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United States
Environmental Protection
Agency

EPA-600/2-89-025

May 1989

EPA

AP-42 Section 1.10
Ref #14

Research and Development

EFFECTS OF BURN RATE, WOOD SPECIES, MOISTURE CONTENT, AND WEIGHT OF WOOD LOADED ON WOODSTOVE EMISSIONS

Office of Environmental Engineering
and Technology Demonstration

Prepared by

Air and Energy Engineering Research
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Research Triangle Park NC 27711

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EPA Contract: 68-02-3992, Work Assignments 7 and 37

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EXECUTIVE SUMMARY

This project is one of a number of studies to characterize toxic/mutagenic compounds emitted by residential wood combustion units such as woodstoves. The Integrated Air Cancer Project (IACP) will use the information gained from this and other such studies to determine the contribution of toxic/mutagenic substances by residential woodburning units to ambient air.

Specifically, this project studies the effect of stove operating variables on organic emissions such as polycyclic aromatic hydrocarbons (PAH), total extractable organics (TEO), particulates, and carbon monoxide. Other emissions studied include C_1-C_7 hydrocarbons.

A one-half factorial experimental test design was employed to evaluate statistically the effects of four stove operating variables; burn rate, wood moisture, wood load, and fuel type on the measured woodstove emissions. Ranges were established according to high and low values and used in the half-factorial test matrix. Burn rate target values were previously determined to be approximately 2 kg/hr for low burn rate and 6 kg/hr for high burn rate. The experimental averages for the low and high burn rates were used. Wood moisture contents were determined gravimetrically for cured and uncured woods which were procured prior to the implementation of testing. Uncured wood remained in log form and was cut one day prior to testing to preserve the wood moisture content. Wood loads (kg) were determined according to the volume of the firebox. High wood loads filled the stove to capacity initially and low wood loads filled the stove to approximately half full. Two wood types were tested: oak and pine. Test variables with actual experimental values are listed below:

Variables	High +	Low -
Fuel	Oak	Pine
Moisture	Cured 16.9%	Uncured 33.2%
Load	High 15.2 kg	Low 8.0 kg
Burn Rate	high 6.56 kg/hr	Low 1.75 kg/hr

The following half-factorial test matrix was used to evaluate the four operating variables on measured emissions:

Test No.	Measured Value	Fuel	Moisture	Load	Burn Rate
		Variables			
1	V1	+	+	+	+
2	V2	+	+	-	-
3	V3	+	-	+	-
4	V4	+	-	-	+
5	V5	-	+	+	-
6	V6	-	+	-	+
7	V7	-	-	+	+
8	V8	-	-	-	-

A total of twelve woodstove tests was run at the rate of one test per week. The first two tests were used to familiarize the test personnel with proper damper setting for desired burn rates, and to test the operation of the continuous CO, CO_2, and O_2 gas analyzers in conjunction with a Metrosonics data logger. The eight tests prescribed by the test matrix were then run. The results of test number three were discounted due to sampling problems and a repeat test was performed. The last test performed was a duplicate of test number two to assess reproducibility.

A Modified Method 5 (MM5) sampling system was used for organic and particulate sampling. CO, CO_2, O_2, ppm hydrocarbons on a flame ionization detector (FID), stack temperature, and stove temperature were measured continuously and recorded at two points per second on a Metrosonics Data Logger. C_1-C_7 bag samples were collected in appropriate sample bags from the bypass on the FID. The CO, CO_2, O_2 and FID were calibrated and checked before and after each test. Stack temperature was recorded as an average of two type K thermocouples located just above the MM5 glass probe. Stove temperature was recorded as an average of four thermocouples placed in thermowells around and on top of the stove. Inlet damper flows were measured periodically with a Kurz hot wire anemometer. Stack flows were measured periodically with a Taylor anemometer. The stove was mounted on a calibrated Detecto 8850 electro balance and the weight of wood was recorded manually.

A test was started by igniting a large pile of kindling cut from the wood to be used in that test. The kindling was lit with a propane torch; no paper was used to preserve the integrity of the ash samples. When the kindling burned down to a hot bed of coals, the scale was tared to zero and the wood was loaded to the proper weight and recorded. Once the desired burn rate (kg/hr) was achieved, organic sampling started. All organic sampling took place during the desired burn rate for each test. Start-up was bypassed because heavy emissions during that period could mask changes due to the stove operating variables in this test design. The MM5 system was leak checked before and after each test.

After each test, the MM5 system was disassembled and each portion was rinsed separately with methylene chloride and methanol. Total particulate mass was determined by desiccating and weighing the probe wash and filter. The XAD-2 resin and heated glass fiber filters were soxhlet extracted separately with the appropriate methylene chloride rinse from each portion of the MM5 train. The water condensate was extracted with methylene chloride and the extract was added to the XAD-2 extract. The samples were then concentrated with K-D evaporators and stored in sealed, teflon coated, amber glass vials in a freezer until analyses.

RTI performed two types of analysis on the extracted samples: gravimetric and total chromatographable organics (TCO). The combination of these two analyses provided total extractable organic analyses.

The FID hydrocarbon results were not valid as the instrument frequently ran off-scale. FID data are not reported.

The C_1-C_7 hydrocarbon analyses were performed by Industrial Environmental Analysts, Incorporated. The bag samples were taken to the analysts immediately after collection for analyses.

The two concentrated methylene chloride MM5 samples for each test were composited with appropriate portions of aliquots, cleaned via EPA Method 610 silica gel cleanup for PAHs, and sent to Radian Corporation for capillary GC/MS PAH analyses. Radian analyzed these samples under EPA Contract Number 68-02-3994, Work Assignment Number 38 entitled, "Analysis of Woodstove Emission Samples." Radian provided RTI with a total PAH analyses by performing gravimetric and TCO on the cleaned samples, as well as a specific analyses of 22 PAHs.

An ICAP elemental analyses was performed by ACUREX on the particulate filters and ash residue from each woodstove test.

The results of all continuous measurements, organic and elemental analyses from each test were fed into the statistical analyses of variance (ANOVA) of the test matrix. For the most part, all main effect changes in emission due to changes in the operating variables are reported with 90%, 95%, and 99% confidence limits. Some main effects were reported at just below a 90% confidence limit.

The following section discusses the results obtained from the experimental test plan. Some recommendations in MM5 testing also follow.

RESULTS AND CONCLUSIONS

For the purpose of discussion, three types of emissions are defined. Concentrations are mass of component per cubic meter of stack gas STP wet (g/m^3), emission factors are mass of component per mass of wet wood burned (g/kg), and emission rates are mass of component emitted per hour (g/hr). All reported effects are the result of the analyses of variance performed by the half factorial statistical test design.

I. BURN RATE

A. The effects of increasing burn rate (kg wood burned/hr) at a 90% or better confidence limit are:

1. The stove and stack gas temperatures increase significantly, as much as 140°C and 170°C, respectively. Maintaining higher temperatures may contribute to better combustion efficiency, and thus, lower total extractable organic, particulate, and carbon monoxide emissions.

2. Carbon dioxide emissions are increased while carbon monoxide emissions are decreased.

3. Particulate matter (probe and filter catch) concentration and emission factors decrease. At high burn rates, particulate concentrations and emission factors are lower, but the stack flow rate is higher; at low burn rates, particulate concentrations and emission rates are higher, but the stack flow is lower. These effects tend to cancel, such that wood load has the most significant effect on particulate emission rates.

4. Gravimetric compounds (> 300°b.p.) emissions decrease

5. TCO compounds (100°C-300°C b.p.) emissions decrease

6. Total extractable organic emissions decrease

7. C_1-C_7 concentration and emission factors decrease

8. H_2O emission rates increase but H_2O emission factors decrease.

9. Benzo (b) fluoranthene emission factor (mg/kg wet wood) increases

10. Potassium emission increases

11. Manganese concentration and emission rate increase

12. Sulfur emissions increase

13. Zinc concentration increases

14. Mutagenic activity as measured by TA98+S9 increases

B. The effects of increasing burn rate (kg wood burned/hr) at just under a 90% confidence limit are:

1. Naphthalene, phenanthrene, fluoranthene, pyrene, chrysene, benzo(b) fluoranthene, and benzo(a) pyrene, emission rates all increase.

2. Naphthalene and fluorene emission factors (mg/kg wood) decrease

3. Chrysene and benzo(b) fluoranthene emission factors increase

4. Benzo(a) pyrene concentration increases

5. TA98-S9 mutagenic activity increases

WOOD MOISTURE

A. The effects of decreasing wood moisture percent at a 90% or better confidence limit are:

1. Lower stack gas moisture concentration, but particulate emission factor increases as well as CO_2 emission factor.

2. Napthalene concentration decreases.

3. Pyrene emission factor decreases.

4. Cadmium emissions decrease.

5. The weight percent of barium in the ash decreases while the weight percent of aluminum, iron, magnesium, and strontium increase.

6. The Fe/K ratio in the ash increases.

WOOD TYPE

A. The effects of changing the wood from pine to oak at a 90% or better confidence limit are:

1. Potassium emissions increase.

2. Manganese emissions decrease.

3. Zinc emission factor decreases.

4. The weight percent in ash of barium, calcium, and strontium increase.

5. The weight percent in ash of aluminum, manganese, magnesium, and zinc decreased.
6. The iron to potassium ratio decreases.

B. Effects of changing the wood from pine to oak just under a 90% or better confidence limit are:

1. Acenaphthylene, phenanthrene, anthracene, and pyrene emission factors decrease.
2. Particulate emission factor increases.
3. Gravimetric and TCO concentrations and emission rates decrease.
4. Total extractable organic concentration decreases.
5. Mutagenic activity as measured by TA98+S9 and -S9 decreases.

WOOD LOAD

A. The effects of increasing wood load at 90% or better confidence limit are:

1. Stack flow increases.
2. Particulate emission rate increases.

B. Effects of increasing wood load just under a 90% confidence limit are:

1. Mutagenic activity (TA98-S9) decreases.

ABSTRACT

Four woodstove operating parameters; burn rate, wood moisture, wood load, and wood species were tested at two levels each. A one-half factorial experimental test design was used to determine statistically significant effects from changes in the operating parameters on measured emissions of CO, CO_2, particulate matter, total extractable organics, polycyclic aromatic hydrocarbons, C_1-C_7 hydrocarbons, elemental and elemental Fe/K ratios. The direction and magnitude of main effects from changing each of the four operating variables on measured emissions are reported within 90%, 95%, and 99% confidence limits. The control of burn rate by changing inlet air available to the fire and the weight percent moisture of the wood burned were the most important and statistically significant parameters affecting organic emissions. Increased burn rate results in more efficient combustion and higher stove and stack temperatures, which may contribute to reduced overall organic and CO emissions. Elemental emissions were most significantly affected by the burn rate and wood type (oak or pine).

Increasing burn rates lowered carbon monoxide emissions, particulate emissions, total extractable organic emissions, and C_1-C_7 emissions. However, the emission rates of several individual PAH compounds such as naphthalene, phenanthrene, fluoranthene, pyrene, chrysene, benzo(b) fluoranthene, and benzo(a) pyrene increased with increased burn rates. Increased burn rates also gave rise to increased elemental emissions of cadmium, potassium, manganese, sulfur, and zinc.

Reducing the wood moisture increased particulate emission factors (g/kg wood). Specific PAH concentrations reduced were napthalene, acenaphthylene, fluorene, and anthracene. Pyrene emission factors were significantly decreased. Cadmium emissions decreased with a decrease in wood moisture. Weight percents of iron, magnesium, and strontium in carbon free ash increased with decreased wood moisture. The weight percent of barium, however, decreased. The weight percent in ash Fe/K ratio increased with a decrease in moisture, however, no significant change in the Fe/K was found in emissions.

Wood type, when changed from pine to oak, only exhibited statistically significant effects in the elemental analyses. Potassium emissions increased, while manganese and zinc emissions decreased. Elements expressed in weight percent of carbon free ash which increased were barium, calcium, and strontium, while magnesium, manganese, and zinc weight percents decreased. Changing from pine to oak also decreased emissions of acenaphthylene, fluorene, phenanthrene, anthracene, and pyrene, but these decreases were significant just below the 90% confidence level.

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1.0 INTRODUCTION

1.1 PURPOSE

During 1985, the Integrated Air Cancer Project (IACP) undertook a number of tasks to develop methods for characterizing source emissions from residential wood combustion (RWC) units, such as woodstoves. This study is a portion of the 1985 IACP to characterize emissions from a RWC unit over a set of typical operating ranges. Specific emphasis is placed on defining the relationships between stove operating parameters and the effects of those parameters on toxic/mutagenic emissions such as polycyclic aromatic hydrocarbons (PAH) and particulate matter (PM). Four independent operating variables are controlled in the experimental design; wood species, wood load (kg wood), wood moisture content (wt % H_2O), and burn rate (kg wood burned/hr).

During 1986, an IACP ambient study in Boise, ID will focus on determining the contribution made by RWC units to the toxic/mutagenicity of ambient air pollutants in a community heavily affected by that source category. For this purpose, source emission characterizations of RWC units must be made. This study provides source emission characterizations of toxic/mutagenic compounds from a woodstove and the effects of four operating parameters on those emissions. This portion of the IACP will be used to help the 1986 IACP ambient study focus on further determining the contribution made of toxic/mutagenic substances by residential wood combustion.

1.2 BACKGROUND

The use of wood for residential heating has become a widespread practice in recent years. As of the end of 1983, there were an estimated 10.6 million residential wood combustion (RWC) units in use. As referred to here, RWC units consist of freestanding woodstoves and fireplace inserts and do not include open fireplaces. In 1980, it was reported that woodstoves had been installed at the rate of one million per year since 1977, and currently annual sales of RWC units are projected to continue at ~one million units per year (1), (2). Recently there has been an increasing concern over the potential environmental health hazards related to the emissions from residential wood combustion sources as they have been implicated as major contributors to the seasonal decline of air quality in several regions (3), (4), (5).

In certain localized areas, woodsmoke has become a seasonal problem because of accumulation of noticeably large, lingering smog-type clouds. One study in a residential neighborhood with a density of woodstoves and fireplaces of about 60 units per square kilometer indicated that wood heating can significantly impact the ambient air quality of local areas with a concentrated use of woodstoves and fireplaces (3). Emissions from RWC are a growing problem throughout all areas of the country where wood supplies are abundant. In fact, several areas are currently violating national ambient air quality standards (NAAQS) for particulate matter (PM) and carbon monoxide (CO) due to RWC (1). Particulate matter is emitted at significant levels from RWC and a large portion of PM is respirable and poses a real health hazard in areas of high woodsmoke concentration. One study shows that worst case 24 hour average ambient concentrations up to 100 $\mu g/m^3$ may be expected for woodsmoke particulates for a housing density of 400 - 500 residences/km^2 or more if the entire heating load is carried by wood (6).

Polycyclic aromatic hydrocarbons (PAH) are indicated as the main cause of mutagenic activity in woodsmoke. A recent compilation of an emission inventory for POM's indicates that residential woodburning may be the largest source of POM's emitted to the atmosphere (7).

Other organic emissions of interest in this study include total extractable organics and C_1-C_7 aliphatic hydrocarbons.

Stack emissions of carbon monoxide are also of great concern. A recent study has shown that significant increases in ambient CO levels in one area directly reflected stove usage.

Aside from the collection and measurement of the noted organic, particulate, and stack gas emissions, other stove operating parameters are to be recorded. These data include wood species, wood moisture content, wood weight, burn time, ash residue weight, stack flow, inlet flows through the dampers, instrument sample times, sample volumes, and stove and stack gas temperatures.

Two woodsmoke identifier compounds have been cited as being unique to RWC emissions. These compounds are retene and levoglucosan. Retene is a general term for alkylated phenanthrenes which consists mainly of 1-methyl, 7-isopropyl phenanthrene. Retene has been found in woodstove emissions and in ambient air in wood-heated residential areas and is related to the combustion of resinous coniferous woods. In emission samples, retene has been found to originate only from combustion of spruce and related resinous softwoods (8).

Levoglucosan (Beta-glucose anhydride) has been found as a major constituent of woodsmoke aerosols, accounting for approximately 5% of the total weight of particulate emissions. Its presence is probably due to the thermal degradation of cellulose and therefore it could be a potential identifier of woodsmoke (9).

These compounds are potential means to identify the presence of woodsmoke in areas where other sources of ambient pollutants may be present. They are cited here because the IACP encompasses such methods for identifying woodsmoke. The usefulness of these two compounds for identifying woodsmoke could not be determined by this study, but may be considered in future studies.

2.0 STOVE AND INSTRUMENTATION SET-UP

The stove used is a Sears Catalog No. 42G84156N free-standing radiant woodstove. The stove, shown in Figures 2.1 and 2.2, is rectangular with a set of hinged interlocking doors on the front and one hinged door on the right side which houses three screw-down air dampers. The air dampers are each three inches in diameter and form a triangle on the door. These dampers are used to control the amount of air into the stove, and thus, the burn rate. The upper damper was sealed shut with silicone high temperature sealant to allow better control of the burn rate. A steel grate is normally located on the front of the stove just inside the two interlocking front doors, but it was removed to facilitate the loading of kindling before each run and removal of ash after each run. The interior of the stove is lined with firebrick. The stove is baffled and the flue exit is in the rear, opposite of the hinged interlocking front doors. The legs of the stove were removed, and the entire stove and flue sections were mounted on a Detecto 5850 scale which was calibrated to 1000 lbs just prior to this study. Before the stove and flue were mounted, the scale was leveled and a 3' x 3' x 1/2" sheet of aluminum was placed atop of the platform along with an asbestos board of the same approximate dimensions. The flue exit from the rear of the stove is 6 inches in diameter and the flue is 8 inches inside diameter. A single-walled 6-inch/8-inch adaptor was used to connect the stove exit to an 8-inch inside diameter double-walled Metalbestos^R insulated tee. All sections of the flue from the tee upward consisted of the same type of double-walled insulated flue. From the tee, two 30-inch and two 9-inch vertical flue sections were mounted.

A schematic overview of the sampling system is provided in Figure 2.3. A Modified Method 5 glass probe and two type K thermocouples were installed in the uppermost 9-inch flue section. The thermocouples were held in place by two 1/8-inch bulkhead Swagelock fittings. Next, another 30-inch section of flue was added which had been drilled for three 1/2-inch bulkhead Swagelock fittings. They were inserted approximately 8 inches above the MM 5 probe and were used for holding three 6" x 1/2" stainless steel probes for flue gas analyses.

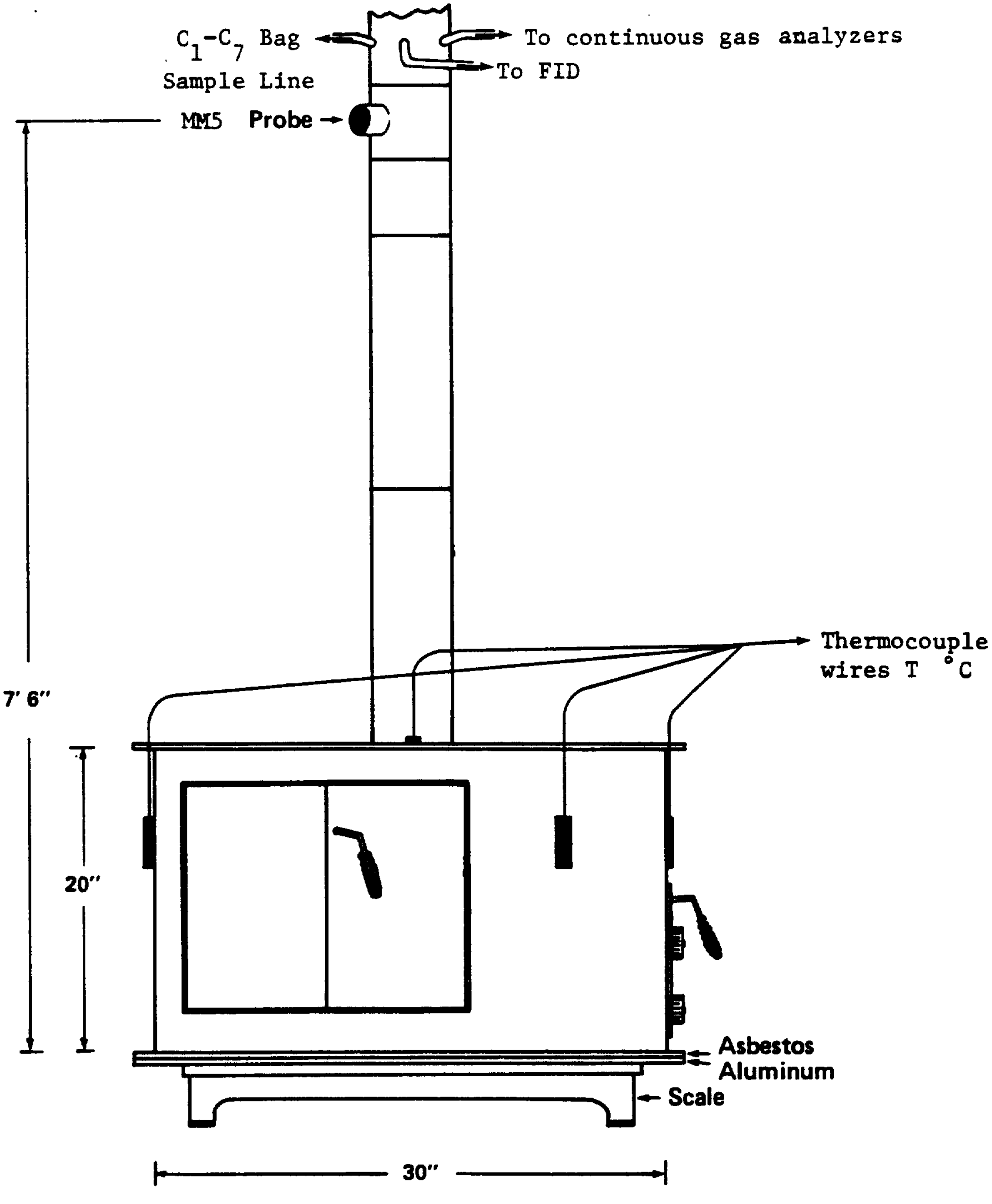

Figure 2.1. Woodstove set-up used in this study (front view).

