8
Iron	mg/kg residue, dry	5300	3800
Lead	mg/kg residue, dry	<20	<20
Magnesium	mg/kg residue, dry	5320	5470
Manganese	mg/kg residue, dry	452	1180
Mercury	mg/kg residue, dry	<0.02	<0.02
Molybdenum	mg/kg residue, dry	<2.0	<2.0
Nickel	mg/kg residue, dry	25.6	8.5
Phosphorus	mg/kg residue, dry	3410	4840
Potassium	mg/kg residue, dry	73,500	16,900

Table 8 (continued)
Residue Analysis

Analysis	Units	Xtra Time Firelog	Douglas Fir Cordwood
Silver	mg/kg residue, dry	<2.0	<2.0
Sodium	mg/kg residue, dry	4910	828
Strontium	mg/kg residue, dry	246	443
Tin	mg/kg residue, dry	<10	<10
Titanium	mg/kg residue, dry	267	205
Vanadium	mg/kg residue, dry	7.8	8.7
Zinc	mg/kg residue, dry	125	105
Heat content	Btu/lb, dry basis	7739	12757
	Mj/kg, dry basis	17.1	28.2
Drying Loss	% as received	8.08	4.21
Carbon	% dry basis	49.2	81.5
Hydrogen	% dry basis	2.73	2.67
Nitrogen	% dry basis	0.65	0.10
Sulfur	% dry basis	20.4	0.04
Oxygen	% dry basis	3.32	12.8
Ash*	% dry basis	35.4	2.44

*Ash here refers to inorganic compounds left after complete, high-temperature combustion in the laboratory.

Table 9
Fuel Characterization

Analysis	Units	Xtra Time Firelog	Douglas Fir Cordwood
Chloride	mg/kg, as received	70	1.2
Moisture	% dry basis	3.3	12.0
Carbon	% dry basis	71.4	51.1
Hydrogen	% dry basis	10.2	5.43
Nitrogen	% dry basis	0.1	0.02
Sulfur	% dry basis	0.23	2.9
Oxygen	% dry basis	18.0	36.8
Ash*	% dry basis	0.59	0.08
Heat content	Btu/lb, dry basis	14960	8516
	Mj/kg, dry basis	32.7	18.8
Wax content	%	48.4	N/A
Fiber content	%	51.6	N/A
Fiber Identification		All softwood: Hard pine, Tsuga (Hemlock), Thuja (Cedar) No Douglas Fir nor Taxus (Yew), Small amount of bark	N/A

*Ash here refers to inorganic compounds left after complete, high-temperature combustion in the laboratory.

Table 10
Wax Analysis

Analysis	Units	Xtra Time Firelog
Needle Penetration	mm	114
Oil Content	%	8.94
Carbon Number Distribution (see Appendix O for detailed results)	% <C13	1.30
	% C13-C30	26.1
	% C31-C50	37.1
	% C51-C70	31.5
	% >70	3.93

Table 11
Firelog Burning and Sampling Durations in Minutes for Dioxin/Furan Emissions Tests

Criteria*	Background	Firelog Run 1	Firelog Run 2	Firelog Run 3	Cordwood Run 4	Cordwood Run 5	Cordwood Run 6
Flame Out, 2nd Log or Cordwood	N/A	511	423	441	198***	192***	194***
Chimney Temp. < 10°F (5.6°C) above Indoor Temp.	600**	532	446	454	270**	270**	240**

*The first number is the flame-out time used for end of burning and the chimney temperature at 1 ft above the fireplace is the end of sampling.
** End of cordwood tests determined by 4.5 hrs or < 10°F (5.6°C) above indoor temp. End of background test determined by 10 hours.
*** Flame out estimated by a chimney temp of < 120°F and tunnel CO < 71 ppmv determined from general emissions cordwood run.

Table 12
Mean and Maximum Temperatures °F(°C) Dioxin/Furan Tests

Temperature	Background	Firelog Run 1	Firelog Run 2	Firelog Run 3	Cordwood Run 4	Cordwood Run 5	Cordwood Run 6
Mean Chimney*	60 (16)	123 (51)	124 (51)	112 (44)	210 (99)	194 (90)	212 (100)
Maximum Chimney*	60 (16)	223 (106)	191 (88)	220 (105)	435 (224)	470 (244)	429 (220)
Mean Room	60 (16)	60 (16)	58 (15)	58 (15)	60 (16)	60 (16)	59 (15)
Mean Chimney Temp. above Mean Room Temp.	N/A	63 (17)	66 (19)	54 (12)	150 (66)	134 (56)	154 (68)

*Measured 30 cm (1 ft) above fireplace

Table 13
Firelog Burning and Sampling Durations in Minutes for General Emissions

Criteria	Duraflame Xtra Time Firelog	Douglas Fir Cordwood
Flame Out, 2nd Log or Cordwood	605	226
Chimney Temp. < 10°F (5.6°C) above Indoor Temp.	679	268

*The first number is the flame-out time used for end of burn duration and the chimney temperature at 1 ft above the fireplace is the end of sampling.

Table 14
Mean and Maximum Temperatures for General Emissions Tests

Temperature	Xtra Time Firelog °F(°C)	Douglas Fir Cordwood °F(°C)
Mean Chimney*	117 (47)	207 (97)
Maximum Chimney*	181 (83)	560 (293)
Mean Room	51 (10)	55 (13)
Mean Chimney Temp. above Mean Room Temp.	66 (19)	152 (67)

*Measured 30 cm (1 ft) above fireplace

Sample Run Numbers and Labeling Conventions

Characterization Tests

Run Number	Brand/Species Name	Size and Manufacturer
Run 1- DF	Duraflame	6 lb Xtra Time Firelog
Run 2 - Cordwood	Douglas Fir	seasoned cordwood

Dioxin Tests

Run Number	Brand/Species Name	Size and Manufacturer
Run 1- D.F.	Duraflame	6 lb Xtra Time Firelog
Run 2- D.F.	Duraflame	6 lb Xtra Time Firelog
Run 3- D.F.	Duraflame	6 lb Xtra Time Firelog
Run 4 - Cordwood	Douglas Fir	seasoned cordwood
Run 5 - Cordwood	Douglas Fir	seasoned cordwood
Run 6 - Cordwood	Douglas Fir	seasoned cordwood

Pictures of General emissions Test Set-up


Picture 1: General emission gas analyzers


Picture 2: General emission sample trains.


Picture 3: Duraflame firelog fire


Picture 4: Douglas fir cordwood fire

Pictures of Dioxin/Furan Emissions Test Set-up


Picture 5: Dioxin/furan emissions sample train


Picture 6: Dioxin/furan emissions test set-up