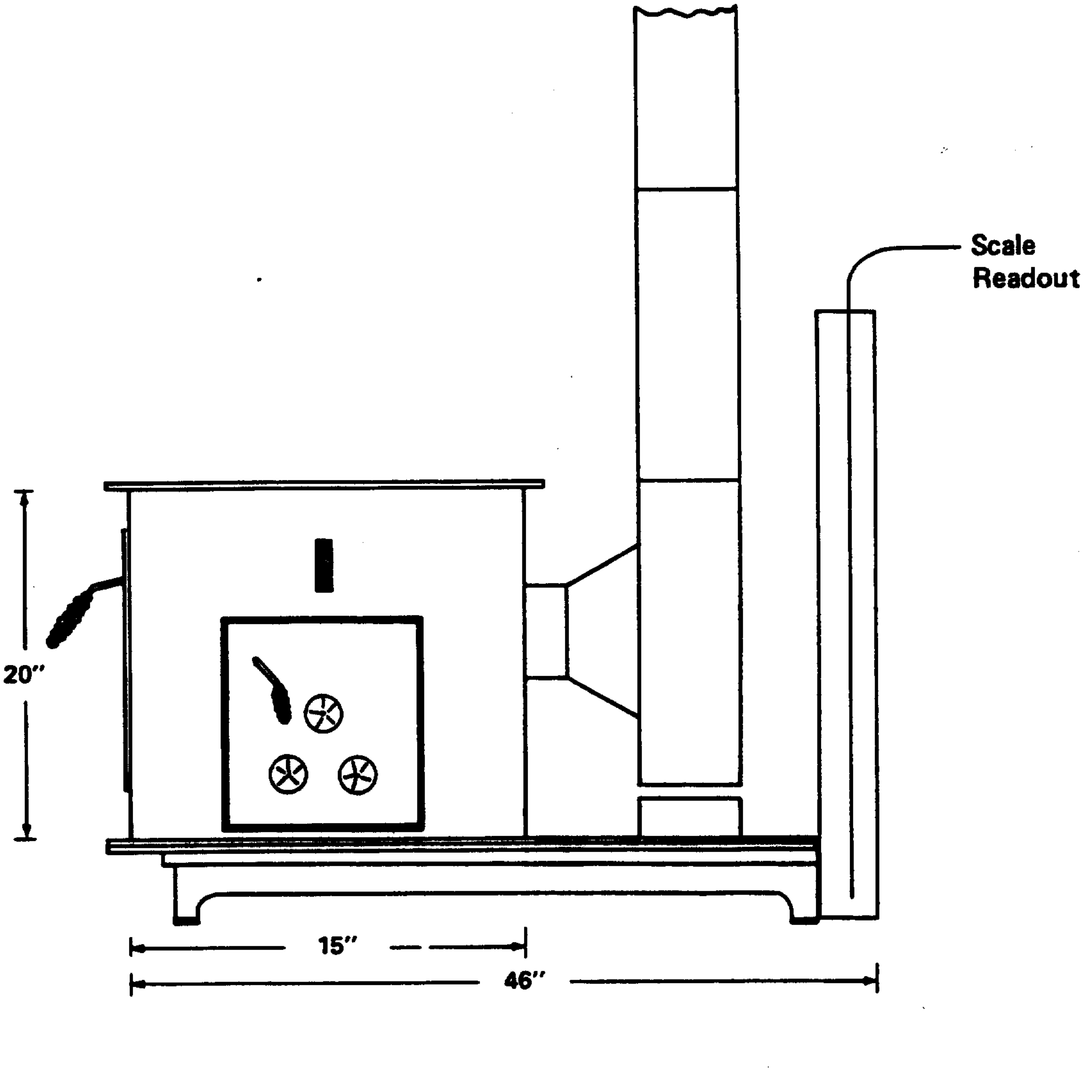

Figure 2.2. Stove and scale set-up side view.

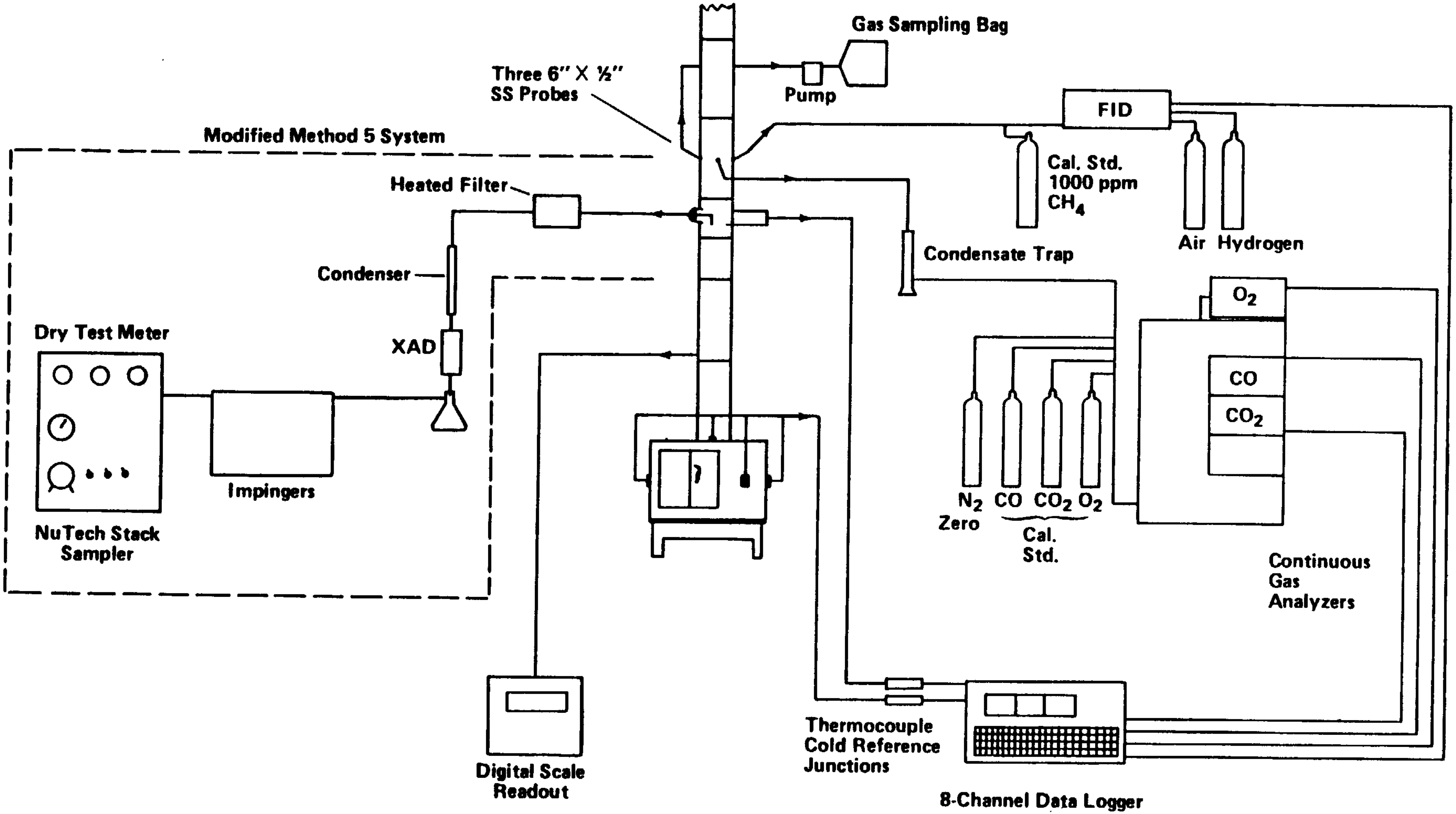

Figure 2.3. Woodstove and sample system overview.

The 6" x 1/2" stainless steel probes were oriented at approximately 120 degree intervals around the flue and each was elevated above the other by approximately 1/2-inch. Another 30-inch section of flue was placed above the gas sampling flue section. From that point upward, several used sections of similar flue were added to extend the flue through the opening in the roof of the test room.

Each of three 6" x 1/2" stainless steel probes was inserted through a separate bulkhead fitting into the flue for gas sampling. A 90° stainless steel elbow was connected to the exterior protruding end of each probe. The probes penetrated the flue interior to approximately 3 1/2 inches. Clean glass wool was placed into each probe before each test. The first probe was used to collect continuous samples for carbon monoxide, carbon dioxide, and oxygen concentration determinations. Instruments measuring these gas concentrations in the flue gas were connected in series. Carbon monoxide and carbon dioxide were measured by RTI's Horiba gas sampling system which consists of two PIR 2000 infrared gas analyses in series. An MSA O_2 analyzer was added in series to measure oxygen concentrations. Each instrument provided output to a separate channel on the data logger. The sample line from the flue to the gas analyzers consisted of a 1/2" ID teflon line containing a condenser-flask condensate trap three feet from the stove. The Horiba system also contains a condensate trap, a filter, and a sampling pump.

The second of the three probes was used to sample total hydrocarbon concentrations. A 1/4" x 1/2" stainless steel line was connected to a Beckman 400 FID, which was located in a hood. The line was heated with several heating tapes and was maintained during sampling at ~200° C.

The third probe initially was to be used for sampling a composite bag sample for C_1-C_7 hydrocarbon analyses. However, due to experimental problems, all C_1-C_7 hydrocarbon bag samples were taken off of the bypass line of the Beckman 400 FID.

Four Type K thermocouples were attached to the stove to monitor the stove box temperature. For this purpose, four 4" x 1/4" stainless steel tubes were cemented to the stove walls on the top, two sides, and front with Devcon^R High Temperature Liquid Metal. The thermocouples then fit snugly into each of the four thermowells, and the wires were connected together, such that the outputs were averaged into one channel into a Metrosonics 721 data logger. The two stack thermocouples were also averaged in the same manner and represented a separate channel to the data logger. Cold reference junctions were used for each temperature recorded by the data logger.

The digital output from the Detecto Scale was mounted on a panel outside of the test room. The weight of wood was recorded manually as each log was loaded until the proper loading was reached. At regular time intervals, the mass of wood was manually recorded, and the burn rate (kg/hr) was calculated and monitored. Room temperature was monitored with a separate Type K thermocouple and readout which was located approximately four feet from the stove in a 1" x 6" stainless steel pipe. Near the room temperature thermocouple, an Abbeon Certified Hygrometer was used to monitor the relative humidity (RH) in the test room. During tests, the RH and temperature of the test room were periodically recorded.

A Kurz hotwire anemometer was used periodically to record the air flow through the two opened dampers on the stove door. A small section of three-inch pipe was placed over each damper, and the hotwire was placed directly in front of the pipe for the periodic measurements. The intake air was re-checked whenever damper settings were changed or wood was added.

Stack flow measurement in woodstove emission tests previously have proven difficult to measure due to very low flue gas velocities. Continuous stack flow measurements have been measured by RTI previously in a woodstove by constructing a mounted turbine meter and continuously recording signals generated by magnets on the hub of the turbine (10). However, for this study, due to project constraints a Taylor series 3231 Jeweled Anemometer was used to periodically measure the stack flow manually. The instrument was hand-held just above the flue outlet for a period of one to two minutes for each measurement. This measurement was taken whenever damper settings were changed or the stove door was open and wood was added. The stack flows for each test were then time averaged over the measured intervals.

Wood moisture content was determined both gravimetrically by oven drying samples of each type of wood and with a Delmhorst wood moisture meter. The moisture meter was operated by driving two insulated pins into the wood at various depths with a sliding inertia impact handle and reading the percent moisture on the analog meter.

3.0 MODIFIED METHOD 5 SAMPLING TRAIN

3.1 DESCRIPTION OF MODIFIED METHOD 5 SAMPLING TRAIN

A Modified Method 5 (MM5) sampling train was used to collect a sample of particulate and organic matter. The MM5 system is shown in Figure 2.3. The MM5 train was constructed of all glass/teflon which consisted of the following components in order from the stack to the sample pump:

1. A heated glass probe 1/2" OD with a 90° turn (180° C).
2. Small 5" teflon 1/2" OD tube connecting the glass probe to a male ball joint connector.
3. Female ball joint connector.
4. Glass fiber filter ball and frit assembly inside a heated aluminum box (200° C).
5. 90° elbow taper jointed.
6. 24" condenser (cooled by a bath and submersible pump).
7. Tee section with thermocouple to measure gas temperature into XAD-2.
8. Water jacketed XAD-2 module (ice bath cooled, submersible pump).
9. Tee
10. U.V. protected condensate flask.
11. Teflon tube 1/2" OD x 3'.
12. Four gas impingers in ice bath.
13. Sample line to NUTECH Model 100 Stack Gas Sampler -- pump, dry gas meter, exit gas temp, system pressure gauge, magnahelix pressure gauges.

Before each test, all glassware and fittings were chromic-acid washed, rinsed with distilled, deionized water, methanol, and methylene chloride, and then assembled. Glass fiber filters were acid washed with 500 cc of 5% nitric acid, rinsed with 2 liters of distilled, deionized water, dried in a 110° C oven for 24 hours, cooled in a desiccator and then weighed on a Mettler HR51A analytical balance. The filters were also weighed after desiccating for 24 hours with the particulate sample collected, and after soxhlet extraction and desiccation. Filters, both used and unused, were stored in covered petri dishes and placed in a desiccator. The filters were not allowed to contact metal objects after pre-test preparation.

Teflon sleeves and metal clamps were used on all tapered joints in the MM5 sample train. All other connections, including Swagelock fittings, ball joints, O-ring/clamps, and impinger fittings were wrapped tightly with Teflon tape and were tested leak tight. Teflon tape was also wrapped around all petri dishes which contained used, extracted glass fiber filters.

The four impingers were each loaded and weighed to the nearest 0.01 g before and after each test. The first two impingers contained 100 ml of distilled deionized water, the third remained empty, and the fourth contained between 600 and 700 g of silica gel. The impingers were placed in an ice bath during testing.

The change in mass of the four impingers along with the volume of condensate collected after the XAD-2 module was recorded as the measure of water in the flue gas.

Data obtained from a Modified Method 5 (MM5) sampling train included polycyclic aromatic hydrocarbons (GC-FID with GC-MS confirmation), gravimetric and total chromatographable hydrocarbons, and spot dilution tests for PAH concentration. Additional data from the MM5 system include total volume sampled, sample gas exit temperature, and the sample system pressure.

3.2 MM5 SAMPLES GENERATED

After each test, MM5 samples were generated by rinsing the sampling system with methylene chloride, then methanol. Methylene chloride and methanol rinses were kept separate. The MM5 system was divided into two sections for sample preparation, heated and cooled. The heated section was from the glass probe to the heated filter bell assembly, and the cool section ran from the exit of the heated filter bell assembly to the Teflon tube leading to the impingers.

Soxhlet extractions were done separately on the glass fiber filter(s) and XAD-2 resin after each test. The methylene chloride rinse from the heated portion of the MM5 system was termed "Probe wash CH_2Cl_2" and was added to the filter soxhlet extraction. The methylene chloride rinse from the cooled portion of the MM5 was termed "Condenser wash CH_2Cl_2" and was added to the XAD-2 soxhlet extraction. Furthermore, the condensate was extracted with portions of methylene chloride, proportional to the volume of condensate, at pH 2 ± 0.5 and 11 ± 0.5. This extract was then combined with the XAD-2 soxhlet extract and later concentrated with a Kuderna-Danish (K-D) evaporator. All solvent samples were stored in 500 cc amber wide-mouth bottles with Teflon-lined caps. The bottles were all chromic acid washed, rinsed with distilled deionized water, methanol, and methylene chloride prior to use. The bottles containing solvent samples were tightly capped, wrapped along the top with Parafilm^R, labeled, and stored in a freezer until K-D concentration. The extracted condensate, extracted XAD-2, and impinger water were also saved and stored in cleaned amber bottles. Table 3.2 shows the MM5 sample analysis matrix.

A complete list of all samples generated by the MM5 system is as follows:

1. Probe wash + filter methylene chloride extract = PWF - CH_2-Cl_2
2. Condenser wash + XAD-2 + condensate methylene chloride extract = CWX-CH_2Cl_2
3. Probe wash methanol
4. Condenser wash methanol

The samples listed above were analyzed for PAH, Gravimetric, TCO, and spot tests (except methanol samples). All remaining portions of the MM5 system are as follows:

5. Extracted glass fiber filter (saved for elemented analyses)
6. Extracted XAD-2 resin (stored in freezer)
7. Extracted condensate (stored in refrigerator)
8. Impinger water (stored in refrigerator)

3.3 IACP SAMPLE IDENTIFICATION AND CHAIN OF CUSTODY

For the purposes of IACP Sample Identification and Tracking, the following code letters have been assigned to the listed MM5 samples:

TABLE 3.2. MODIFIED METHOD 5 - SAMPLE ANALYSIS MATRIX

					Specific Compounds		
Sample Description		(1) TCO	(2) Grav.	(3) Total PAH (Spot) Dilution Test)	(4) Individual PAH	(5) Retene B-Glucose	(6) Elemental Analysis and Fe/K
A. Probe rinses							
1. MeOH			X	*X			
2. $MeCl_2$ (combine with filter extract)	(PWF)	X	X	X	X	*X	X
B. Filter							
Extracted filter							X
C. XAD-2 extract							
D. XAD-2 condensate extract $MeCl_2$ (combined with filter extract)	(CWX)	X	X	X	X	*X	
E. Condenser wash							
1. $CeCl_2$							
2. MEOH		X	*X				
F. Ash							X

(1) TCO Analytical Procedure in Appendix C
(2) Gravimetric Analytical Procedure in Appendix C
(3) Spot Dilution Test in Appendix C
(4) PAH GC/MS Capillary by Radian in Appendix A and B
(5) Retene and B-Glucose anaalyses not performed
(6) Elemental and Fe/K analyses by Acurex Appendix D
*Not performed

IACP85R $\underset{(i)}{\underline{S}}$ $\underset{(ii)}{\underline{0}}$ $\underset{(iii)}{\underline{\hspace{2em}}}$

(i) Sampler Type "S" = Modified Method 5

(ii) Paired Sample Code "0" = non-paired

(iii) Sampler Type "G" = Filter + Probe wash CH_2-Cl_2 (PWF)

"E" = Condenser wash + XAD-2 +
Condensate CH_2-Cl_2 extract (CWX)

"C" = Composite cleaned (G+E)

"M" = Probe wash methanol

"W" = Condenser wash methanol

"H" = Extracted filter

"R" = Extracted impinger water

"I" = Impinger extract

"D" = Extracted condensate

"X" = Extracted XAD-2

"Z" = Blank solvent

Tables 3.3.1 and 3.3.2 lists and cross-references IACP-85 sample I.D. numbers with RTI sample I.D. numbers. Table 3.3.3 shows an actual chain of custody record of a portion of the samples, and Table 3.3.4 shows one of the IACP-85 sample number generators for a particular sample. Table 3.3.5 shows the cleaned composited sample ID numbers for PAH GC/MS analyses.

TABLE 3.3.1 IACP-85 AND RTI SAMPLE I.D. NUMBERS FOR GLASS FIBER FILTERS

Number	RTI Run Number	IACP I.D. Number
1	Extracted Blank	IACP85R Z0Z 01811
2	50403	IACP85R S0H 01801
3	50411	IACP85R S0H 01802
4	50417	IACP85R S0H 01803
5	50424	IACP85R S0H 01804
6	50424	IACP85R S0H 01804
7	50501	IACP85R S0H 01805
8	50501	IACP85R S0H 01805
9	50501	IACP85R S0H 01805
10	50508	IACP85R S0H 01806
11	50515	IACP85R S0H 01807
12	50515	IACP85R S0H 01807
13	50515	IACP85R S0H 01807
14	50522	IACP85R S0H 01808
15	50605	IACP85R S0H 01809
16	50605	IACP85R S0H 01809
17	50612	IACP85R S0H 01810
18	50612	IACP85R S0H 01810
19	50625	IACP85R Z0Z 01815

TABLE 3.3.2 IACP-85 AND RTI SAMPLE I.D. NUMBERS METHYLENE CHLORIDE EXTRACTS

RTI Sample Number		IACP Sample Number
50625 PAH2		IACP85R Z00 01813
50625 PAH4		IACP85R Z00 01814
50403 CWX		IACP85R S0E 01767
50403 PWF		IACP85R S0G 01766
	IEA	
50411 CWX	A, B	IACP85R S0E 01769
50411 PWX	A, B	IACP85R S0G 01759
50417 CWX		IACP85R S0E 01770
50417 PWF		IACP85R S0G 01760
50424 CWX		IACP85R S0E 01771
50424 PWF		IACP85R S0G 01761
	IEA	
50501 CWX	A, B	IACP85R S0E 01772
50501 PWF		IACP85R S0G 01762
50508 CWX		IACP85R S0E 01773
50508 PWF		IACP85R S0G 01763
50515 CWX		IACP85R S0E 01774
50515 PWF		IACP85R S0G 01764
50522 CWX		IACP85R S0E 01775
50522 PWF		IACP85R S0G 01765
50401 CWX	XAD Blank	IACP85R S0E 01799
50401 PWF	Filter Blank	IACP85R S0G 01800
50605 CWX		IACP85R S0E 01776
50605 PWF		IACP85R S0G 01777
50612 CWX		IACP85R S0E 01812
50612 PWF		IACP85R S0G 01778
50401 CWX	Blank EXT	IACP85R Z0Z 01799
50401 PWF	Blank EXT	IACP85R Z0Z 01800
50605 PWF		IACP85R S0G 01816
50605 PWF		IACP85R S0G 01818

TABLE 3.3.3. IACP-85 SAMPLE CHAIN OF CUSTODY FORM

Integrated Air Cancer Project
Sample Custody Form

Sample ID No. IACP85R S0E 01776, 01882 (RTI 50605, 50612 CWX)
IACP85R S0G 01777, 01778 (RTI 50605, 50612 PUF)
IACP85R Z00 01813, 01814 (RTI 50625 PAH 2, 4)

Description: Concentrated methylene chloride extracts from a Modified Method 5 flue sampler ~~from~~ on a woodstove flue.

RTI CROSS REFERENCE #S

50605 CWX	50612 CWX	50625 PAH 2 - RUSH -
50605 PUF	50612 PWF	50625 PAH 4 - RUSH -

Released by	Received by	Date	Time	Reason for Transfer	Storage and/or Transfer Conditions
Keith E Leese		6/25/85	10:45a	IEA TRANSFER FOR PAH	DRY ICE IN METAL SEALED CONTAINER. (VIALS- AMBER)
	Carol Williams	[illegible]	[illegible]	IEA TRANS FOR [illegible]	"

Comments: (Parent ID No., etc.)

2 ml aliquots of IACP85R S0E 01776, 01882
2 ml aliquots of IACP85R S0G 01777, 01778
0.4 ml of IACP85R Z00 01813
0.8 ml of IACP85R Z00 01814

TABLE 3.3.4. IACP-85 SAMPLE ID GENERATION AND RECORD FORM

SITE Bacon St RTI
COLLECTOR LOCATION Durham
FILTER NUMBER ______
DATE(MMDDYY) 6/5/85
START HOUR 10:55
STOP HOUR 14:53
FLOW 0.45
FLOW UNITS acfm
SAMPLER-ID ______ STACK

SAMPLER-TYPE		
HIVOL-TSP..........		A
PM-10 HIVOL.......		B
PM-2.5 HIVOL(A)...		C
PM-2.5 HIVOL(S)...		D
PM-10 4CFM........		E
PM-2.5 MOD.SIERRA..		F
PM-10 DICHOT		G
S-M DICHOT		H
DENUDER............		I
TENAX.............		J
VOC...............		K
ALDEHYDE (IMP)....		L
ALDEHYDE (CART)...		M
MASSIVE A/V.......		N
McFARLAND.........		O
LUNDGREN..........		P
OTHER.............	S	

50605 PWF (OAK)

PAIRED SAMPLE CODE		
DICHOT COARSE....		C
DICHOT FINE.....		F
DENUDER.........		D
NON-DENUDER.....		N
OTHER(_____).....		
ELSE		
NON-PAIRED.....	✓	0

SAMPLE TYPE		
CANNISTER......		C
TENAX..........		T
XAD............		X
PALLFLEX.......		P
TEFLON.........		F
QUARTZ.........		Z
NYLON..........		N
ALDEHYDE.......		A
COLLECTOR PLATE		L
OTHER(____).....	G	

DUPLICATE
SEND
TO
DATA
MGMT

COPY

SAMPLE-ID: I A C P 8 5 R S 0 G D1816 Aliquot 2 ml FOR ICAP

TABLE 3.3.5. INTEGRATED AIR CANCER PROJECT--SOURCE MEASUREMENT COMPOSITE CLEANED METHOD FIVE SAMPLES FOR PAH ANALYSES

IACP85R Sample # Composites	Composited from IACP85R Samples	RTI Sample Composite
IACP85RS01819	IACP85RS0E1767 and IACP85RS0G01766	50403
IACP85RS01821	IACP85RS0E1769 and IACP85RS0G01759	50411
IACP85RS01822	IACP85RS0E1769 and IACP85RS0G01759	50411A
IACP85RS01823	IACP85RS0E1771 and IACP85RS0G01761	50424
IACP85RS01824	IACP85RS0E1772 and IACP85RS0G01762	50501
IACP85RS01825	IACP85RS0E1773 and IACP85RS0G01763	50508
IACP85RS01826	IACP85RS0E1774 and IACP85RS0G01764	50515
IACP85RS01827	IACP85RS0E1775 and IACP85RS0G01765	50522
IACP85RS01828	IACP85RS0E1776 and IACP85RS0G01777	50605
IACP85RS01829	IACP85RS0E1812 and IACP85RS0G01778	50612
IACP85RS01820	Blank Solvent 2:3 $MeCl_2$, pentane	60103

4.0 STOVE OPERATING PARAMETERS

4.1 WOOD TYPE AND MOISTURE CONTENT

Oak and pine obtained locally (Research Triangle Park, NC) were the two wood species used for this study. High and low moisture contents were desired for each type of wood used, therefore, a total of four wood types were acquired, cured oak, uncured oak, cured pine, and uncured pine. The cured oak and pine were each cut and split one year prior to this study. They were air dried outside under plastic. The uncured oak and pine were cut three months prior to the beginning of this study and were not split. Rather, they were delivered as logs and were split one day prior to each test in which they were required. This was done to preserve the moisture in the wood as much as possible. A Delmhorst G-30 wood moisture meter was purchased to check the moisture contents of the wood. The moisture meter measures from 6% to 30% and was equipped with standards to check the instrument at 12% and 22%. Two insulated pins were driven into the wood with a sliding inertia impact handle and the percent moisture was read on the analog meter.

Initially, four readings from each log to be burned were taken. A set of two measurements from each end of the exposed (split) portion of the split log were taken. One measurement was taken between 1/4 inch and 3/8 inches deep and another at 1 inch deep. It became clear from this procedure that gravimetric moisture determinations for each type of wood would be more representative, hence, more desirable since readings taken deeper in the wood (1 inch) increased on the order of 10 to 15 percent. Also, many times the reading exceeded the maximum of 30% with cured oak at 1 inch of penetration. Thus, obtaining good readings from uncured wood would not be possible.

Twenty-five cured oak logs were measured at the four previously described points (See Table 4.1.1). The average of the 100 measurements is 21.4% for cured oak. This compares higher than the gravimetric determination which averages 18.7%. Although the sample number is smaller for the gravimetric determination, (two logs, eight samples for each type of wood), the value was used over the moisture meter because it included the moisture present in the whole cross section of wood. Also, the meter could not be used effectively with uncured wood. Once the moistures were gravimetrically determined for all

TABLE 4.1.1. CURED OAK PERCENT MOISTURE VALUES OBTAINED FROM A DELMHORST MODEL 30 WOOD MOISTURE METER

LOG NUMBER	1/4 inch	3/8 inch	1 inch	1 inch
1	10.5%	10.5%	21.0%	20.0%
2	11.0	11	19	24
3	16	19	30^{+}	30^{+}
4	12	18	28	28
5	12.5	15	30	30
6	12	11	24	21
7	13	21	30	30
8	11.5	10	11	18
9	11	23	27	30
10	12	21	30^{+}	30^{+}
11	18	19	30^{+}	30^{+}
12	17	17	30^{+}	29
13	13	20	27	29
14	16	13	28	28
15	16	18	30^{+}	30^{+}
16	14	15	20	17
17	13	20	28	30
18	16	15	28	28
19	25	15	29	26
20	12	14	28	28
21	18	16	30	29
22	13	14	27	28
23	21	21	30^{+}	30^{+}
24	18	17	29	28
25	21	17	30^{+}	30^{+}
Average %	**14.9%**	**16.4%**	**27.0%**	**27.2%**

Average of 100 measurements = 21.4%

wood types, the moisture meter served as a pre-test check whenever cured wood was tested.

The gravimetric determination of wood moisture contents was performed using two randomly selected split logs of each of the four types of wood. Each log was sawed in half with a band saw. From the center of each log, four slices were taken approximately one inch thick. Each slice was weighed to the nearest 0.01 g with a Fisher Model 7224D top loading digital balance and placed in a Blue M drying oven at 110° C for 72 hours. After cooling in a desiccator, each wood-pie slice was reweighed to the nearest 0.01 g. The percent moisture was calculated from the average percent weight loss of eight slices of each type of wood (See Table 4.1.2). The gravimetric wood percent moisture values found for this study are: cured oak 18.7%, uncured oak 34.9%, cured pine 15.1%, and uncured pine 31.8%. A proximate analysis was run on the wood used in this study. The range applied to the statistical analyses of variance for the operating parameter of wood moisture will be the average of the two cured woods and the average of the two uncured woods. Thus, the average cured wood moisture content is 16.9% and the average uncured moisture content is 33.2%. The percent ash, sulfur, and BTU per pound are shown in Table 4.1.3.

In the half factorial experimental test design, cured wood was assigned a plus (+) for wood moisture content, and uncured wood was assigned a minus (-). Thus, all main effects observed in the statistical analyses of the effect of wood moisture on emissions occur due to decreasing wood moisture content.

It should be noted in this study that the cured pine had no bark. This was initially overlooked when testing was underway. The first pine burn, as dictated by the test matrix, indicated cured pine. The test was completed and the next test indicated uncured pine. At this time, it was realized that the test with cured pine had no pine bark. Therefore, to avoid adding a new variable to the test matrix and invalidating our test plan, the bark was cut off of the uncured pine prior to burning. This procedure eliminated pine bark from this study. It is realized that elimination of pine bark may not be completely representative of normal use, however, to maintain consistency, it was eliminated.

TABLE 4.1.2. GRAVIMETRIC DETERMINATIONS OF MOISTURE CONTENT FOR WOOD USED IN THIS STUDY

Log	Cured Pine		Uncured Pine	
	Wet (g) Dry (g) ΔW (g)	%	Wet (g) Dry (g) ΔW (g)	%
1	88.46 - 76.82 = 11.64	13.16	80.30 - 47.69 = 32.61	40.61
	73.74 - 63.58 = 10.16	13.78	101.78 - 62.06 = 39.72	39.02
	80.98 - 69.75 = 11.23	13.87	48.84 - 30.86 = 17.98	36.81
	75.53 - 65.19 = 10.34	13.69	77.69 - 49.04 = 28.65	36.88
2	89.73 - 76.28 = 13.45	14.99	86.05 - 63.83 = 22.22	25.82
	80.15 - 67.26 = 12.89	16.08	94.58 - 70.17 = 24.41	25.81
	98.18 - 81.45 = 16.13	17.04	86.41 - 64.63 = 21.78	25.20
	124.65 - 102.37 = 22.28	17.87	76.12 - 57.36 = 18.76	24.62
Average %	15.06		31.85	

TABLE 4.1.2 (continued)

Log	Cured Oak		Uncured Oak	
	Wet (g) Dry (g) ΔW (g)	%	Wet (g) Dry (g) ΔW (g)	%
1	95.25 - 76.24 = 19.01	19.96	205.65 - 133.71 = 71.94	34.98
	79.68 - 63.13 = 16.55	20.77	219.34 - 142.10 = 77.24	35.22
	47.10 - 37.22 = 9.88	20.98	265.97 - 170.95 = 95.02	35.73
	79.00 - 63.00 = 16.00	20.25	326.27 - 210.77 = 115.50	35.40
2	100.17 - 82.76 = 17.41	17.38	257.77 - 166.69 = 91.08	35.33
	117.18 - 96.59 = 20.59	17.57	146.67 - 95.94 = 50.73	34.59
	118.25 - 98.33 = 19.92	16.85	177.12 - 116.41 = 60.71	34.28
	96.92 - 81.64 = 15.28	15.77	201.14 - 134.04 = 67.10	33.36
Average %	18.69		34.86	

TABLE 4.1.3. PROXIMATE ANALYSIS OF WOOD USED IN THIS STUDY

PROXIMATE ANALYSIS OF WOODS TESTED				
Sample	Residual % Moisture	% Ash	% Sulfur	BTU/LB
Oak (Uncured)				
as received	20.45	1.29	0.07	6576
dry basis		1.62	0.09	8266
Oak (Cured)				
as received	16.18	2.58	0.13	6714
dry basis		3.08	0.16	8010
Pine (Uncured)				
as received	23.95	0.46	0.07	6639
dry basis		0.60	0.09	8730
Pine (Cured)				
as received	14.80	0.42	0.49	7193
dry basis		0.49	0.07	8442

4.2 WOOD LOAD AND BURN RATE

Wood loads (kg wood charged to the stove initially) were determined by the volume of the firebox. A high wood load for both oak and pine was defined as the stove being filled to capacity at the beginning of each test burn. Because of the difference in densities between oak and pine, equal volumes did not provide equal weights, however, since the split logs were all approximately the same size. Typically, six to eight split logs were loaded for all high load tests. A low load was usually half a high load in terms of split logs loaded. Typically, three to four logs were loaded in a low load test. Table 4.2.1 lists the mass (kg) of each high and low load from the tests performed and provides an average for those parameters. The average high load was 15.2 ± 3.4 kg and the average low load was 8.0 ± 2.8 kg. The volume of the fire box was measured at 2.4 ft^3 or 0.068 m^3.

The burn rate for each test was established in the following manner. Before loading wood, an 8 inch to 12 inch pile of finely split kindling of the type of wood to be burned for the planned test was carefully placed into the stove. A propane torch was used to ignite the pile of kindling. Paper was not used in order to preserve the integrity of the ash generated by each run. Once the kindling had burned down to a hot bed of coals, the scale was tared, wood was loaded and the weight was recorded for each split log. A total weight load was recorded and the logs were allowed to ignite. The dampers were closed to previously determined levels and the weight change was observed over several five to ten minute intervals. Adjustments were made to the inlet air flow accordingly until the desired burn rate was attained. A steady desired burn rate signaled the start of organic sampling from the MM5 system. During each test, at least one recharge was performed up to the initial wood load. After the test, the total MM5 time and the weight losses during during the MM5 interval were computed and a burn rate (kg/hour) was calculated for the entire test (See Table 4.2.2). The range applied to the statistical analyses of variance for the operating parameter of burn rate will be the average of the low burn rates, 1.75 ± 0.48 kg/hr and the average of the high burn rates, 6.56 ± 0.85 kg/hr.

TABLE 4.2.1 CHARACTERIZATION OF WOOD LOADS (kg)

High (+)			Low (-)		
Test 1	OAK	17.0	Test 2	OAK	8.8
Test 3	OAK	20.3	Test 4	OAK	12.6
Test 5	PINE	12.0	Test 6	PINE	6.4
Test 7	PINE	13.8	Test 8	PINE	5.4
*Test 9	OAK	13.0	**Test 10	OAK	7.0
Average =		15.2 ± 3.4 kg	Average =		8.0 ± kg

*Test 9 replaces Test 3.
**Test 10 is a duplicate of Test 2.

TABLE 4.2.2 CHARACTERIZATION OF BURN RATES (kg/hr)

High (+)		Low (-)	
Test 1	7.10	Test 2	1.25
Test 4	6.83	Test 5	1.87
Test 6	5.31	Test 8	2.17
Test 7	6.92	*Test 9	2.22
		**Test 10	1.24
Average = 6.56 ± 0.85 kg/hr		Average = 1.75 ± 0.48 kg/hr	

*Test 9 replaces Test 3.
**Test 10 is a duplicate of Test 2.

5.0 EXPERIMENTAL TEST DESIGN

A one-half factorial experimental test design was used with four stove operating variables. The independent variables studied were wood species, moisture content, wood load, and burn rate, each at two levels as the variables in the test matrix. Two shakedown tests were performed to familiarize the experimenters with the operational characteristics of the stove such as damper settings, burn rates, gas sampling, and the data recording system. Following these pre-tests, eight tests were conducted according to the one-half factorial test design. Preliminary analyses of the results indicated that one test (No. 3) should be repeated because of a low MM5 sampling rate and a burn rate which was too high for a low burn rate test. Test No. 3 was repeated and a duplicate for test No. 2 was also performed for a total of twelve tests.

The statistical analysis of experimental results was performed as described in Probability and Statistics for Engineers and Scientists, 2nd Edition, (Ronald E. Walpole and Raymond H. Meyers, MacMillan Publishing Co., Inc., 1978, pp. 463-468). The experimental matrix and calculations are outlined in the following:

A. TEST VARIABLES

Variables	High (+)	Low (-)
Fuel	Oak	Pine
Moisture	Cured	Uncured
Load	High	Low
Burn Rate	High	Low

B. TEST MATRIX

Test No.	Measured Value	Variables Fuel	Moisture	Load	Burn Rate
1	V1	+	+	+	+
2	V2	+	+	-	-
3	V3	+	-	+	-
4	V4	+	-	-	+
5	V5	-	+	+	-

Test No.	Measured Value	Variables Fuel	Moisture	Load	Burn Rate
6	V6	-	+	-	+
7	V7	-	-	+	+
8	V8	-	-	-	-

C. STATISTICAL ANALYSIS CALCULATIONS

CONTRASTS:

Fuel Contrast $= + V1 + V2 + V3 + V4 - V5 - V6 - V7 - V8$

Moisture Contrast $= + V1 + V2 - V3 - V4 + V5 + V6 - V7 - V8$

Load Contrast $= + V1 - V2 + V3 - V4 + V5 - V6 + V7 - V8$

Burn Rate Contrast $= + V1 - V2 - V3 + V4 - V5 + V6 + V7 - V8$

Fuel x Moisture Contrast = Load x Rate Contrast
$= + V1 + V2 - V3 - V4 - V5 - V6 + V7 + V8$

Fuel x Load Contrast = Moisture x Rate Contrast
$= + V1 - V2 + V3 - V4 - V5 + V6 - V7 + V8$

Fuel x Rate Contrast = Moisture x Load Contrast
$= + V1 - V2 - V3 + V4 + V5 - V6 - V7 + V8$

SUM OF SQUARES:

SS Fuel = $(\text{Fuel Contrast})^2 / 2^3$

SS Moisture = $(\text{Moisture Contrast})^2 / 2^3$

SS Load = $(\text{Load Contrast})^2 / 2^3$

SS Burn Rate = $(\text{Burn Rate Contrast})^2 / 2^3$

$$\text{SS Total} = V^2 + V2^2 + V3^2 + V4^2 = V5^2 + V6^2 + V7^2 + V8^2 - \frac{(V1 + V2 + V3 + V4 + V5 + V6 + V7 + V8)^2}{2^3}$$

SS Error = SS Total - SS Fuel - SS Moisture - SS Load - SS Burn Rate

MAIN EFFECTS:

ME Fuel = (Fuel Contrast) / 2^2

ME Moisture = (Moisture Contrast) / 2^2

ME Load = (Load Contrast) / 2^2

ME Burn Rate = (Burn Rate Contrast) / 2^2

Table 5.1 illustrates the analyses of varience used for determining the significance of each variable on each emission parameter.

The calculations of contrasts, main effects, and analyses of variance (ANOVA) tables were performed using LOTUS 1-2-3^R spreadsheets. This permitted rapid insertion of results and performance of calculations. The ANOVA procedure takes any set of experimental results for the eight tests and divides the variation of the data (Sum of Squares) into variation attributable to the changed variables (FUEL, MOISTURE, LOAD, and RATE) and variation due to second order effects and experimental error (ERROR).

Table 5.1 shows the equations used in the ANOVA procedure. A comparison of the sum of squares for a variable to the error sum of squares in an f test indicates whether the variation attributed to a variable (FUEL, MOISTURE, LOAD, and RATE) is statistically significant. Calculated f values are compared to tabulated f values at 99% (α = 0.01), 95% (α = 0.05), and 90% (α = 0.10) confidence intervals.

Table 5.2 is an ANOVA for total extractable organic (TCO + GRAV) emission factors. The RATE (Burn Rate) affected the total EO at a 95% confidence interval (the f value 14.13 is greater than 10.13 for 95% confidence interval) with a main effect of -48.4 g/kg. This main effect indicates that total EO emissions decreased by 48.4 g/kg wood burned as the burn rate increased from minus one to one (-1 → 1). Minus one to one refers to the change from a low burn rate to a high burn rate. These ranges are derived from the average value of the low burn rate and high burn rate as shown in Table 4.2.2. None of the other variables, (Fuel, Moisture, or Load) produced a significant effect on total EO emission factors (g/kg wood burned). Burn rate accounted for 4679/6583 x 100 = 71% of the observed variation in EO emission factors. Error contributed to 981/6583 x 100 = 15% of the observed variation.

TABLE 5.1. ANALYSIS OF VARIANCE (ANOVA)

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	f
Fuel	(SS Fuel)	2-1=1	(SS Fuel)/1	(SS Fuel)/ $\frac{\text{SS Error}}{3}$
Moisture	(SS Moisture)	2-1=1	(SS Moisture)/1	(SS Moisture)/ $\frac{\text{SS Error}}{3}$
Load	(SS Load)	2-1=1	(SS Load)/1	(SS Load)/ $\frac{\text{SS Error}}{3}$
Rate	(SS Burn Rate)	2-1=1	(SS Burn Rate)/1	(SS Burn Rate)/ $\frac{\text{SS Error}}{3}$
Error	(SS Error)	7-4=3	(SS Error)/3	
Total	(SS Total)	$2^3 - 1 = 7$		

From this the f values for comparison are:

α	df_N	df_D	f
0.01	1	3	34.12
0.05	1	3	10.13
0.10	1	3	5.54

TABLE 5.2 ANOVA FOR TOTAL EXTRACTABLE ORGANICS

Analysis of Variance (ANOVA) for Total EO (g/kg Wood)

Run No.	Value	Fuel	Moisture	Load	Rate	AB	AC	AD
1	3.812	A	B	C	D	CD	BD	1
2	48.927	1	1	-1	1	1	-1	-1
9	35.219	1	-1	1	1	-1	1	-1
4	5.041	1	-1	-1	1	-1	-1	1
5	90.388	-1	1	1	-1	-1	-1	1
6	1.358	-1	1	-1	1	-1	1	-1
7	14.010	-1	-1	1	1	1	-1	-1
8	43.794	-1	-1	-1	-1	1	1	1
Contrast		-57.181	45.791	44.938	-193.475	-22.1	-73.6	44.2
Sum of Squares		408.705	262.103	252.431	4679.093	61.0	676.2	243.7
SSTotal		6583.252						
Main Effect		-14.295	11.448	11.235	-48.369			

Source	SS	DF	MS	F
Fuel	408.705	1	408.70	1.25
Moisture	262.103	1	262.10	0.80
Load	252.431	1	252.43	0.77
Rate	4679.093	1	4679.09	14.31
Error	980.919	3	326.97	
Total	6583.252	7		

F(0.01, 1,1) = 34.12
F(0.05, 1.3) = 10.13
F(0.10, 1,3) = 5.54

	Fuel	Moisture	Load	Rate	AB	AC	AD
Sum of Squares	408.705	262.103	252.431	4679.093	61.0	676.2	243.0

6.0 ANALYTICAL PROCEDURES

6.1 TOTAL EXTRACTABLE ORGANICS

Total extractable organics (Total EO) were calculated as the sum of two separate analytical procedures, gravimetric (Grav) and total chromatographable organics (TCO). The gravimetric procedure provides a measure of organics with boiling points above 300° C while the TCO provides a measure of organics between 100° C and 300° C. The detailed procedure used for Grav and TCO analyses can be found in Appendix C.

For gravimetric analyses, a known aliquot (between 1-5 ml depending on the degree of concentration) of the concentrated samples is placed in a weighed, desiccated aluminum pan. It is placed in a hood and covered until dry, usually 24-48 hours. It is then desiccated for 8-10 hours and reweighed for the mass of the residue. All weighings were performed on a recently calibrated Mettlar HR51A analytical balance. The samples which were analyzed gravimetrically included the concentrated methylene chloride condenser wash, XAD-2 extract (CWX-CH_2-Cl_2), the concentrated methylene chloride probe wash, filter extract (PWF-CH_2-Cl_2), the methanol probe wash, and the methanol condenser wash. For each woodstove test, the total of these four samples constituted the gravimetric mass. Blank solvents and several duplicates were also analyzed.

The gravimetric values were corrected by subtracting the blank results within each set of analyses. Two duplicate gravimetric analyses were performed in each category of samples as previously described here. The duplicates analyzed had the following percent agreement: 99.9, 99.6, 99.6, 98.8, 89.0, 99.8, 96.7, and 94.4%. All fell well within the specified 80% agreement range specified by the procedure which is described in Appendix C.

The TCO procedure was performed on a Varian 3700 gas chromatograph with an FID. A calibration curve was generated with known concentrations of three aliphatic hydrocarbons within the range of 100°-300° C. This chromatographic range was determined with known amounts of heptane bp 98° and hexadecane bp 289° C. The areas of the three calibration aliphatic hydrocarbons were added together for each concentration. Each known concentration was analyses in duplicate and an average area count for each concentration was plotted on the calibration curve. Once the calibration was complete, the samples were analyzed. Only the methylene chloride samples were run. (PWF-CH_2-Cl_2 and CWX-CH_2-Cl_2). All samples were run in duplicate to assess precision. Prior to analyses, known standards were analyzed to check the chromatograph and assess accuracy. For each woodstove test, the PWF-CH_2-Cl_2 and CWX-CH_2-Cl_2 TCO values were added together for total TCO. The CWX (condenser wash, XAD-2 extract) contributed more than 99% of the TCO total. The PWF (probe wash filter extract) typically contributed $<$ 1% to the TCO total.

The total extractable organics for the sampling period during each test consist of the sum of the Gravimetric and TCO procedures.

6.2 C_1-C_7 HYDROCARBONS

C_1-C_7 gas samples were collected by RTI in bag samples and were measured with GC-FID by Industrial Environmental analysts (IEA). A column of 0.19% picric acid on carbopak C was used with a flame ionization detector (FID). The chromatographs were integrated and recorded with a Perkin-Elmer Sigma 10 integrator. The FID was calibrated with 5 ml of a gas standard (Supelco, C_1-C_6 hydrocarbons, 100 ± 5 ppm, methane, ethane, propane, butane, pentane, and hexane) prior to 5 ml sample injection. Response factors for C_1-C_6 were calculated from the standard injection and used to calculate the sample C_1-C_7 hydrocarbon concentration. The chromatograph for the sample was divided into ranges for C_1, C_2, C_3, C_4, C_5, C_6, and C_7 and the response factors from the standard were applied to the sum of the peak areas in each range. The C_7 hydrocarbon response factor was assumed to be the same as C_6 hydrocarbons. Further discussion of C_1-C_7 hydrocarbon analysis can be found in Section 9.4.

6.3 POLYNUCLEAR AROMATIC HYDROCARBONS

Polynuclear aromatic hydrocarbon (PAH) analyses were performed by Radian Corporation on RTI composited methylene chloride PWF, CWX samples. Capillary GC/MS was used to obtain PAH results. An attempt had been made previously by Industrial Environmental Analysts (IEA) to analyze for PAH on original sample concentrates by Method SW846 packed column procedures for PAH; however, the sample matrix proved too complex. RTI then composited aliquots of the methylene chloride PWF and CWX samples from each woodstove test and performed EPA Method 610 silica gel cleanup. IEA then analyzed aliquots of the cleaved composite samples by EPA Method 610 HPLC. Better analytical results were obtained; however, most of the samples were too dilute, and little data were obtained. The data were inadequate to perform the ANOVA statistical analyses.

Subsequently, all remaining cleaned composite samples were sent to Radian Corporation for capillary GC/MS PAH analyses. A total of eleven samples were sent. Radian then concentrated each sample from approximately 30 ml to 5 ml (individual volumes varied slightly). Radian performed an initial total chromatographable organics (TCO) on the cleaned composite samples and determined that they were concentrated enough to proceed with PAH capillary GC/MS analyses. A gravimetric analyses was also performed on the cleaned samples. Table 3.3.5 lists the cleaned composite sample IACP ID numbers and RTI sample numbers sent to Radian. A list of the compounds analyzed for by Radian capillary GC/MS procedures is shown in Table 6.3.1.

The Radian PAH analyses can be found in Appendix A. The Radian QA/QC documentation is in Appendix B. A PAH spot dilution test as described in Appendix C was performed.

TABLE 6.3.1. WOODSTOVE TARGET COMPOUNDS IN RADIAN CAPILLARY GC/MS ANALYSES

phenol
napthalene
acenaphthylene
acenaphthene
fluorene
nitronaphthalene
phenanthrene
anthracene
acridine
carbozole
fluoranthene
phenanthrol
pyrene
benzo (a) anthracene
chrysene
benzo (b) fluoranthene
benzo (k) fluoranthene
benzo (a) pyrene
3-methyl cholanthrene
benzo (g,h,i) perylene
dibenzo (a,h) anthracene
indeno (1,2,3 cd) pyrene

6.4 ELEMENTAL ICAP ANALYSES

Elemental ICAP analyses were performed by ACUREX Corporation on wood ash and MM5 glass fiber filters for each woodstove test. Additional ICAP analyses were performed on each type of wood used in the test matrix and one set of woodsmoke concentrated extract. A list of elements analyzed follows in Table 6.4.1. The ACUREX report lists all procedures, samples, analyses, quality control measures, and results and is contained in Appendix D.

TABLE 6.4.1. TARGET ELEMENTS IN ICAP ELEMENTAL ANALYSES AS PERFORMED BY ACUREX

Ag
Al
As
Ba
Ca
Cd
Co
Cr
Cu
Fe
Hg
K
Li
Mg
Mn
Na
Ni
P
Pb
S
Sb
Se
Si
Sn
Sr
Ti
Tl
V
Zn

6.5 RETENE AND LEVOGLUCOSAN

No analysis was performed for either retene or levoglucosan. The analytical procedures required for levoglucosan would have hindered other organic analyses. Retene was not included in the Radian capillary GC/MS PAH analyses.

6.6 CONTINUOUS ANALYTICAL PROCEDURES FOR OXYGEN, CARBON MONOXIDE, CARBON DIOXIDE, HYDROCARBONS FID, STOVE TEMPERATURE AND STACK TEMPERATURE

Stack gas %CO_2, %CO, %O_2, ppm hydrocarbons, temperature, and stove temperature were continuously measured during the experimental tests. The instruments and ranges for these measurements are presented in Table 6.6.1. Outputs from these instruments were recorded by a Metrosonics dl-721^R. The datalogger measured data for six channels every two seconds, and then stored the high, low, and average values for each minute.

Stack gas was conditioned through two condensers and a filter prior to analysis for %CO_2, %CO, and %O_2. These three analyzers were connected in series. The stack gas sample for the FID hydrocarbon analyzer was fed continuously to the analyzer though a separate heated line with a glass wool filter. This sample line was heated to approximately 200° C.

Each instrument and the datalogger measurements were calibrated at zero and a span concentration prior to each test burn. This involved feeding zero and span gas to the instruments, adjusting the instrument, then adjusting the datalogger. After the instruments and datalogger were calibrated, the zero and span gases were again fed to the instruments and the measured values from

TABLE 6.6.1 INSTRUMENTS AND RANGES FOR CONTINUOUS ANALYSIS

Measured Parameter	Instrument	Range
$\%CO_2$	Horiba PIR-2000 NDIR	0-20%
%CO	Horiba PIR-2000 NDIR	0-3%
$\%CO_2$	MSA Magnetic O_2 Analyzer	0-25%
ppm Hydrocarbon as CH_4	Beckman Model 400 FID Hydrocarbon Analyzer	0-20,000 ppm
Stack Gas Temperature	Average of 2 K type thermocouples	10-800° C
Stove Temperature	Average of 4 K type thermocouples	10-800 ° C

the datalogger were recorded and compared to the actual concentrations. This verified correct instrument operation and data storage. The instruments and datalogger were rechecked with zero and span gases at the end of each test run to check for instrument drift.

Data collected with the datalogger was transferred to an IBM-PC immediately after each test burn. This produced both computer files and a hardcopy of the data collected. A copy of the printout from two channels on Test No. 7 is contained in Appendix E. The computer files were used with Lotus 1-2-3^R spreadsheets to calculate average $\%CO_2$, %CO, $\%O_2$, ppm HC, stack temperature, and stove temperature during the Method 5 sampling period of each test burn.

6.7 BIOASSAY

The Ames Salmonella typhimurium plate incorporation assay was used in this study to determine mutagenic potential. The Ames bioassay was conducted in strain TA98 both with and without S9 activation. Separate analyses were performed on the filter and XAD extracts. In this analysis, aliquots of the samples dissolved in DMSO are added to agar plates. The S9 activation enzyme, prepared from mouse livers, provides an indication of the potency of the mutagens requiring a promoter to become active while the nonactivated applications provide a measure of the direct acting mutagens. The mutagenic activity is determined by measuring the slope of the dose response curve generated by applying a range of dose concentrations to the agar plates. After exposure, the plates are stained and the number of bacteria which have reverted, or mutated, back to their original form are counted.

7.0 RESULTS

7.1 SUMMARY OF ALL DATA COLLECTED

A complete summary of all run conditions, measured emission concentrations, rates, and factors is provided in Tables 7.1.1 through 7.1.14. Data from these tables are used in the ANOVA statistical analyses of any measured stove variable or emission. Runs 2 and 10 are duplicate woodstove tests, and average values from Runs 2 and 10 are used in the statistical analyses. Also, Run 9 is a replacement for Run 3 for reasons previously discussed. For the purpose of discussion, emission concentrations are in g/m^3 STP wet, emission rates are in g/hr, and emission factors are in g/kg wet wood, unless otherwise specified. The units of burn rate are in kg/hr and stack flow is in m^3/min STP wet. All temperatures are in °C. All ANOVA results can be found in Appendix G.

All results derived in Tables 7.1.1 through 7.1.14 were calculated using equations listed in Section 9.9. An example set of calculations is also provided for Test Number 4.

During several tests, the MM5 sampling train plugged at the heated filter. When this occurred, the MM5 train was stopped, the heated filter holder was disassembled, a new filter was installed, the filter holder was replaced, brought up to temperature, and sampling was resumed. This occurred once during tests 4 and 9 (repeat of test 3) for 35 minutes and 95 minutes, respectively. During tests 5, 7, and 10 (duplicate of test 2), filter replacement occurred twice. Test 5 was interrupted for 53 and 58 minutes, test 7 for 62 minutes each time, and test 10 was interrupted for 94 and 14 minutes. A filter change did not occur during the 14 minute interruption as it was near the end of the test. During the longer interruptions (>90 minutes), expended heating tapes were replaced.

To avoid biasing results from sampling interruptions as much as possible the following measures were taken. During MM5 sampling interruptions, the woodstove operating parameters were maintained at proper test conditions. Burn rates were monitored and wood load was controlled such that when MM5 sampling resumed, the woodstove was at or near the same conditions as when sampling was stopped. At least one wood addition was included during the MM5

TABLE 7.1.1. WOODSTOVE TESTING DATA SUMMARY

	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Aver2R10	%Diff R2R10
									Rep 3	Dup 2		
RTI Run Number	50403	50411	50417	50424	50501	50508	50515	50522	50605	50612		
Fuel	Oak	Oak	Oak	Oak	Pine	Pine	Pine	Pine	Oak	Oak	Oak	
Moisture	Cured	Cured	Uncured	Uncured	Cured	Cured	Uncured	Uncured	Uncured	Cured	Cured	
(Grav %)	18.7	18.7	34.9	34.9	15.1	15.1	31.6	31.6	34.9	18.7	18.7	0.0%
Load	High	Low	High	Low	High	Low	High	Low	High	Low	Low	
(Initial (kg)	17.00	8.80	20.30	12.60	12.00	6.40	13.80	5.40	13.00	7.00	7.9	22.8%
Burn Rate	High	Low	Low	High	Low	High	High	Low	Low	Low	Low	
(M5 kg/hr)	7.20	1.25	3.53	6.83	1.87	5.31	6.92	2.17	2.22	1.24	1.25	0.9%
Method 5 Times (hr min)												
Start	14.41	12.37	15.45	13.25	11.00	12.00	11.40	10.40	10.55	9.30		
Stop	15.51	15.44	17.10	13.49	12.01	16.02	13.00	14.41	12.55	10.10		
Start				14.24	12.54		14.12		14.30	11.54		
Stop				17.40	14.14		14.49		14.53	13.10		
Start					15.12		15.51			13.24		
Stop					16.16		16.05			13.29		
Dry Gas M5 (ft^3)	35.31	96.40	22.49	100.04	93.58	110.92	52.29	115.00	57.27	50.64	73.52	62.2%
Gas Temp M5 (°F)	100	100	92	106	102	107	105	101	100	101	100.5	-1.0%
M5 Sample Time (min)	70	187	85	219.5	205	242	131	241	143	121	154	42.9%
Fuel Burned M5 (kg)	8.4	3.9	5.0	25.0	6.4	21.4	15.1	8.7	5.3	2.5	3.2	43.8%
Condensate (ml)	71	95	42	230	93	166	156	264	211	119	107	-22.4%
Impinger Wt Gain (g)	13.1	35.2	6.8	35.3	50.2	47	31.2	58	30.9	29		
Total Water Col (g)	84.1	130.2	48.8	265.3	143.2	213	187.2	322	241.9	148	139	-12.8%
Pressure atm (mm Hg)	746	758	758	754	757	759	756	754	755	749	753.9	1.2%
Room Temp (C)	26	26	25	30	30	30	30	27	29	26	26	0.0%
Relative Humidity (%)	24	38	83	62	66	63	71	82	74	80	59	-71.2%

continued

TABLE 7.1.1. WOODSTOVE TESTING DATA SUMMARY (Continued)

RTI Run Number	Run 1 50403	Run 2 50411	Run 3 50417	Run 4 50424	Run 5 50501	Run 6 50508	Run 7 50515	Run 8 50522	Run 9 Rep 3 50605	Run 10 Dup 2 50612	Aver2R10	%Diff R2R10
Inlet Flow (ft/min)	154	46	91	320	57	283	242	30	40		23	200.0%
STK Flow (ft/min)	274	59	114	161	100	250	196	52	55	36	47.5	48.4%
STK Temp (°)	240	69	79	249	87	270	226	79	73	62	65.5	10.7%
STV Temp (°)	267	105	96	246	164	322	238	124	109	97	101	7.9%
CO_2 (%)	6.8	3.6	3.1	6.8	4.2	6.3	5.4	4.7	5.0	4.9	4.3	-30.6%
CO (%)	0.82	0.79	0.80	0.83	0.97	0.20	0.68	1.18	1.03	1.09	0.94	-31.9%
O_2 (%)	14.5	17.0	17.8	14.7	16.3	16.0	16.5	18.5	16.9	18.1	17.6	-6.3%
STP = 20 °C, 1 atm												
Vol Samp (m^3 STP)	0.93	2.57	0.61	2.63	2.48	2.93	1.38	3.05	1.52	1.33	1.95	63.5%
Samp Rate (m^3/min STP)	0.013	0.014	0.007	0.012	0.012	0.012	0.011	0.013	0.011	0.011	0.012	22.1%
Water Vol (m^3 STP)	0.112	0.174	0.065	0.354	0.191	0.284	0.250	0.430	0.323	0.198	0.186	-12.8%
Stack Moisture (%)	10.81	6.33	9.67	11.89	7.15	8.86	15.35	12.37	17.51	12.92	9.63	-68.4%
Flue Flow (m^3/min STP)	1.52	0.50	0.94	0.89	0.80	1.33	1.13	0.42	0.46	0.31	0.40	47.6%
Burn Rate (kg dry/hr)	5.85	1.02	2.30	4.45	1.59	4.50	4.73	1.48	1.45	1.01	1.01	0.9%
Burn Rate (kg/hr)	7.20	1.25	3.53	6.83	1.87	5.31	6.92	2.17	2.22	1.24	1.25	0.9%
C_1-C_7 Hydrocarbons												
C_1		2.45	2.15	0.26	1.23	0.11	1.17	2.25	2.38	2.99	2.72	-19.9%
C_2		1.02	0.76	0.47	0.82	0.07	0.82	0.83	0.77	0.82	0.92	21.7%
C_3		0.47	0.52	0.05	0.2	0.01	0.18	0.63	1.04	1.3	0.89	-93.8%
C_4		0.42	0.52	0.07	0.17	0	0.14	0.57	0.54	0.48	0.50	-32.0%
C_5		0.26	0.33	0.14	0.22	0.02	0.09	0.49	0.32	0.4	0.33	-42.4%
C_6		0.22	0.18	0.15	0.18	0.01	0.29	0.26	0.15	0.2	0.21	9.5%
C_7		0.07	0.11	0	0	0	0.06	0.11	0.03	0.05	0.06	33.3%
Total C_1-C_7 Hydrocarbons (mg/l)		4.9	4.6	1.1	2.8	0.2	2.8	5.1	5.2	6.3	5.63	-25.4%

continued

TABLE 7.1.1. WOODSTOVE TESTING DATA SUMMARY (Continued)

	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Aver2R10	%Diff
									Rep 3	Dup 2		R2R10
RTI Run Number	50403	50411	50417	50424	50501	50508	50515	50522	50605	50612		
Particulates												
Filter (g)	0.1026	1.0565	0.0828	0.2365	0.6950	0.1996	0.3729	0.9645	1.0944	0.7200		
CH_2Cl_2 Probe Wash (g)	0.1553	0.2435	0.1687	0.1792	0.2017	0.1058	0.0129	0.2637	0.0492	0.0080		
CH_3CH Probe Wash (g)	0.0760	0.1199	0.0842	0.0750	0.1072	0.0637	0.0086	0.2192	0.0116	0.0040		
Total g(g)	0.3339	1.4198	0.3357	0.4908	1.0039	0.3691	0.3944	1.4473	1.551	0.7320		
Grav (Total g)	0.5410	4.6999	0.9703	1.4416	7.5814	0.1910	1.6827	9.6992	4.1267	3.7461		
TCO (Total g)	0.1292	1.0315	0.2893	0.4892	1.8395	0.0985	0.6414	3.2473	1.1382	1.0683		
Total (EO)	0.6702	5.7314	1.2596	1.9308	9.4209	0.2895	2.3241	12.9465	5.2659	4.8144		
Mutagenicity (rev/µg)												
BUM												
CWX	0.10	0.00	0.02	0.14	0.01	2.77	0.07	0.06	0.02	0.04		
PWF	0.17	0.02	0.02	0.63	0.06	34.52	0.03	0.01	0.01	0.01		
BUP												
CWX	0.25	0.02	0.09	0.60	0.08	2.46	0.29	0.08	0.00	0.05		
PWF	0.66	0.12	0.16	1.34	0.17	20.05	0.84	0.14	0.18	0.23		
$MeCl_2$ Grav Results (total g)												
CWX	0.443	3.395	0.824	1.398	6.486	0.154	1.272	6.948	3.267	3.296		
PWF	0.037	1.024	0.080	0.025	0.393	0.008	0.240	1.694	0.549	0.349		
$MeCl_2$ TCO Results (total g)												
CWX	0.1287	1.0012	0.2817	0.4888	1.8303	0.0979	0.6399	3.2210	1.1191	1.0661		
PWF	0.0005	0.0303	0.0076	0.0004	0.0092	0.0006	0.0015	0.0263	0.0191	0.0022		

continued

TABLE 7.1.1. WOODSTOVE TESTING DATA SUMMARY (Continued)

	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9 Rep 3	Run 10 Dup 2	Aver2R10	%Diff R2R10
RTI Run Number	50403	50411	50417	50424	50501	50508	50515	50522	50605	50612		
Initial Sample Volume (ml)												
CWX	6.5	14.0	7.0	14.0	30.0	7.0	14.0	36.0	30.0	30.0		
PWF	7.0	14.0	7.0	14.0	7.0	7.0	7.0	25.0	20.0	25.0		
Total Reversions in Samples												
BUM												
CWX	57179	0	22112	264135	83163	697868	133829	620138	87722	174464		
PWF	6376	21081	1751	15945	24119	308540	7247	17202	5681	3509		
Total	63555	21081	23863	280081	107282	1006408	141077	627340	93403	177973		
BUP												
CWX	142949	87930	99506	1132009	665303	619767	554436	813517	0	218080		
PWF	24753	126488	14005	33915	68337	179207	202920	240826	102251	80715		
Total	167702	214418	113511	1165924	733641	798974	757356	1054344	102251	298795		
Emissions (g/m^3 STP Wet Basis)												
CO_2	110.94	61.68	51.22	109.60	71.33	105.03	83.61	75.34	75.44	78.05	69.87	-23.4%
CO	8.51	8.61	8.41	8.51	10.49	2.12	6.70	12.04	9.89	11.05	9.83	-24.8%
O_2	172.01	211.78	213.84	172.27	201.29	193.94	185.77	215.61	185.40	209.63	210.70	1.0%
H_2O	80.93	47.43	72.43	89.02	53.53	66.35	114.94	92.64	131.14	96.74	72.08	-68.4%
C_1-C_7 Hydrocarbons		4.60	4.13	1.00	2.62	0.20	2.33	4.50	4.31	5.52	5.06	-18.2%
Particulate	0.321	0.517	0.498	0.165	0.375	0.115	0.242	0.416	0.626	0.478	0.498	7.8%
Grav	0.521	1.712	1.440	0.484	2.834	0.060	1.033	2.790	2.237	2.448	2.080	-35.4%
TCO	0.124	0.376	0.429	0.164	0.688	0.031	0.394	0.934	0.617	0.698	0.537	-60.1%
Total EO	0.645	2.088	1.869	0.648	3.521	0.090	1.427	3.724	2.854	3.146	2.627	-40.5%
PAH Analysis												
GC/MS Total	0.005	0.005		0.041	0.016	0.011	0.049	0.017	0.012	0.000	0.003	176.7%

continued

TABLE 7.1.1. WOODSTOVE TESTING DATA SUMMARY (Continued)

RTI Run Number	Run 1 50403	Run 2 50411	Run 3 50417	Run 4 50424	Run 5 50501	Run 6 50508	Run 7 50515	Run 8 50522	Run 9 Rep 3 50605	Run 10 Dup 2 50612	Aver2R10	%Diff R2R10
Emissions (kreversions/m^3 STP Wet Basis)												
BUM												
CWX	55.0	0.0	32.8	88.6	31.1	217.4	82.2	175.5	47.6	114.0	57.0	-200.0%
PWF	6.1	7.7	2.6	5.3	9.0	96.1	4.4	4.9	3.1	2.3	5.0	108.0%
Total	61.2	7.7	35.4	94.0	40.1	313.5	86.6	180.5	50.6	116.3	62.0	-175.2%
BUP												
CWX	137.5	32.0	147.7	379.8	248.7	193.0	340.4	234.0	0.0	142.5	87.3	-126.6%
PWF	23.8	46.1	20.8	11.4	25.5	55.8	124.6	69.3	55.4	52.8	49.4	-13.5%
Total	161.4	78.1	168.5	391.2	274.2	248.9	465.0	303.3	55.4	195.3	136.7	-85.7%
Emissions (g/hr)												
CO_2	10109	1844	2875	5829	3430	8394	5678	1919	2070	1436	1640	24.9%
CO	776	258	472	453	504	170	455	307	271	203	230	23.5%
O_2	15674	6332	12003	9162	9678	15499	12615	5491	5088	3858	5095	48.6%
H_2O	7374	1418	4066	4734	2574	5303	7805	2359	3599	1780	1599	-22.6%
C_1-C7 Hydrocarbons		138	232	53	126	16	158	115	118	102	120	30.0%
Particulate	29.3	15.5	28.0	8.8	18.0	9.2	16.4	10.6	17.2	8.8	12.1	54.9%
Grav	47.4	51.2	80.8	25.7	136.3	4.8	70.2	71.1	61.4	45.1	48.1	12.7%
TCO	11.3	11.2	24.1	8.7	33.1	2.5	26.7	23.8	16.9	12.8	12.0	-13.4%
Total TEO	58.8	62.4	104.9	34.5	169.3	7.2	96.9	94.9	78.3	57.9	60.2	7.5%
PAH Analysis												
GC/MS Total	0.5	0.1	0.0	2.2	0.8	0.9	3.3	0.	0.3	0.0	0.1	185.3%

continued

TABLE 7.1.1. WOODSTOVE TESTING DATA SUMMARY (Continued)

RTI Run Number	Run 1 50403	Run 2 50411	Run 3 50417	Run 4 50424	Run 5 50501	Run 6 50508	Run 7 50515	Run 8 50522	Run 9 Rep 3 50605	Run 10 Dup 2 50612	Aver2R10	%Diff R2R10
Emissions (Mreversions/hr)												
BUM												
CWX	5.01	0.00	1.84	4.71	1.49	17.37	5.58	4.47	1.30	2.10	1.0	-200.0%
PWF	0.56	0.23	0.15	0.28	0.43	7.68	0.30	0.13	0.08	0.04	0.1	137.9%
Total	5.57	0.23	1.99	5.00	1.93	25.05	5.88	4.60	1.39	2.14	1.2	-161.3%
BUP												
CWX	12.53	0.96	8.29	20.20	11.96	15.43	23.11	5.96	0.00	2.62	1.8	-93.0%
PWF	2.17	1.38	1.17	0.61	1.23	4.46	8.46	1.76	1.52	0.97	1.2	34.6%
Total	14.70	2.34	9.46	20.80	13.18	19.89	31.57	7.73	1.52	3.59	3.0	-42.5%
Emissions (g/kg Wet Wood)												
CO_2	1404	1474	815	853	1831	1582	821	886	931	1159	1316	23.9%
CO	108	206	134	66	269	32	66	142	122	164	185	22.6%
O_2	2177	5060	3401	1341	5167	2921	1824	2535	2288	3112	4086	47.7%
H_2O	1024	1133	1152	693	1374	999	1129	1089	1618	1436	1285	-23.6%
C_1-C_7 Hydrocarbons		109.9	65.6	7.8	67.2	3.0	22.9	53.0	53.2	82.0	95.9	29.1%
Particulate	4.1	12.4	7.9	1.3	9.6	1.7	2.4	4.9	7.7	7.1	9.7	54.0%
Grav	6.6	40.9	22.9	3.8	72.7	0.9	10.1	32.8	27.6	36.3	38.6	11.8%
TCO	1.6	9.0	6.8	1.3	17.6	0.5	3.9	11.0	7.6	10.4	9.7	-14.3%
Total EO	8.2	49.9	29.7	5.0	90.4	1.4	14.0	43.8	35.2	46.7	48.3	6.6%
PAH Analysis												
GC/MS Total	0.06	0.12	0.00	0.32	0.42	0.17	0.48	0.20	0.14	0.00	0.1	185.2%
Emissions (Mreversions/kg Wet Wood)												
CWX	0.70	0.00	0.52	0.69	0.80	3.27	0.81	2.06	0.59	1.69	0.8	-200.0%
PWF	0.08	0.18	0.04	0.04	0.23	1.45	0.04	0.06	0.04	0.03	0.1	137.4%
Total	0.77	0.18	0.56	0.73	1.03	4.72	0.85	2.12	0.62	1.73	1.0	-161.6%

continued

TABLE 7.1.1. WOODSTOVE TESTING DATA SUMMARY (Continued)

RTI Run Number	Run 1 50403	Run 2 50411	Run 3 50417	Run 4 50424	Run 5 50501	Run 6 50508	Run 7 50515	Run 8 50522	Run 9 Rep 3 50605	Run 10 Dup 2 50612	Aver2R10	%Diff R2R10
BUP												
CWX	1.74	0.77	2.35	2.96	6.38	2.91	3.34	2.75	0.00	2.12	1.4	-93.8%
PWF	0.30	1.10	0.33	0.09	0.66	0.84	1.22	0.81	0.68	0.78	0.9	33.7%
Total	2.04	1.87	2.68	3.04	7.04	3.75	4.57	3.57	0.68	2.90	2.4	-43.3%
Emissions (g/kg Dry Wood)												
CO_2	1727	1813	1251	1310	2157	1863	1200	1295	1430	1425	1619	23.9%
CO	133	253	206	102	317	38	96	207	187	202	227	22.6%
O_2	2678	6224	5224	2059	6086	3441	2667	3706	3514	3828	5026	47.7%
H_2O	1260	1394	1770	1064	1618	1177	1650	1593	2486	1766	1580	-23.6%
C_1-C_7		135	101	12	79	4	33	77	82	101	118	29.1%
Particulate	5.0	15.2	12.2	2.0	11.3	2.0	3.5	7.2	11.9	8.7	12.0	54.0%
Grav	8.1	50.3	35.2	5.8	85.7	1.1	14.8	48.0	42.4	44.7	47.5	11.8%
TCO	1.9	11.0	10.5	2.0	20.8	0.5	5.7	16.1	11.7	12.7	11.9	-14.3%
Total EO	10.0	61.4	45.7	7.7	106.5	1.6	20.5	64.0	54.1	57.5	59.4	6.6%
PAH Analysis												
GC/MS Total	0.08	0.15	0.00	0.49	0.49	0.20	0.70	0.29	0.22	0.01	0.1	185.2%
Emissions (Mreversions/kg Dry Wood)												
BUM												
CWX	0.86	0.00	0.80	1.06	0.94	3.86	1.18	3.02	0.90	2.08	1.0	-200.0%
PWF	0.10	0.23	0.06	0.06	0.27	1.70	0.06	0.09	0.06	0.04	0.1	137.4%
Total	0.95	0.23	0.87	1.12	1.21	5.56	1.24	3.10	0.96	2.12	1.2	-161.6%
BUP												
CWX	2.14	0.94	3.61	4.54	7.52	3.42	4.89	4.02	0.00	2.60	1.8	-93.8%
PWF	0.37	1.35	0.51	0.14	0.77	0.99	1.79	1.19	1.05	0.96	1.2	33.7%
Total	2.51	2.30	4.12	4.68	8.29	4.42	6.67	5.21	1.05	3.57	2.9	-43.3%

For TA98, BUM = -S9, BUP = +S9
CWX = XAD-2 Extract
PWF = Filter Extract

TABLE 7.1.2. RESULTS OF PAH SPOT TESTS ON ORIGINAL CONCENTRATED SAMPLES

	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8	RUN 9 REP 3	RUN 10 DUP 2	AVER2R10	%DIFF R2R10
RTI RUN NUMBER	50403	50411	50417	50424	50501	50508	50515	50522	50605	50612		
PAH SPOT TEST												
CWX (mg)	26	56	28	560	1200	280	560	144	12	12		
PWF (mg)	1	140	7	14	700	7	70	25	200	250		
TOTAL SPOT PAH (mg)	27	196	35	574	1900	287	630	169	212	262		
PAH SPOT TEST (g/m^3)												
CWX	0.0250	0.0204	0.0416	0.1879	0.4485	0.0872	0.3438	0.0414	0.0065	0.0078	0.0141	88.9%
PWF	0.0010	0.0510	0.0104	0.0047	0.2617	0.0022	0.0430	0.0072	0.1084	0.1634	0.1072	-104.9%
TOTAL SPOT PAH	0.0260	0.0714	0.0519	0.1926	0.7102	0.0894	0.3868	0.0486	0.1149	0.1712	0.1213	-82.3%
PAH SPOT TEST (g/hr)												
CWX	2.2795	0.6099	2.3326	9.9920	21.5664	6.9698	23.3468	1.0551	0.1785	0.1443	0.3771	123.5%
PWF	0.0877	1.5247	0.5831	0.2498	12.5804	0.1742	2.9184	0.1832	2.9751	3.0069	2.2658	-65.4%
TOTAL SPOT PAH	2.3672	2.1346	2.9157	10.2418	34.1468	7.1440	26.2652	1.2382	3.1536	3.1513	2.6429	-38.5%
PAH SPOT TEST (g/kg WOOD)												
CWX	0.3166	0.4874	0.6609	1.4622	11.5133	1.3136	3.3758	0.4871	0.0803	0.1164	0.3019	122.9%
PWF	0.0122	1.2185	0.1652	0.0366	6.7161	0.0328	0.4220	0.0846	1.3379	2.4256	1.8220	-66.3%
TOTAL SPOT PAH	0.3288	1.7059	0.8261	1.4987	18.2294	1.3465	3.7977	0.5717	1.4181	2.5420	2.1239	-39.4%

TABLE 7.1.3. RADIAN CAPILLARY GC/MS ANALYSES RESULTS FOR EACH WOODSTOVE TEST (TOTAL µg COLLECTED DURING MM5)

	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8	RUN 9 REP 3	RUN 10 DUP 2	AVER2R10	%DIFF R2R10
RTI RUN NUMBER	50403	50411	50417	50424	50501	50508	50515	50522	50605	50612		
PHENOL	0	0		89	0	0	0	0	0	0		
NAPHTHALENE	3852	9767		84356	26352	23780	50243	38341	17526	472		
ACENAPHTHYLENE	304	492		8753	4868	2054	8663	6873	764	0		
ACENAPHTHENE	0	156		624	563	100	810	0	210	0		
FLUORENE	94	770		2541	2603	631	2816	3023	919	0		
NITRONAPHTHALENE	0	0		0	0	0	0	0	0	0		
PHENANTHRENE	640	1400		11555	5176	4418	8370	7382	1506	0		
ANTHRACENE	70	310		1883	1103	495	1628	1336	310	0		
ACRIDINE	0	0		0	0	0	0	0	0	0		
CARBAZOLE	0	0		18	0	0	0	0	0	0		
FLUORANTHENE	123	275		3942	1045	1670	2800	1082	177	0		
PHENANTHROL	0	0		0	0	0	0	0	0	0		
PYRENE	90	290		3671	887	1301	2214	955	188	0		
BENZO(a)ANTHRACENE	0	59		750	263	261	509	0	0	0		
CHRYSENE	66	99		982	274	325	748	0	0	0		
BENZO(b)FLUORANTHENE	0	22		1076	0	427	725	0	0	0		
BENZO(k)FLUORANTHENE	0	0		179	178	0	0	0	0	0		
BENZO(a)PYRENE	0	12		610	82	167	378	0	0	0		
3-METHYLCHOLANTHRENE	0	0		0	0	0	0	0	0	0		
BENZO(g,h,i)PERYLENE	0	0		273	0	0	0	0	0	0		
DIBENZO(a,h)ANTHRACENE	0	0		0	0	0	0	0	0	0		
INDENO(1,2,3cd)PYRENE	0	0		346	0	59	0	0	0	0		
TOTAL GCMSPAH (ug)	5239	13854		121649	43394	35687	79905	58991	21600	472		

TABLE 7.1.4. PAH CONCENTRATIONS (mg/m^3) FROM EACH WOODSTOVE TEST

	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8	RUN 9 REP 3	RUN 10 DUP 2	AVER2R10	%DIFF R2R10
RTI RUN NUMBER	50403	50411	50417	50424	50501	50508	50515	50522	50605	50612		
PHENOL	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
NAPHTHALENE	3.71	3.56	0.00	28.30	9.85	7.41	30.85	11.03	9.50	0.31	1.9	168.1%
ACENAPHTHYLENE	0.29	0.18	0.00	2.94	1.82	0.64	5.32	1.98	0.41	0.00	0.1	200.0%
ACENAPHTHENE	0.00	0.06	0.00	0.21	0.21	0.03	0.50	0.00	0.11	0.00	.0	200.0%
FLUORENE	0.09	0.28	0.00	0.85	0.97	0.20	1.73	0.87	0.50	0.00	0.1	200.0%
NITRONAPHTHALENE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
PHENANTHRENE	0.62	0.51	0.00	3.88	1.93	1.38	5.14	2.12	0.82	0.00	0.3	200.0%
ANTHRACENE	0.07	0.11	0.00	0.63	0.41	0.15	1.00	0.38	0.17	0.00	0.1	200.0%
ACRIDINE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
CARBAZOLE	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
FLUORANTHENE	0.12	0.10	0.00	1.32	0.39	0.52	1.72	0.31	0.10	0.00	0.1	200.0%
PHENANTHROL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
PYRENE	0.09	0.11	0.00	1.23	0.33	0.41	1.36	0.27	0.10	0.00	0.1	200.0%
BENZO(a)ANTHRACENE	0.00	0.02	0.00	0.25	0.10	0.08	0.31	0.00	0.00	0.00	.0	200.0%
CHRYSENE	0.06	0.04	0.00	0.33	0.10	0.10	0.46	0.00	0.00	0.00	.0	200.0%
BENZO(b)FLUORANTHENE	0.00	0.01	0.00	0.36	0.00	0.13	0.45	0.00	0.00	0.00	.0	200.0%
BENZO(k)FLUORANTHENE	0.00	0.00	0.00	0.06	0.07	0.00	0.00	0.00	0.00	0.00	0.0	
BENZO(a)PYRENE	0.00	.00	0.00	0.20	0.03	0.05	0.23	0.00	0.00	0.00	.0	200.0%
3-METHYLCHOLANTHRENE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
BENZO(g,h,i)PERYLENE	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
DIBENZO(a,h)ANTHRACENE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
INDENO(1,2,3cd)PYRENE	0.00	0.00	0.00	0.12	0.00	0.02	0.00	0.00	0.00	0.00	0.0	
TOTAL	5.04	4.97	0.00	40.81	16.22	11.12	49.06	16.97	11.71	0.31	2.6	176.7%

TABLE 7.1.5. PAH EMISSION RATES (mg/hr) FROM EACH WOODSTOVE TEST

	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8	RUN 9 REP 3	RUN 10 DUP 2	AVER2R10	%DIFF R2R10
RTI RUN NUMBER	50403	50411	50417	50424	50501	50508	50515	50522	50605	50612		
PHENOL	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
NAPHTHALENE	337.7	106.4	0.0	1505.2	473.6	591.9	2094.7	280.9	260.7	5.7	56.0	179.7%
ACENAPHTHYLENE	26.6	5.4	0.0	156.2	87.5	51.1	361.2	50.4	11.4	0.0	2.7	200.0%
ACENAPHTHENE	0.0	1.7	0.0	11.1	10.1	2.5	33.8	0.0	3.1	0.0	0.9	200.0%
FLUORENE	8.3	8.4	0.0	45.3	46.8	15.7	117.4	22.1	13.7	0.0	4.2	200.0%
NITRONAPHTHALENE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
PHENANTHRENE	56.1	15.2	0.0	206.2	93.0	110.0	349.0	54.1	22.4	0.0	7.6	200.0%
ANTHRACENE	6.1	3.4	0.0	33.6	19.8	12.3	67.9	9.8	4.6	0.0	1.7	200.0%
ACRIDINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
CARBAZOLE	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
FLUORANTHENE	10.8	3.0	0.0	70.3	18.8	41.6	116.7	7.9	2.6	0.0	1.5	200.0%
PHENANTHROL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
PYRENE	7.9	3.2	0.0	65.5	15.9	32.4	92.3	7.0	2.8	0.0	1.6	200.0%
BENZO(a)ANTHRACENE	0.0	0.6	0.0	13.4	4.7	6.5	21.2	0.0	0.0	0.0	0.3	200.0%
CHRYSENE	5.8	1.1	0.0	17.5	4.9	8.1	31.2	0.0	0.0	0.0	0.5	200.0%
BENZO(b)FLUORANTHENE	0.0	0.2	0.0	19.2	0.0	10.6	30.2	0.0	0.0	0.0	0.1	200.0%
BENZO(k)FLUORANTHENE	0.0	0.0	0.0	3.2	3.2	0.0	0.0	0.0	0.0	0.0	0.0	
BENZO(a)PYRENE	0.0	0.1	0.0	10.9	1.5	4.1	15.8	0.0	0.0	0.0	0.1	200.0%
3-METHYLCHOLANTHRENE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
BENZO(g,h,i)PERYLENE	0.0	0.0	0.0	4.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
DIBENZO(a,h)ANTHRACENE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
INDENO(1,2,3cd)PYRENE	0.0	0.0	0.0	6.2	0.0	1.5	0.0	0.0	0.0	0.0	0.0	
TOTAL	459.3	148.7	0.0	2170.6	779.9	888.3	3331.3	432.2	321.3	5.7	77.2	185.3%

TABLE 7.1.6. PAH EMISSION FACTORS (mg/kg wet wood) FROM EACH WOODSTOVE TEST

	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8	RUN 9 REP 3	RUN 10 DUP 2	AVER2R10	%DIFF R2R10
RTI RUN NUMBER	50403	50411	50417	50424	50501	50508	50515	50522	50605	50612		
PHENOL	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
NAPHTHALENE	46.91	85.00	0.00	220.25	252.83	111.57	302.87	129.70	117.24	4.58	44.8	179.6%
ACENAPHTHYLENE	3.70	4.28	0.00	22.85	46.71	9.63	52.22	23.25	5.11	0.00	2.1	200.0%
ACENAPHTHENE	0.00	1.36	0.00	1.63	5.40	0.47	4.88	0.00	1.41	0.00	0.7	200.0%
FLUORENE	1.15	6.70	0.00	6.64	24.97	2.96	16.97	10.22	6.15	0.00	3.4	200.0%
NITRONAPHTHALENE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
PHENANTHRENE	7.79	12.18	0.00	30.17	49.66	20.73	50.46	24.97	10.07	0.00	6.1	200.0%
ANTHRACENE	0.85	2.70	0.00	4.92	10.58	2.32	9.81	4.52	2.07	0.00	1.3	200.0%
ACRIDINE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
CARBAZOLE	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
FLUORANTHENE	1.50	2.40	0.00	10.29	10.03	7.83	16.88	3.66	1.18	0.00	1.2	200.0%
PHENANTHROL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
PYRENE	1.10	2.52	0.00	9.58	8.51	6.10	13.35	3.23	1.26	0.00	1.3	200.0%
BENZO(a)ANTHRACENE	0.00	0.52	0.00	1.96	2.53	1.22	3.07	0.00	0.00	0.00	0.3	200.0%
CHRYSENE	0.80	0.86	0.00	2.57	2.63	1.53	4.51	0.00	0.00	0.00	0.4	200.0%
BENZO(b)FLUORANTHENE	0.00	0.19	0.00	2.81	0.00	2.01	4.37	0.00	0.00	0.00	0.1	200.0%
BENZO(k)FLUORANTHENE	0.00	0.00	0.00	0.47	1.71	0.00	0.00	0.00	0.00	0.00	0.0	
BENZO(a)PYRENE	0.00	0.11	0.00	1.59	0.79	0.78	2.28	0.00	0.00	0.00	0.1	200.0%
3-METHYLCHOLANTHRENE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
BENZO(g,h,1)PERYLENE	0.00	0.00	0.00	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
DIBENZO(a,h)ANTHRACENE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
INDENO(1,2,3cd)PYRENE	0.00	0.00	0.00	0.90	0.00	0.27	0.00	0.00	0.00	0.00	0.0	
TOTAL	63.79	118.83	0.00	317.63	416.34	167.43	481.68	199.55	144.49	4.58	61.7	185.2%

TABLE 7.1.7. PAH EMISSION FACTORS (mg/kg dry wood) FOR EACH WOODSTOVE TEST

	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8	RUN 9 REP 3	RUN 10 DUP 2	AVER2R10	%DIFF R2R10
RTI RUN NUMBER	50403	50411	50417	50424	50501	50508	50515	50522	50605	50612		
PHENOL	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
NAPHTHALENE	8.01	83.55	0.00	49.51	158.98	24.77	64.02	87.54	80.98	4.54	44.0	179.4%
ACENAPHTHYLENE	0.63	4.21	0.00	5.14	29.37	2.14	11.04	15.69	3.53	0.00	2.1	200.0%
ACENAPHTHENE	0.00	1.34	0.00	0.37	3.40	0.10	1.03	0.00	0.97	0.00	0.7	200.0%
FLUORENE	0.20	6.59	0.00	1.49	15.70	0.66	3.59	6.90	4.25	0.00	3.3	200.0%
NITRONAPHTHALENE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
PHENANTHRENE	1.33	11.98	0.00	6.78	31.23	4.60	10.67	16.85	6.96	0.00	6.0	200.0%
ANTHRACENE	0.15	2.65	0.00	1.11	6.65	0.52	2.07	3.05	1.43	0.00	1.3	200.0%
ACRIDINE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
CARBAZOLE	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
FLUORANTHENE	0.26	2.36	0.00	2.31	6.30	1.74	3.57	2.47	0.82	0.00	1.2	200.0%
PHENANTHROL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
PYRENE	0.19	2.48	0.00	2.15	5.35	1.35	2.82	2.18	0.87	0.00	1.2	200.0%
BENZO(a)ANTHRACENE	0.00	0.51	0.00	0.44	1.59	0.27	0.65	0.00	0.00	0.00	0.3	200.0%
CHRYSENE	0.14	0.85	0.00	0.58	1.65	0.34	0.95	0.00	0.00	0.00	0.4	200.0%
BENZO(b)FLUORANTHENE	0.00	0.19	0.00	0.63	0.00	0.45	0.92	0.00	0.00	0.00	0.1	200.0%
BENZO(k)FLUORANTHENE	0.00	0.00	0.00	0.11	1.08	0.00	0.00	0.00	0.00	0.00	0.0	
BENZO(a)PYRENE	0.00	0.11	0.00	0.36	0.50	0.17	0.48	0.00	0.00	0.00	0.1	200.0%
3-METHYLCHOLANTHRENE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
BENZO(g,h,i)PERYLENE	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
DIBENZO(a,h)ANTHRACENE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
INDENO(1,2,3cd)PYRENE	0.00	0.00	0.00	0.20	0.00	0.06	0.00	0.00	0.00	0.00	0.0	
TOTAL	10.90	116.81	0.00	71.40	261.80	37.17	101.82	134.69	99.81	4.54	60.7	185.0%

TABLE 7.1.8. ACUREX ICAP ELEMENTAL ANALYSES RESULTS OF CARBON FREE ASH FROM EACH WOODSTOVE TEST (WT% CARBON FREE)

	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8	RUN 9 REP 3	RUN 10 DUP 2	AVER2R10	%DIFF R2R10
RTI RUN NUMBER	50403	50411	50417	50424	50501	50508	50515	50522	50605	50612		
% CARBON FREE ASH	61.66	86.14	89.57	89.25	11.82	18.22	33	9.56	72	89.58	87.86	-3.9%
Ag SILVER	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	
Al ALUMINUM	0.219	0.000	0.157	0.182	0.454	0.294	0.190	0.183	0.000	0.182	0.09	-200.0%
As ARSENIC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	
Ba BARIUM	0.269	0.252	0.192	0.173	0.189	0.249	0.071	0.119	0.189	0.261	0.26	-3.6%
Ca CALCIUM	30.003	29.255	30.591	27.451	12.098	11.361	10.394	11.088	30.556	29.471	29.36	-0.7%
Cd CADMIUM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	
Co COBALT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	
Cr CHROMIUM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	
Cu COPPER	0.000	0.000	0.000	0.000	0.020	0.000	0.000	0.000	0.000	0.000	0.00	
Fe IRON	0.075	0.052	0.078	0.019	0.217	0.111	0.043	0.058	0.074	0.110	0.08	-71.4%
Hg MERCURY	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	
K POTASSIUM	7.298	7.534	8.909	7.664	7.310	6.696	5.788	6.423	11.167	6.731	7.13	11.3%
Li LITHIUM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	
Mg MAGNESIUM	1.930	1.753	1.262	1.434	3.959	3.782	2.533	3.410	1.597	1.998	1.88	-13.1%
Mn MANGANESE	0.840	0.772	0.891	0.961	2.428	2.810	1.630	1.810	1.190	0.816	0.79	-5.5%
Na SODIUM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	
Ni NICKEL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	
P PHOSPHOROUS	0.946	0.925	0.482	0.337	0.458	0.428	0.524	0.484	0.439	1.039	0.98	-11.6%
Pb LEAD	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	
S SULFUR	0.000	0.000	0.000	0.000	0.063	0.000	0.000	0.000	0.000	0.000	0.00	
Sb ANTIMONY	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	
Se SELENIUM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	
Sn TIN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	
Sr STRONTIUM	0.326	0.337	0.151	0.165	0.102	0.108	0.044	0.063	0.165	0.328	0.33	2.5%
Ti TITANIUM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	
Tl THALLIUM	0.000	0.000	0.000	0.000	0.000	0.000	0.062	0.000	0.000	0.000	0.00	
V VANADIUM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	
Zn ZINC	0.039	0.000	0.000	0.000	0.144	0.104	0.093	0.109	0.047	0.000	0.00	
Fe/K RATIO	0.010	0.007	0.000	0.003	0.030	0.017	0.007	0.009	0.007	0.016	0.01	-81.0%

TABLE 7.1.9. ELEMENTAL ICAP ANALYSES RESULTS OF PARTICULATE ON MM5 FROM EACH WOODSTOVE FILTERS TEST (TOTAL µg DURING MM5)

RTI RUN NUMBER	RUN 1 50403	RUN 2 50411	RUN 3 50417	RUN 4 50424	RUN 5 50501	RUN 6 50508	RUN 7 50515	RUN 8 50522	RUN 9 REP 3 50605	RUN 10 DUP 2 50612	AVER2R10	%DIFF R2R10
Ag SILVER	8.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Al ALUMINUM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
As ARSENIC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Ba BARIUM	0.0	0.0	10.3	13.0	12.6	0.0	0.0	15.3	7.3	0.0		
Ca CALCIUM	0.0	0.0	0.0	0.0	608.4	0.0	0.0	0.0	0.0	0.0		
Cd CADMIUM	0.0	0.0	0.0	31.8	0.0	7.5	6.4	8.8	8.7	0.0		
Co COBALT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Cr CHROMIUM	0.0	0.0	0.0	0.0	0.0	7.1	0.0	0.0	0.0	0.0		
Cu COPPER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Fe IRON	23.9	14.2	13.1	0.0	0.0	63.1	26.4	27.7	351.2	0.0		
Hg MERCURY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
K POTASSIUM	2610.0	2460.0	1180.0	13884.0	0.0	1910.0	2246.0	1320.0	2642.0	2190.0		
Li LITHIUM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Mg MAGNESIUM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Mn MANGANESE	6.1	5.1	0.0	36.6	45.1	108.0	36.7	53.4	7.3	3.9		
Na SODIUM	0.0	0.0	1060.0	0.0	3181.6	0.0	3505.0	0.0	0.0	0.0		
Ni NICKEL	15.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
P PHOSPHOROUS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Pb LEAD	0.0	0.0	0.0	286.0	0.0	0.0	0.0	0.0	0.0	0.0		
S SULFUR	805.0	849.0	0.0	5654.0	0.0	801.0	1786.0	0.0	494.0	695.0		
Sb ANTIMONY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Se SELENIUM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Sn TIN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Sr STRONTIUM	0.0	0.0	0.0	2.4	4.3	0.0	0.0	1.5	0.0	0.0		
Ti TITANIUM	0.0	4.4	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Tl THALLIUM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
V VANADIUM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Zn ZINC	0.0	0.0	0.0	387.0	167.3	834.0	538.8	78.2	0.0	0.0		

TABLE 7.1.10. ELEMENTAL CONCENTRATIONS ($\mu g/m^3$) FROM MM5 FILTERS FROM EACH WOODSTOVE TEST

	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8	RUN 9	RUN 10	AVER2R10	%DIFF
									REP 3	DUP 2		R2R10
RTI RUN NUMBER	50403	50411	50417	50424	50501	50508	50515	50522	50605	50612		
Ag SILVER	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Al ALUMINUM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
As ARSENIC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Ba BARIUM	0.0	0.0	15.3	4.4	4.7	0.0	0.0	4.4	4.0	0.0	0.0	
Ca CALCIUM	0.0	0.0	0.0	0.0	227.4	0.0	0.0	0.0	0.0	0.0	0.0	
Cd CADMIUM	0.0	0.0	0.0	10.7	0.0	2.3	3.9	2.5	4.7	0.0	0.0	
Co COBALT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Cr CHROMIUM	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	
Cu COPPER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Fe IRON	23.0	5.2	19.4	0.0	0.0	19.7	16.2	8.0	190.4	0.0	2.6	200.0%
Hg MERCURY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
K POTASSIUM	2511.3	896.1	1751.3	4658.0	0.0	594.9	1378.9	379.7	1432.2	1431.3	1163.7	-46.0%
Li LITHIUM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Mg MAGNESIUM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Mn MANGANESE	5.9	1.9	0.0	12.3	16.9	33.6	22.5	15.4	4.0	2.5	2.2	-31.4%
Na SODIUM	0.0	0.0	1573.2	0.0	1189.2	0.0	2151.8	0.0	0.0	0.0	0.0	
Ni NICKEL	15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
P PHOSPHOROUS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Pb LEAD	0.0	0.0	0.0	96.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
S SULFUR	851.5	309.3	0.0	1896.9	0.0	274.4	1096.5	0.0	267.8	454.2	381.7	-38.0%
Sb ANTIMONY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Se SELENIUM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Sn TIN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Sr STRONTIUM	0.0	0.0	0.0	0.8	1.6	0.0	0.0	0.4	0.0	0.0	0.0	
Ti TITANIUM	0.0	1.6	6.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	200.0%
Tl THALLIUM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
V VANADIUM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Zn ZINC	0.0	0.0	0.0	129.8	62.5	259.8	330.8	22.5	0.0	0.0	0.0	

TABLE 7.1.11. ELEMENTAL EMISSION RATES (mg/hr) FROM EACH WOODSTOVE TEST

	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8	RUN 9 REP 3	RUN 10 DUP 2	AVER2R10	%DIFF R2R10
RTI RUN NUMBER	50403	50411	50417	50424	50501	50508	50515	50522	50605	50612		
Ag SILVER	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Al ALUMINUM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
As ARSENIC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Ba BARIUM	0.00	0.00	0.86	0.23	0.23	0.00	0.00	0.11	0.11	0.00	0.00	
Ca CALCIUM	0.00	0.00	0.00	0.00	10.93	0.00	0.00	0.00	0.00	0.00	0.00	
Cd CADMIUM	0.00	0.00	0.00	0.57	0.00	0.19	0.27	0.06	0.13	0.00	0.00	
Co COBALT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Cr CHROMIUM	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	
Cu COPPER	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Fe IRON	2.10	0.15	1.09	0.00	0.00	1.57	1.10	0.20	5.22	0.00	0.08	200.00%
Hg MERCURY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
K POTASSIUM	228.83	26.79	98.30	247.73	0.00	47.54	93.64	9.67	39.30	26.34	26.57	1.70%
Li LITHIUM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Mg MAGNESIUM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Mn MANGANESE	0.53	0.06	0.00	0.65	0.81	2.69	1.53	0.39	0.11	0.05	0.05	16.86%
Na SODIUM	0.00	0.00	88.30	0.00	57.18	0.00	146.13	0.00	0.00	0.00	0.00	
Ni NICKEL	1.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
P PHOSPHOROUS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Pb LEAD	0.00	0.00	0.00	5.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
S SULFUR	77.59	9.25	0.00	100.88	0.00	21.93	74.46	0.00	7.35	8.36	8.80	10.08%
Sb ANTIMONY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Se SELENIUM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Sn TIN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Sr STRONTIUM	0.00	0.00	0.00	0.04	0.08	0.00	0.00	0.01	0.00	0.00	0.00	
Ti TITANIUM	0.00	0.05	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	200.00%
Tl THALLIUM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
V VANADIUM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Zn ZINC	0.00	0.00	0.00	6.91	3.01	20.76	22.46	0.57	0.00	0.00	0.00	
Fe/K RATIO	0.009	0.006	0.011	0.000	0.000	0.033	0.012	0.021	0.133	0.000	0.00	

TABLE 7.1.12. ELEMENTAL EMISSION FACTORS (mg/kg **Wet** Wood) FROM EACH WOODSTOVE TEST

	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8	RUN 9 REP 3	RUN 10 DUP 2	AVER2R10	%DIFF R2R10
RTI RUN NUMBER	50403	50411	50417	50424	50501	50508	50515	50522	50605	50612		
Ag SILVER	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Al ALUMINUM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
As ARSENIC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Ba BARIUM	0.00	0.00	0.24	0.03	0.12	0.00	0.00	0.05	0.05	0.00	0.0	
Ca CALCIUM	0.00	0.00	0.00	0.00	5.84	0.00	0.00	0.00	0.00	0.00	0.0	
Cd CADMIUM	0.00	0.00	0.00	0.08	0.00	0.04	0.04	0.03	0.06	0.00	0.0	
Co COBALT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Cr CHROMIUM	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.0	
Cu COPPER	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Fe IRON	0.29	0.12	0.31	0.00	0.00	0.30	0.16	0.09	2.35	0.00	0.1	200.0%
Hg MERCURY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
K POTASSIUM	31.78	21.41	27.85	36.25	0.00	8.96	13.54	4.47	17.67	21.25	21.3	0.8%
Li LITHIUM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Mg MAGNESIUM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Mn MANGANESE	0.07	0.04	0.00	0.10	0.43	0.51	0.22	0.18	0.05	0.04	.0	15.9%
Na SODIUM	0.00	0.00	25.02	0.00	30.53	0.00	21.13	0.00	0.00	0.00	0.0	
Ni NICKEL	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
P PHOSPHOROUS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Pb LEAD	0.00	0.00	0.00	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
S SULFUR	10.78	7.39	0.00	14.76	0.00	4.13	10.77	0.00	3.30	6.74	7.1	9.1%
Sb ANTIMONY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Se SELENIUM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Sn TIN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Sr STRONTIUM	0.00	0.00	0.00	0.01	0.04	0.00	0.00	0.01	0.00	0.00	0.0	
Ti TITANIUM	0.00	0.04	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.0	200.0%
Tl THALLIUM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
V VANADIUM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Zn ZINC	0.00	0.00	0.00	1.01	1.60	3.91	3.25	0.26	0.00	0.00	0.0	
Fe/K RATIO	0.009	0.006	0.011	0.000	0.000	0.033	0.012	0.021	0.133	0.000	0.003	200.0%

TABLE 7.1.13. ELEMENTAL EMISSION FACTORS (mg/kg Dry Wood) FROM EACH WOODSTOVE TEST

	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8	RUN 9	RUN 10	AVER2R10	%DIFF
									REP 3	DUP 2		R2R10
RTI RUN NUMBER	50403	50411	50417	50424	50501	50508	50515	50522	50605	50612		
Ag SILVER	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Al ALUMINUM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
As ARSENIC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Ba BARIUM	0.00	0.00	0.11	0.01	0.08	0.00	0.00	0.03	0.03	0.00	0.0	
Ca CALCIUM	0.00	0.00	0.00	0.00	3.67	0.06	0.00	0.00	0.00	0.00	0.0	
Cd CADMIUM	0.00	0.00	0.00	0.02	0.00	0.01	0.01	0.02	0.04	0.00	0.0	
Co COBALT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Cr CHROMIUM	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.0	
Cu COPPER	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Fe IRON	0.05	0.12	0.13	0.00	0.00	0.07	0.03	0.06	1.62	0.00	0.1	200.0%
Hg MERCURY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
K POTASSIUM	5.43	21.05	12.12	8.15	0.00	1.99	2.86	3.01	12.21	21.08	21.1	-0.2%
Li LITHIUM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Mg MAGNESIUM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Mn MANGANESE	0.01	0.04	0.00	0.02	0.27	0.11	0.05	0.12	0.03	0.04	.0	15.0%
Na SODIUM	0.00	0.00	10.89	0.00	19.19	0.00	4.47	0.00	0.00	0.00	0.0	
Ni NICKEL	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
P PHOSPHOROUS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Pb LEAD	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
S SULFUR	1.84	7.26	0.00	3.32	0.00	0.92	2.28	0.00	2.28	6.69	7.0	8.2%
Sb ANTIMONY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Se SELENIUM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Sn TIN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Sr STRONTIUM	0.00	0.00	0.00	.00	0.03	0.00	0.00	.00	0.00	0.00	0.0	
Ti TITANIUM	0.00	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.0	200.0%
Tl THALLIUM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
V VANADIUM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Zn ZINC	0.00	0.00	0.00	0.23	1.01	0.87	0.69	0.18	0.00	0.00	0.0	

TABLE 7.1.14. ELEMENTAL ANALYSES OF WOOD USED (ELEMENT WT%)

WOOD ANALYSES	PINE UNCURED	PINE CURED	OAK CURED	OAK UNCURED	OAK CURED DUPLICATE DIGEST
ELEMENT	440C SAMPLE WT%	440D SAMPLE WT%	440E SAMPLE WT%	440F SAMPLE WT%	440E SAMPLE WT%
Ag SILVER					
Al ALUMINUM		0.006270	0.001910	0.013800	
As ARSENIC					
Ba BARIUM	0.000337	0.001060	0.006090	0.001980	0.007200
Ca CALCIUM	0.063800	0.057100	1.140000	0.301000	1.310000
Cd CADMIUM					
Co COBALT	0.007200	0.009240	0.003090	0.002140	0.008470
Cr CHROMIUM	0.000328	0.000353	0.000159	0.000234	0.000333
Cu COPPER		0.000114	0.000129	0.000185	0.000197
Fe IRON	0.011200	0.019100	0.004910	0.017000	0.007250
Hg MERCURY					
K POTASSIUM	0.033500	0.038900	0.061200	0.081900	0.102000
Li LITHIUM					
Mg MAGNESIUM	0.016300	0.019500	0.021400	0.016200	0.032800
Mn MANGANESE	0.008290	0.014000	0.016900	0.010100	0.019200
Na SODIUM					
Ni NICKEL	0.001680	0.001960	0.001010	0.001300	0.002270
P PHOSPHOROUS	0.002950	0.003160	0.015200	0.005950	0.014300
Pb LEAD	0.004820	0.019300		0.004400	0.020200
S SULFUR		0.009270	0.012300	0.011400	0.022100
Sb ANTIMONY					
Se SELENIUM					
Sn TIN					
Sr STRONTIUM	0.000249	0.000476	0.010600	0.001150	0.013600
Ti TITANIUM		0.000202	0.000308	0.000646	0.000365
Tl THALLIUM					
V VANADIUM					
Zn ZINC	0.001280	0.001290		0.000872	0.000404

sampling period for each test. Also, all emission factors, rates, and concentrations were calculated based on the volume of MM5 sampled. Thus biased results due to sampling interruptions were minimized as much as possible.

7.2 A SUMMARY STATISTICALLY SIGNIFICANT EFFECTS OF STOVE OPERATING PARAMETERS ON PERFORMANCE AND EMISSIONS

Table 7.2.1 is a summary of the statistically significant effects of the four stove operating parameters on measured emissions with the exception of PAH and elemental results, which are discussed in detail in the appropriate sections.

The burn rate had the greatest number of statistically significant effects on emissions listed in Table 7.2.1. Wood moisture content was second, followed by wood load and fuel type.

Lowering the inlet air flow produced lower burn rates, lower flue flows, and lower stove and stack temperatures. Figure 7.2.1 shows that the lower burn rate tests produced lower flue flows than higher burn rate tests. Looking at Table 7.2.1, we see the main effect of increasing the burn rate was increasing the flue flow 0.70 m^3/min STP, and this effect was significant at a 99% confidence interval (CI): Figures 7.2.2 and 7.2.3 show the increase in stove and stack temperatures, respectively, with corresponding increases in burn rates. The main effect on increasing burn rates on stove temperature was +143.8 °C and stack temperature +170.1 °C. Both of these effects were significant at 99% CI's with respect to burn rate. The "+" symbols on all graphs indicate the two duplicate tests.

Besides burn rate, wood moisture and wood load also significantly affected stack flow. A decrease in wood moisture increased stack flow at a 95% CI. This is probably because drier wood burns more readily. An increase in wood load also increased stack flow. This effect was significant at a 90% CI. Figure 7.2.4 shows the effect of wood load on stackflow. The effect of burn rate is also shown on this plot as the higher burn rates (circled) group above the lower burn rates (also circled) for stack flow. Figure 7.2.5 shows the effect of wood moisture on stack flow with the separate effects (circled) of burn rate clearly visible. The decrease of stack flow by increasing wood

TABLE 7.2.1 STATISTICALLY SIGNIFICANT RESULTS WITH A MEASURE OF THE MAIN EFFECT FROM EACH PARAMETER

Test Parameter	Burn Rate (kg/hr)		Wood Moisture %		Wood Load (kg)		Wood Type	
From To	1.88 → 6.56 kg/hr		33.2 → 16.9 %		8.3 → 14.0 kg		Pine → Oak	
	CI	ME	CI	ME	CI	ME	CI	ME
Burn Rate (kg/hr)	99%	+4.67						
Stack Flow (m^3/min)	99%	+0.70	95%	+0.29	90%	+0.22		
Stack Moisture %			95%	-5.17				
Stack Temperature, °C	99%	+170.1						
Stove Temperature, °C	99%	+143.8						
CO_2 (g/m^3)	95%	+29.30						
CO_2 (g/m^3)	95%	+5237.7		+2019.3				
CO_2 (g/kg)			95%	+660.6				
CO (g/m^3)		-4.10						
CO (g/hr)						+211.8		
CO (g/kg)	90%	-111.5						
Particulates (g/m^3)	95%	-0.27		-0.035		+0.039		+0.115
Particulates (g/hr)					90%	+10.06		
Particulates (g/kg)	99%	-5.63	90%	+2.22		+1.54		+1.04
Gravimetric (g/m^3)	99%	-1.96						-0.44
Gravimetric (g/hr)		-42.19				+41.49		
Gravimetric (g/kg)	95%	-37.6						
TCO (g/m^3)	99%	-0.52		-0.18				-0.15
TCO (g/hr)		-9.14				+10.26		
TCO (g/kg)	95%	-9.68						-9.25
Total Extractable Organics (AS TLO + Gravimetric)								
TEO (g/m^3)	99%	-2.48		-0.53				-0.59
TEO (g/hr)		-51.33				+51.65		
TEO (g/kg)	95%	-47.28						-41.95

continued

TABLE 7.2.1 STATISTICALLY SIGNIFICANT RESULTS WITH A MEASURE OF THE MAIN EFFECT FROM EACH PARAMETER (continued)

Test Parameter		Burn Rate (kg/hr)		Wood Moisture %		Wood Load (kg)		Wood Type	
From	To	1.88 → 6.56 kg/hr		33.2 → 16.9 %		8.3 → 14.0 kg		Pine → Oak	
		CI	ME	CI	ME	CI	ME	CI	ME
C_1-C_7 HC (g/m^3)		90%	-2.65						
C_1-C_7 HC (g/kg)		90%	-51.4						
O_2 (g/m^3)		95%	-22.26			90%	-12.01	90%	-14.06
O_2 (g/hr)		99%	+6899.4	95%	+3397.6	90%	+1951.7		
O_2 (g/kg)		95%	-1453.3	95%	+1590.8				
H_2O (g/m^3)				95%	-38.71				
H_2O (g/hr)		99%	+3377.2			95%	+1839.1		
H_2O (g/kg)		90%	-380.4				+269.7		

+, - = Indicates the direction of the main effect. Where no CI is given, the main effect is just below a 90% Confidence Interval.

CI = Confidence Level.

ME = Main Effect.

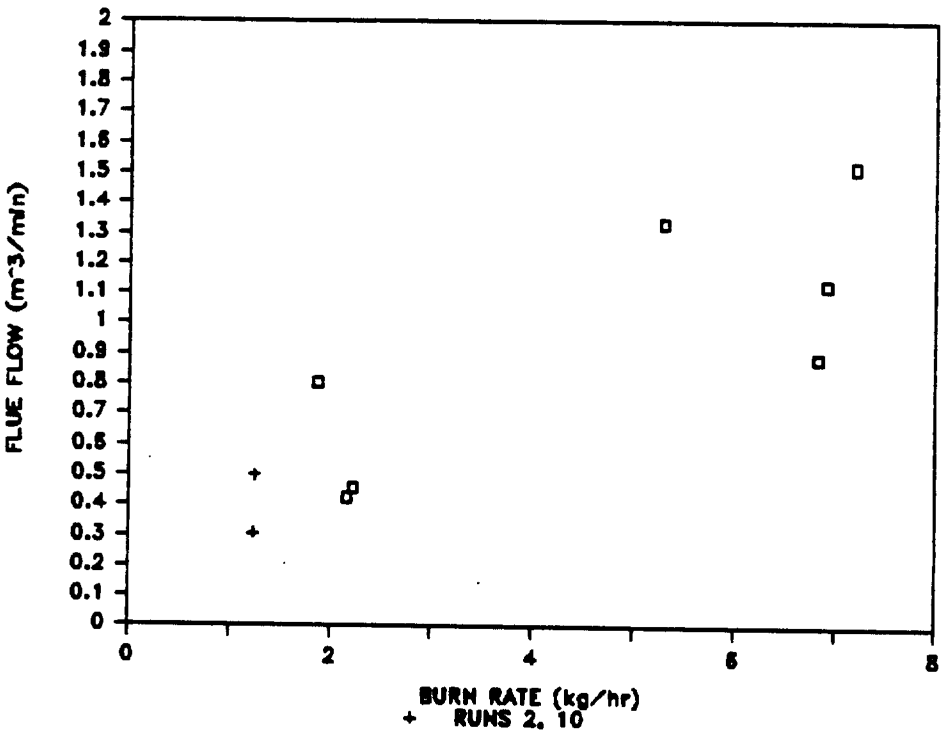

Figure 7.2.1. Flue flow (m^3/min) versus burn rate (kg/hr).

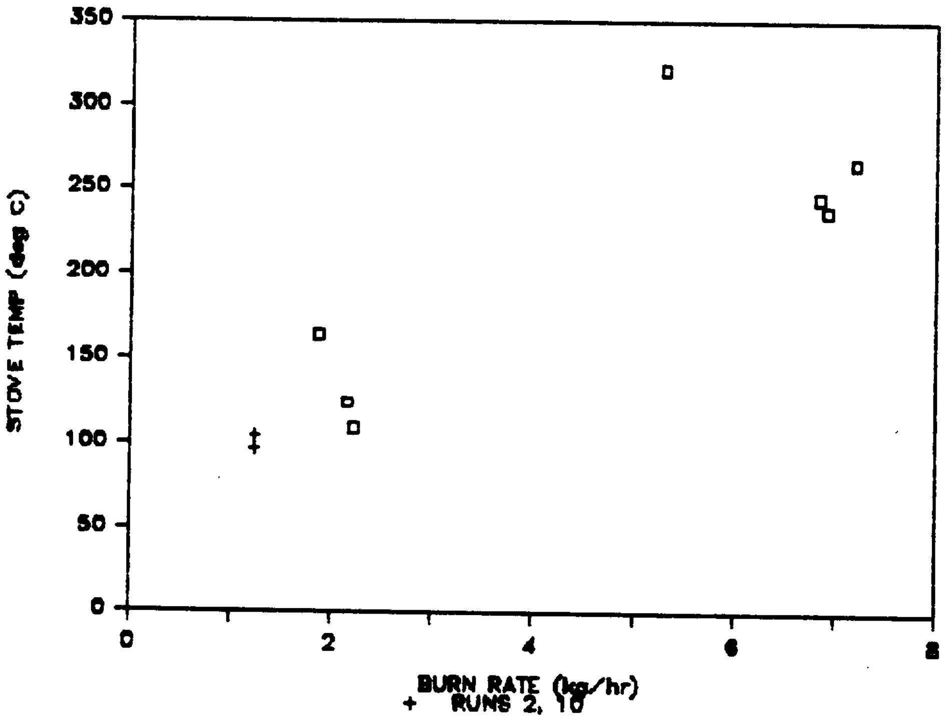

Figure 7.2.2. Stove temp (°C) versus burn rate (kg/hr).

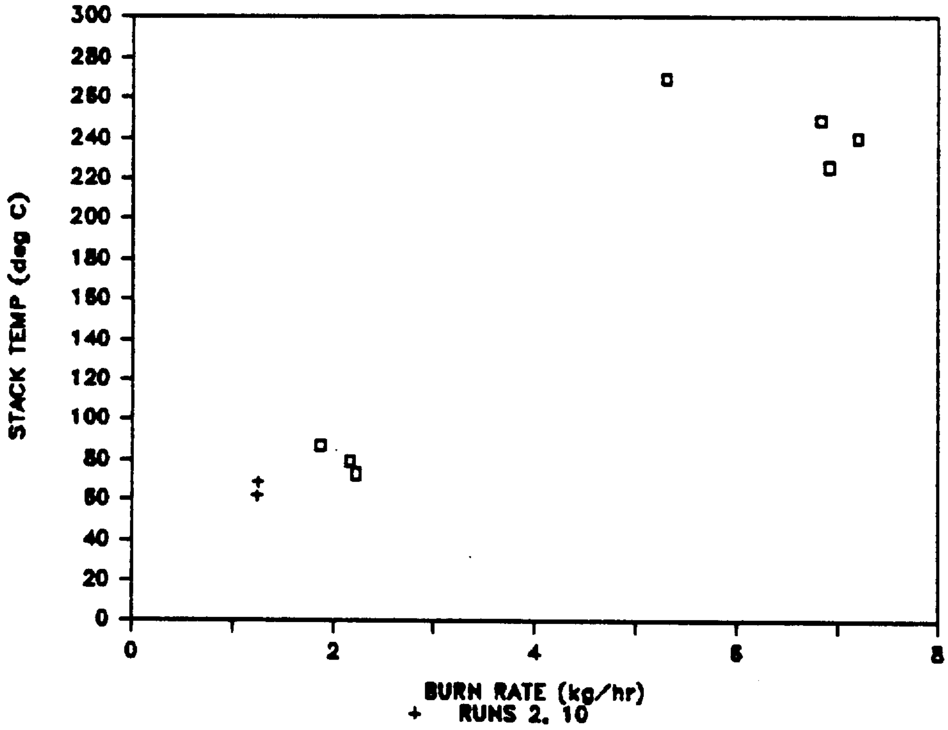

Figure 7.2.3. Stack temp (°C) versus burn rate (kg/hr).

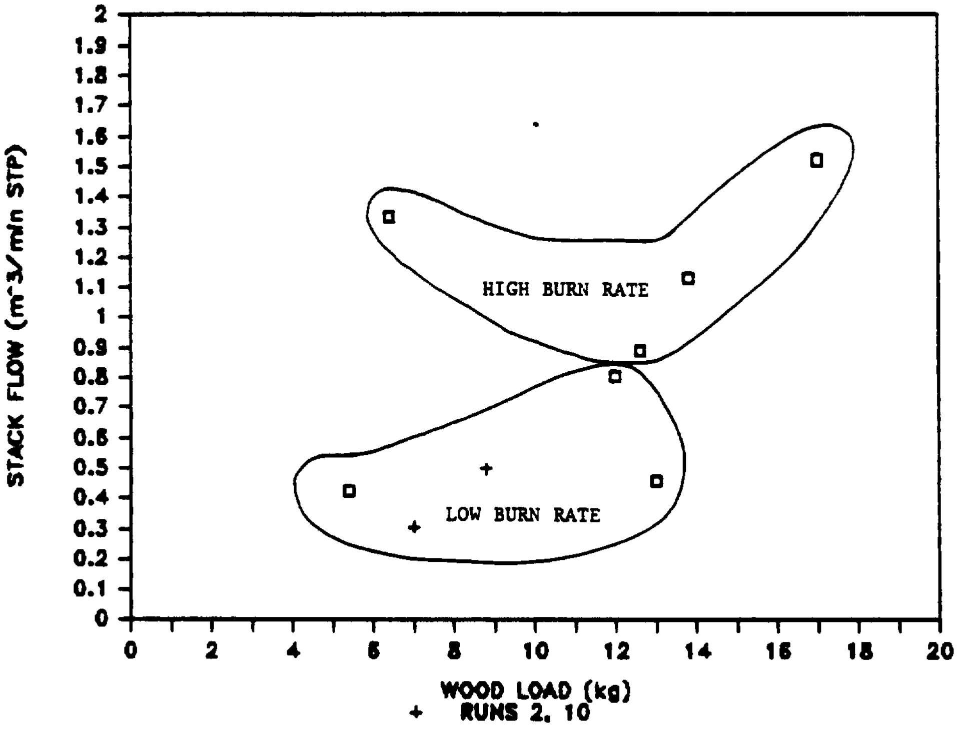

Figure 7.2.4. Stack flow (m^3/min STP) versus wood load (kg).

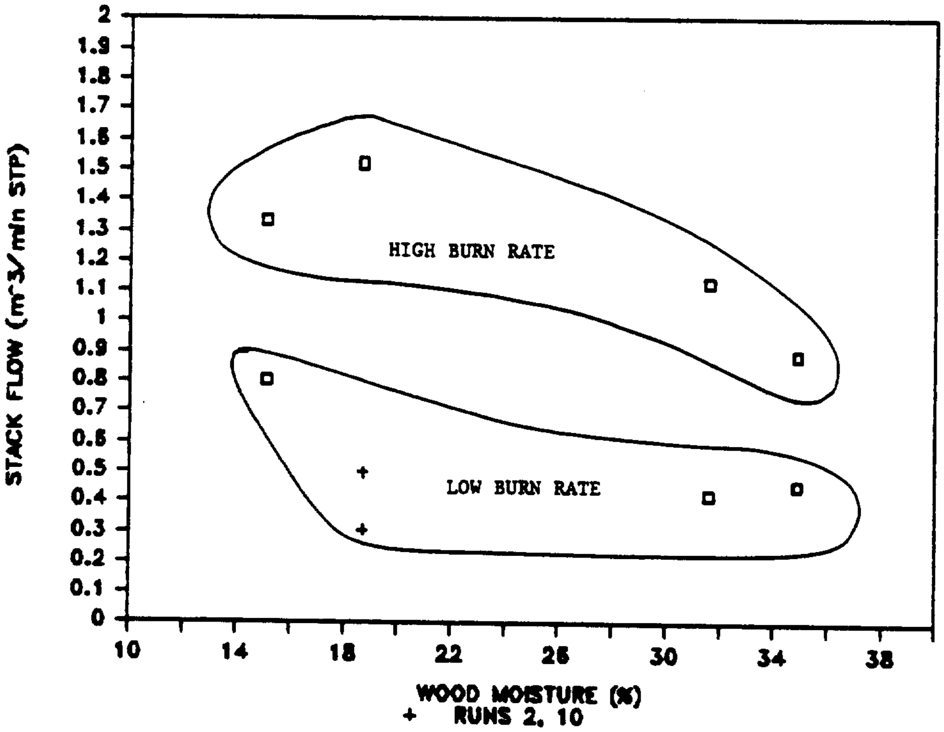

Figure 7.2.5. Stack flow (m^3/min STP) versus wood moisture (%).

moisture content appears to be more effective at the high burn rates. At a 99% confidence interval (CI), the burn rate when increased from an average of 1.88 to 6.56 kg/hr, decreased particulate matter emission factors, gravimetric (high b.p. >300° C organics) concentration, TCO (300 > b.p. > 100° C) concentration, and total extractable organics (TEO) concentration. TEO is the sum of gravimetric and TCO organics. Increased burn rate also increased O_2 emission rates at a 99% CI, due to higher stack flows, and H_2O emission rates. At a 95% CI, the increased burn rate decreased particulate concentration, gravimetric emission factors, TCO and TEO emission factors. Also, at a 95% CI, O_2 concentration and the O_2 emission factors were reduced due to better combustion efficiency. For the same reason, the CO_2 concentration and emission rate also increased at a 95% CI. Bioassay results which were affected at a 95% CI by increasing the burn rate included the following: with +S9 activation, the XAD extract mutation rate (Mrev/hr) increased, the combined XAD and filter extracts mutation rate (Mrev/hr) increased, and without +S9 activation the XAD extract mutation rate increased. At a 90% CI, the CO emission factor decreased as did the CO and TEO emission rates, and the H_2O emission factor. At less than 90% CI, CO concentration was reduced as were the TCO emission rates. The lowering of the CO emission factor and concentration suggest more complete combustion at higher burn rates. Lower organic concentrations, emission rates, and emission factors were observed with higher burn rates.

Wood moisture content exhibited the second most significant impact on emissions in Table 7.2.1. At a 95% CI, changing from a high moisture content to a low moisture content (averages 33.2% to 16.9% H_2O) increased the CO_2 emission factor, stack flow (m^3/min STP), O_2 emission factors and emission rates. Higher wood moisture perhaps dilutes the stack gases such as CO_2 and O_2. H_2O measured as g/m^3 and percent decreased at a 95% CI. Particulate matter emission factors increased at a 90% CI when moisture was reduced. Other effects from reducing wood moisture content included an increase in CO_2 emission rate, a decrease in particulate concentration, and a decrease in TCO and TEO concentration.

Wood load was the third most important operating parameter on the emission in Table 7.2.1. Increasing the initial wood load from an average of 8.3 to

14.0 kg increased the H_2O emission rates at a 95% CI. This probably occurs because increasing the initial load allows more wood to heat initially and more moisture is available to pass up the flue. Also at 95% CI, increasing the initial wood load decreased the XAD extract mutation concentration ($krev/m^3$) decreased the XAD extract mutation emission factor (Mrev/kg dry wood), and decreased the XAD + filter extract mutation concentration ($krev/m^3$), all without +S9 activation. At a 90% CI, increasing the wood load increased the particulate emission rates, O_2 emission rates and the stack flow (m^3/min STP). The O_2 concentration, however, was decreased, probably due to a dilution from the increase in H_2O emission rates. Other effects noted from increased wood load include increased CO emission rates, increased particulate concentration, increased particulate emission factor, increased gravimetric and TCO emission rates, and an increase in H_2O emission factor.

Wood type had the least noticeable effect on emissions listed in Table 7.2.1. However, when wood was changed from pine to oak there were some significant effects on mutagenicity tests at a 95% CI. With +S9 activation the mutation rate (Mrev/hr) of the XAD and filter extract decreased, as did the mutation emission factor (Mrev/kg wet wood). Without +S9 activation, the XAD extract mutation emission factor (Mrev/kg dry wood) decreased. The main effects found from burning oak than pine are all below the 90% significant CI except O_2 concentration, which decreased with a 90% CI. Increases occurred with particulate concentration and emission factors. Decreases occurred with gravimetric and TCO concentration and emission rates. TEO concentration also decreased.

7.3 PARTICULATE EMISSIONS

The particulate emission factors decreased with increased burn rates. This effect is significant at a 99% CI. Low burn rates correspond to low heat demands when the woodstove is operated under severe air restrictions. Tests of woodstoves indicate that emissions of particulates vary inversely with heat demand, such that nighttime emissions at low combustion rates may be worse than those during maximum heat demand conditions (12). Figure 7.3.1 shows the correspondence of low burn rate, high particulate emission factors compared to high burn rate, low particulate emissions factors. Wood moisture had the

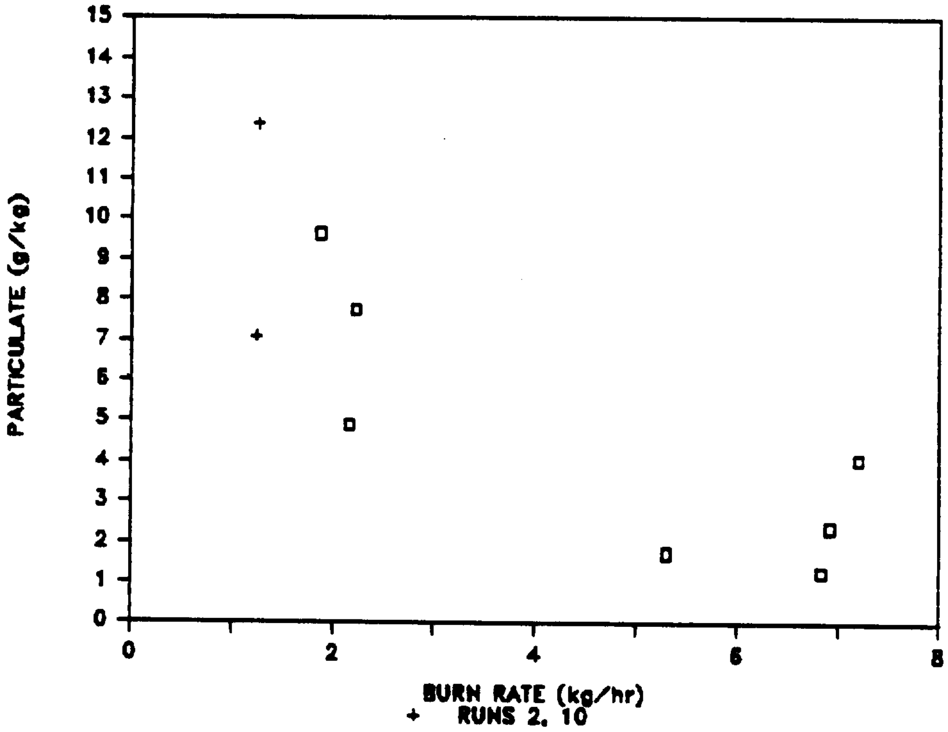

Figure 7.3.1. Particulate emissions (g/kg) versus burn rate (kg/hr).

effect at a 90% CI of lowering particulate emission factors from a low moisture to a high moisture content when combined with burn rate. The trends of burn rate and wood moisture content are shown in Figure 7.3.2.

Increased wood load had the effect of lowering particulate emission factors, however, this effect was not significant above a 90% CI. Figure 7.3.3 shows the effect of wood load with the trends circled of wood moisture. Note that high wood moistures are generally all lower in particulate emission factors than low wood moisture when shown with increasing wood loads.

Particulate emission rates were increased with increasing wood loads at a 90% CI. Wood load had the only statistically significant effect on particulate emission rates. This is explained from the relationship of burn rate to particulate emissions. As one raises the burn rate, less particulates are emitted (g/kg) as previously mentioned. Likewise, as one lowers the burn rate, particulate emissions (g/kg) are increased. At lower burn rates, when particulate emissions are high, less wood is consumed and at higher burn rates, (kg/hr), when the particulate emissions are lower, more wood is consumed. Thus, a cancellation may be occurring which leaves the amount of wood loaded as the only significant factor governing particulate emission rates (g/hr). Figure 7.3.4 shows the effects of increasing wood loads on particulate emissions in (g/hr).

Particulate concentration was also decreased at a 95% CI with an increase in burn rate. Other effects in PM concentration were seen, but were not statistically significant above 90% CI. As wood moisture decreased, particulate concentrations decreased. As wood load increased, particulate concentrations increased, and when pine instead of oak was burned, particulate concentrations increased. The magnitude of these effects are shown in Table 7.2.1.

7.4 TOTAL EXTRACTABLE ORGANIC (TEO) RESULTS

TEO is defined as the sum of the Gravimetric (> 300° C b.p) hydrocarbons and the Total Chromatographable Organics (TCO between 100° C and 300° C b.p).

At a 95% CI, the high boiling gravimetric organic emission factors decreased when the burn rate was increased. The main effect shows a

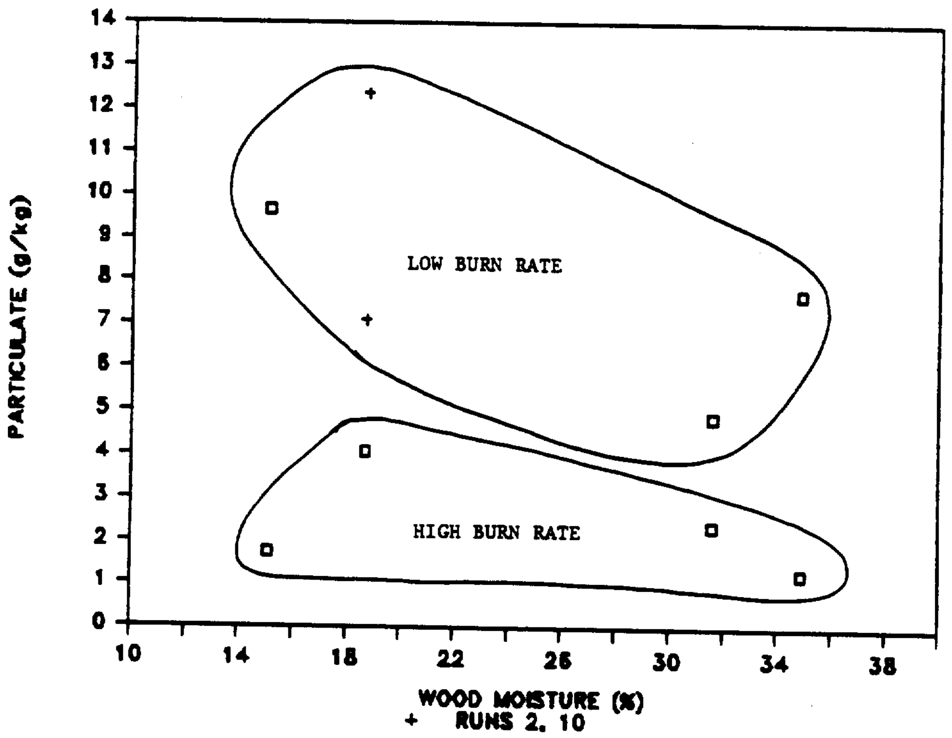

Figure 7.3.2. Particulate emission (g/kg) versus wood moisture (%).

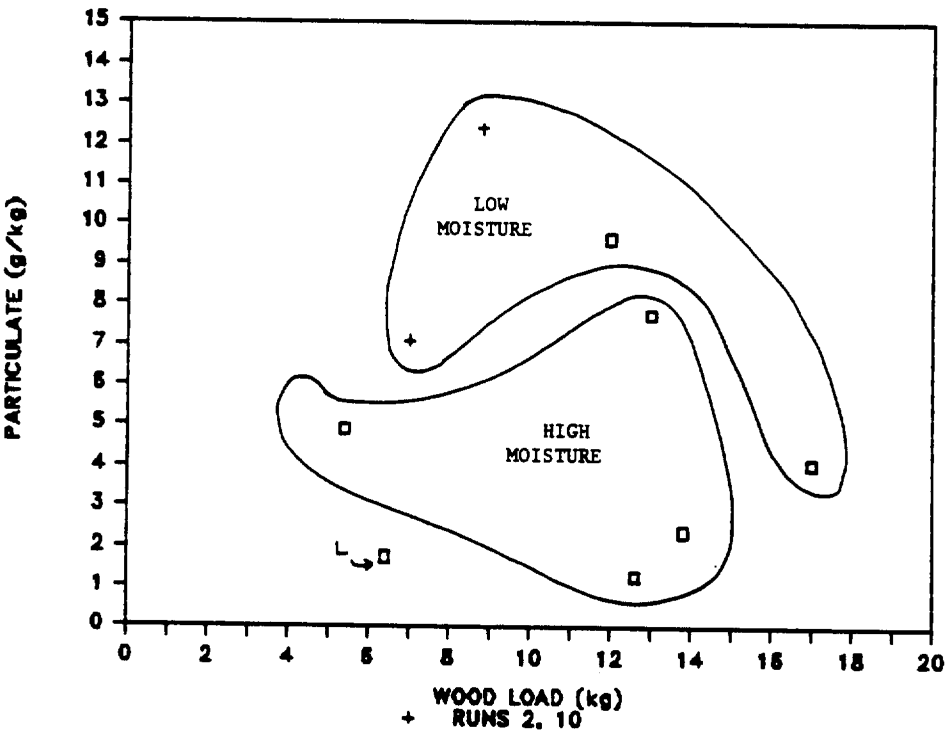

Figure 7.3.3. Particulate emissions (g/kg) versus wood load (kg).

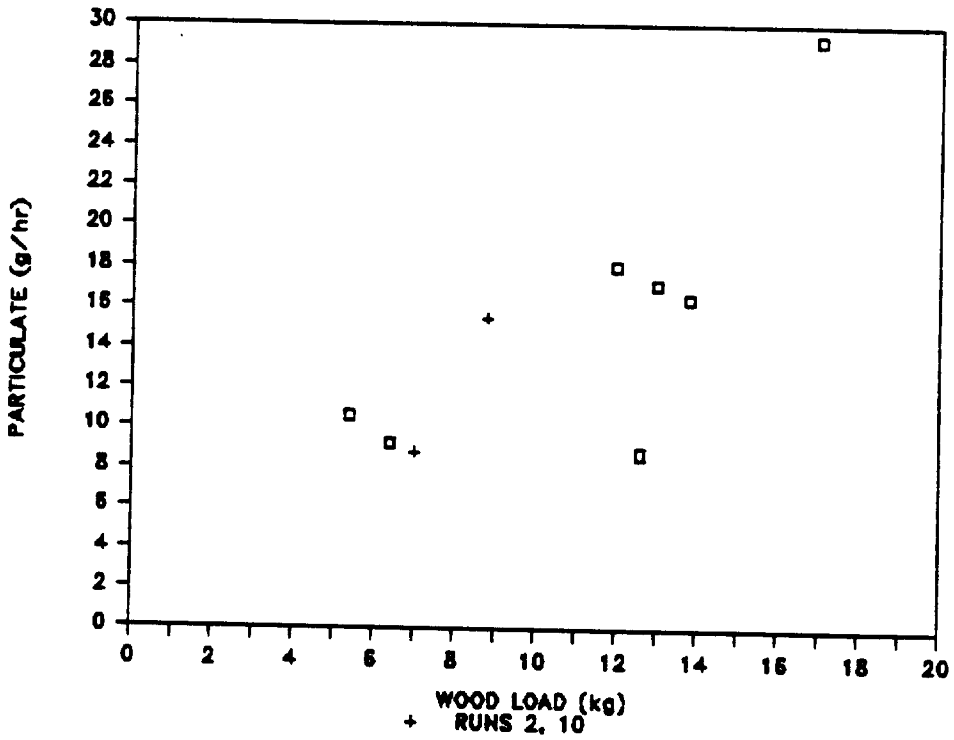

Figure 7.3.4. Particulate emission rates (g/hr) versus wood load (kg).

gravimetric decrease of 37.6 g/kg. Figure 7.4.1 illustrates this decrease. A higher burn rate also showed a decrease in the emission rates of gravimetric organics. Low wood loads showed a slight tendency to lower gravimetric emission rates as they seem lower on a graph of burn rate. This is shown in Figure 7.4.2. Gravimetric organics also decreased in concentration as the burn rate increased. This effect is significant at a 99% CI. The magnitude of this effect is a decrease of 1.96 g/m^3.

The TCO portion of the TEO displayed similar trends. The concentration decreased at a 99% CI with an increase in burn rate. Fuel type also had an effect, although the significance is statistically below the 90% CI. Figure 7.4.3 shows a slight increase in TCO concentration when pine is burned instead of oak. TCO emission factors decreased due to an increase in burn rate at a 95% CI. The net main effect is a decrease of 9.68 g/kg. Figure 7.4.4 shows the decrease of TCO emission factors as the burn rate increases.

Increasing wood load had the effect of raising TCO emission rates although the effect is below 90% significant CI. A slight trend is seen when TCO emissions are graphed with wood load. Pine tests (circled) tend to remain higher than oak tests (also circled) in TCO emission rates. Wood type did show a decreasing effect from pine to oak on TCO emission rates, however, it was below the 90% significant CI. Figure 7.4.5 shows this effect. Figure 7.4.6 shows a slight decrease in TCO emission rates with increasing burn rates although this effect was also below the 90% CI.

TEO's were most significantly affected by the burn rate. TEO concentrations significantly decreased with an increase of burn rate above a 99% CI. Other decreasing effects on the TEO concentration were decreasing moisture and burning oak instead of pine. These effects were below the 90% CI. The TEO emission rates were solely decreased by an increase in burn rate at a 90% CI. This is shown in Figure 7.4.7. Here, also, oak tests tend to group below pine tests for TEO emission rates. TEO emission factors were reduced with an increase in burn rate. This effect, significant at a 95% CI, is shown in Figure 7.4.8.

The most significant operating condition affecting TEO was the burn rate. As the burn rate increased the TEO concentration decreased (99% CI), the emission factor decreased (95% CI), and the emission rate decreased (90% CI).

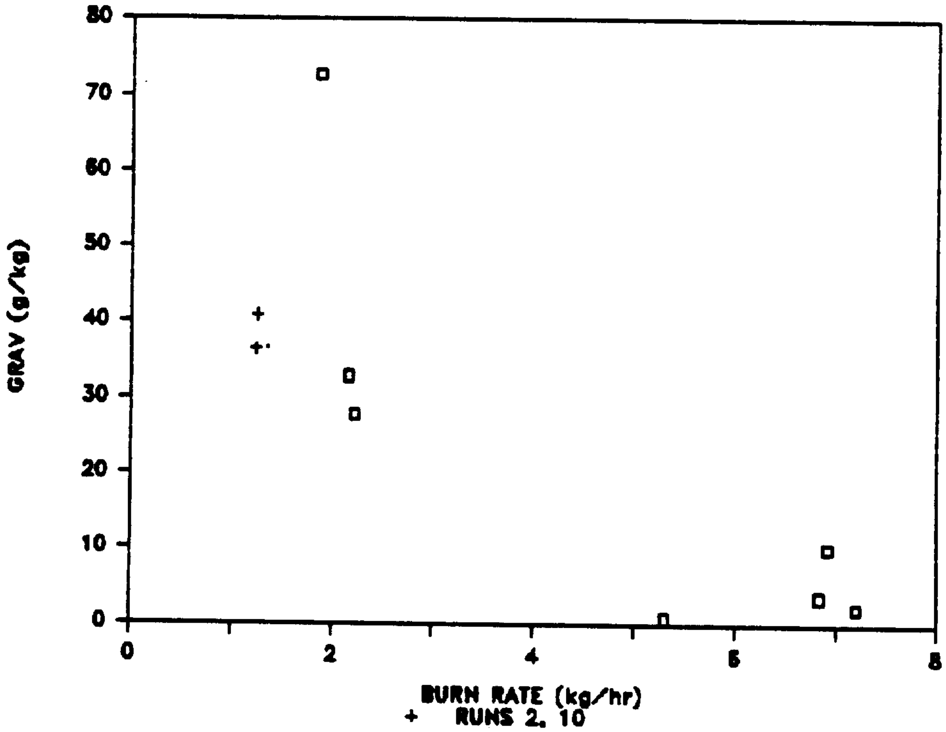

Figure 7.4.1. Grav (g/kg) versus burn rate (kg/hr).

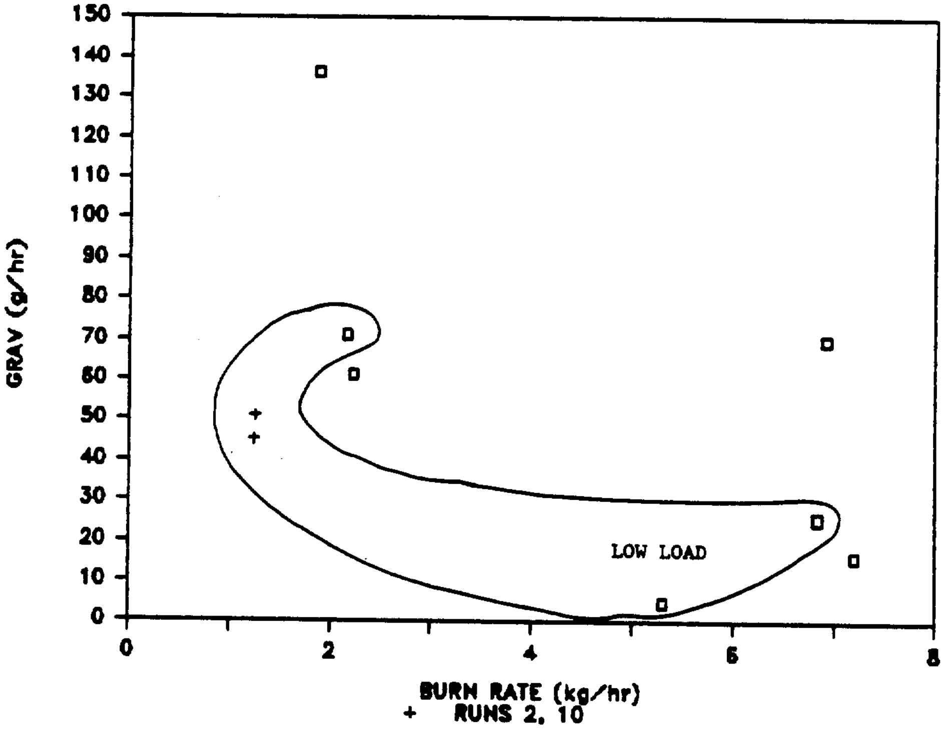

Figure 7.4.2. Grav (g/hr) versus burn rate (kg/hr).

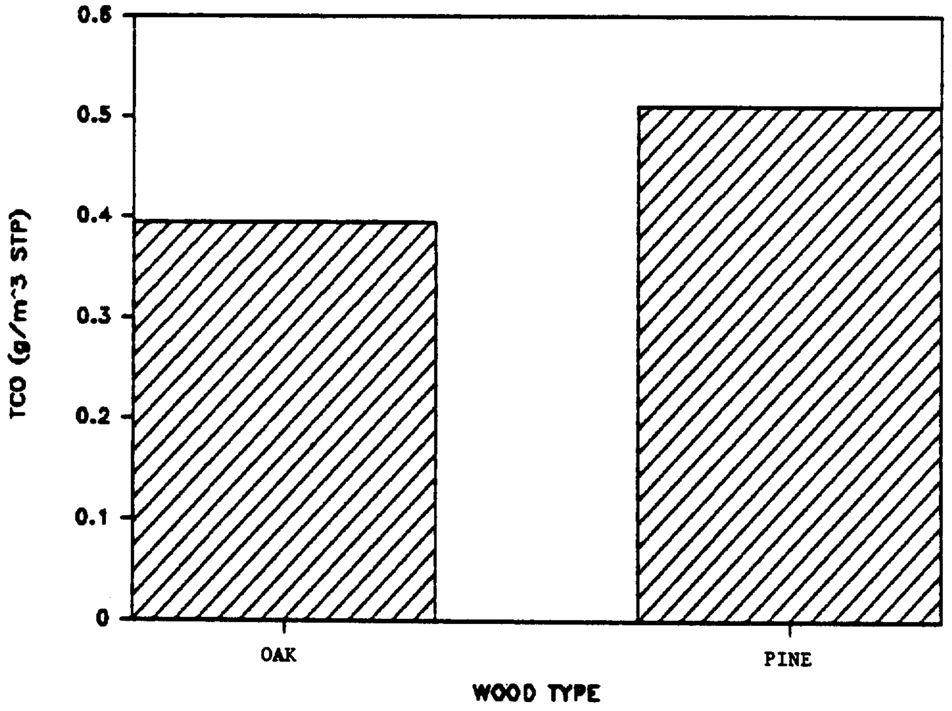

Figure 7.4.3. TCO (g/m^3 STP) versus wood type.

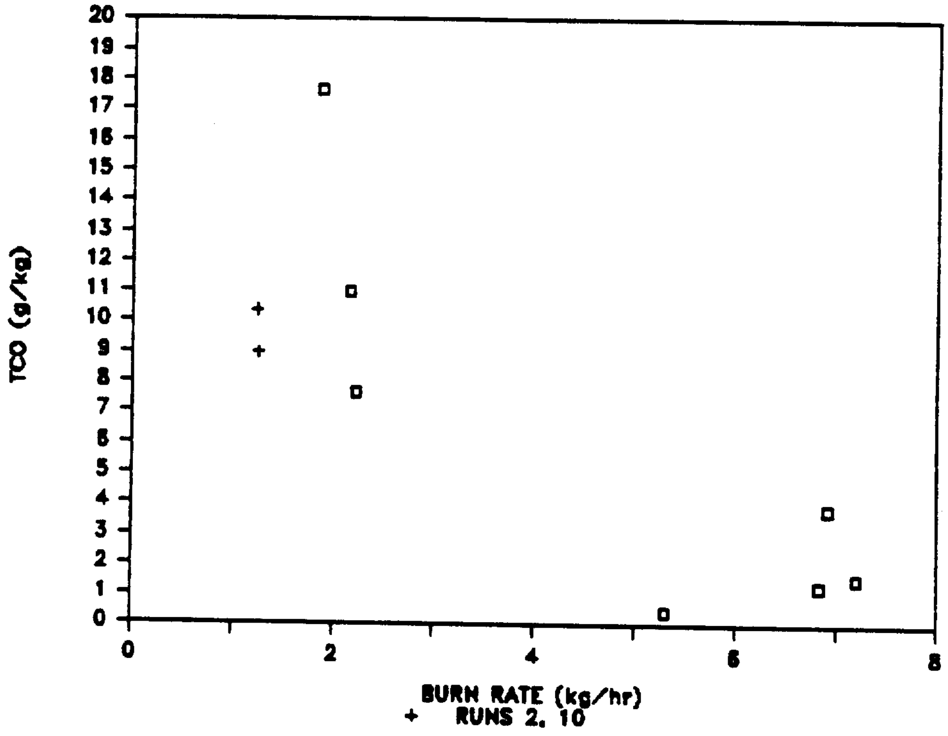

Figure 7.4.4. TCO (g/kg) versus burn rate (kg/hr).

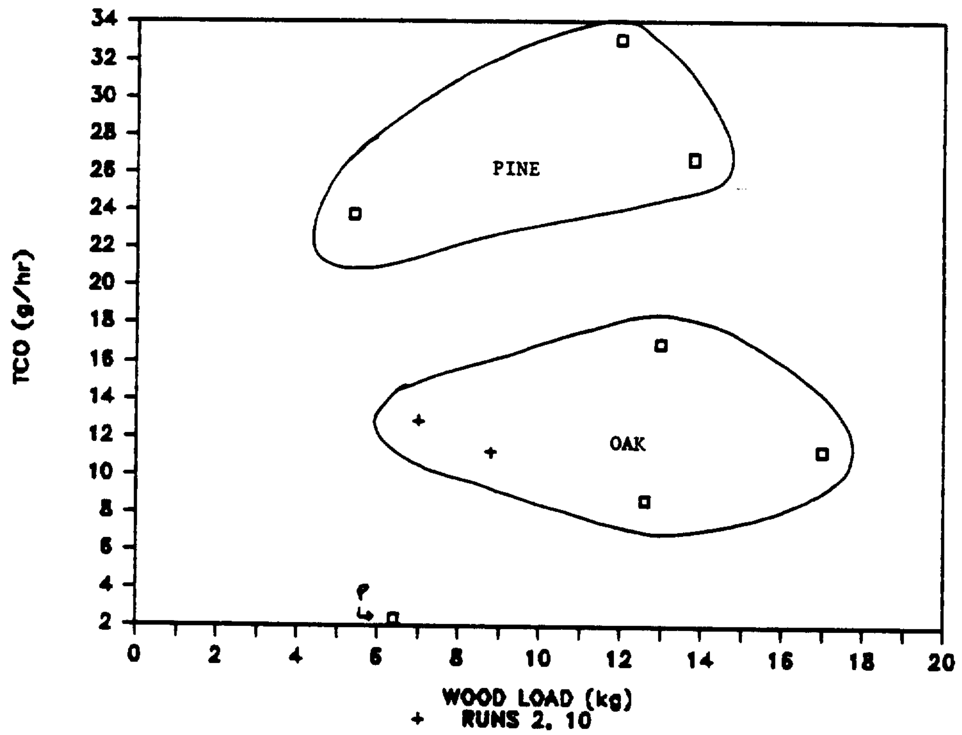

Figure 7.4.5. TCO (g/hr) versus wood load (kg).

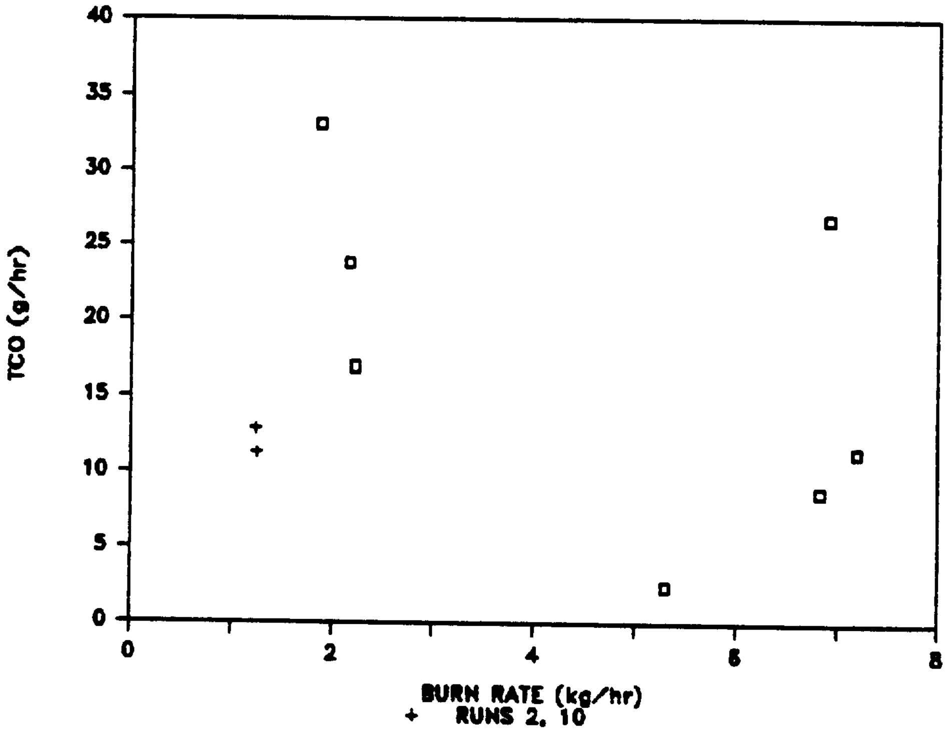

Figure 7.4.6. TCO (g/hr) versus burn rate (kg/hr).

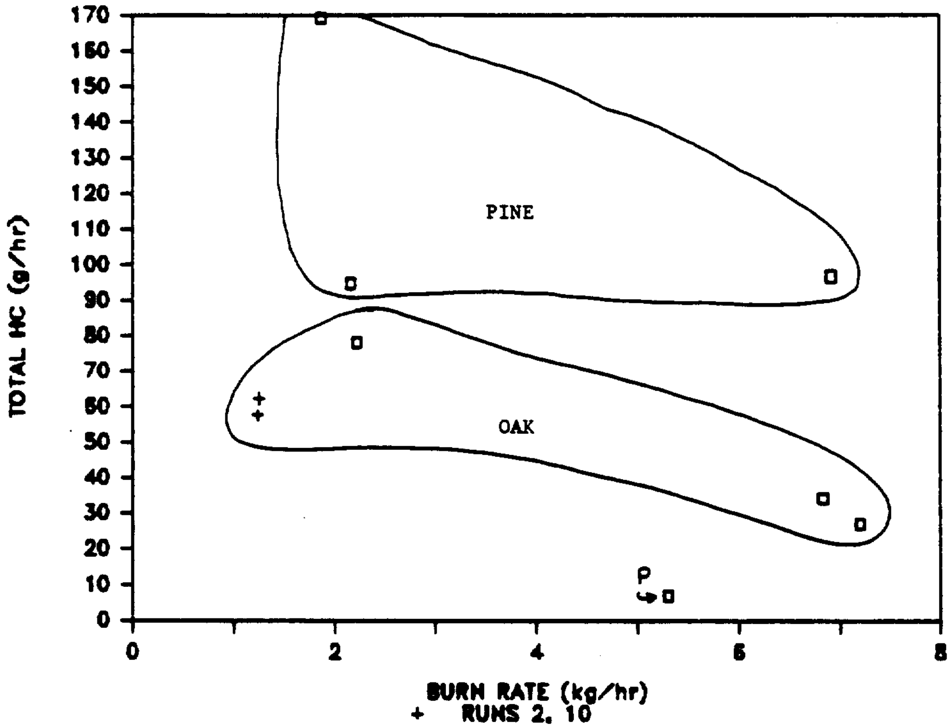

Figure 7.4.7. Total EO (g/hr) versus burn rate (kg/hr).

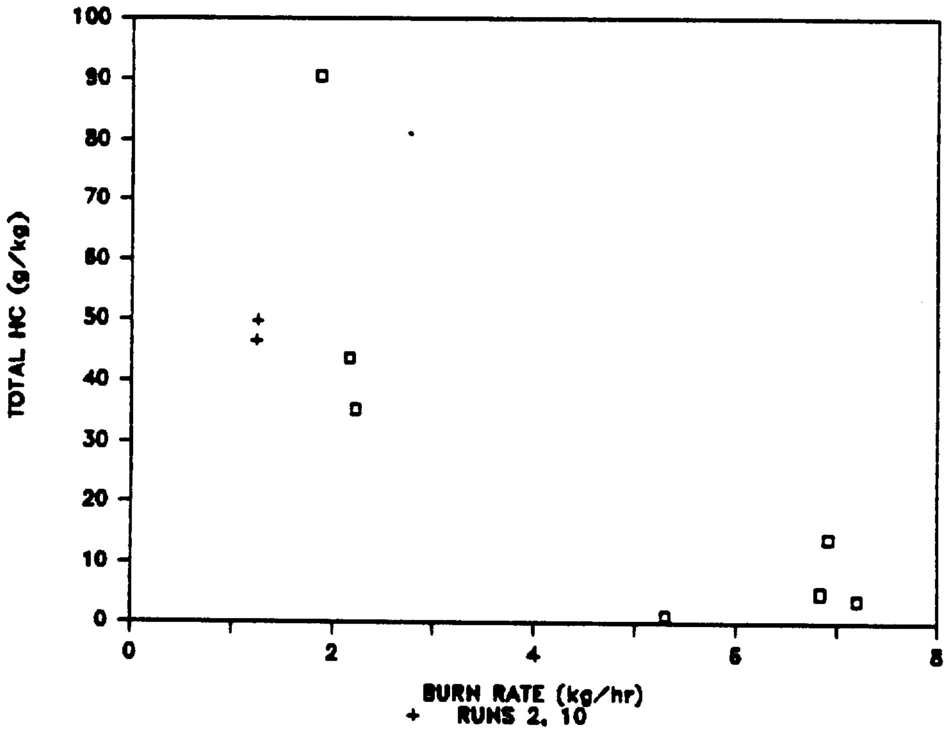

Figure 7.4.8. Total EO (g/kg) versus burn rate (kg/hr).

7.5 C_1-C_7 HYDROCARBONS

Light hydrocarbons C_1-C_7 emission factors were found to decrease with an increase in burn rate. The main effect was a decrease of 51.4 g/kg wood at a 90% CI. Figure 7.5.1 illustrates the effect of burn rate on C_1-C_7 emission factors. The concentration of C_1-C_7 hydrocarbons also decreased with an increase in burn rate. This effect, however, was below the 90% CI. Figure 7.5.2 shows the general decrease of C_1-C_7 concentration with increases in burn rate. The burn rate had the only statistically significant effect on C_1-C_7 emissions.

7.6 POLYCYCLIC AROMATIC HYDROCARBONS

The cleaned composite samples were analyzed by Radian Corporation for PAH compounds.

Table 7.6.1 lists specific PAH compounds from the Radian GC/MS PAH analyses, the main effects of the stove operating parameters, and, where applicable, the confidence interval associated with the main effect. Most of the main effects shown in Table 7.6.1 occur just below the 90% confidence interval.

The effects of increasing the burn rate are as follows. The naphthalene emission rate increases while the emission factor (mg/kg dry wood) decreases. The fluorene emission factor (mg/kg dry wood) also decreases. Phenanthrene and fluoranthene emission rates increase. Fluoranthene concentration also increases. Pyrene concentration and emission rate increase. Figure 7.6.1 shows the increase of pyrene emission rate (g/hr) as the burn rate increases. One data point on this curve occurs at a low level during a high emission rate. This point is probably due to a lower level of PAH present in the sample because the sample was dropped during preparation and only a small fraction was recovered for analyses. Otherwise, a definite trend in increasing pyrene emission rates with an increased burn rate is visible.

Chrysene concentration, emission rate and emission factor (g/kg dry wood) all also increased with an increase in burn rate. Figure 7.6.2 illustrates the increase in chrysene emission rate as the burn rate increases.

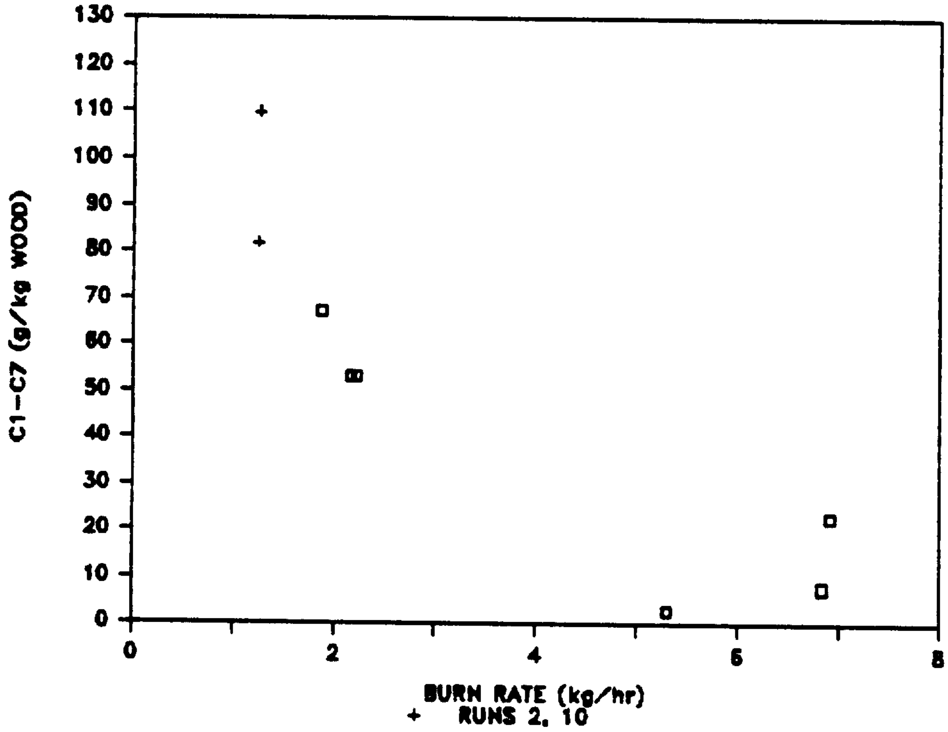

Figure 7.5.1. C_1-C_7(g/kg wood) versus burn rate (kg/hr).

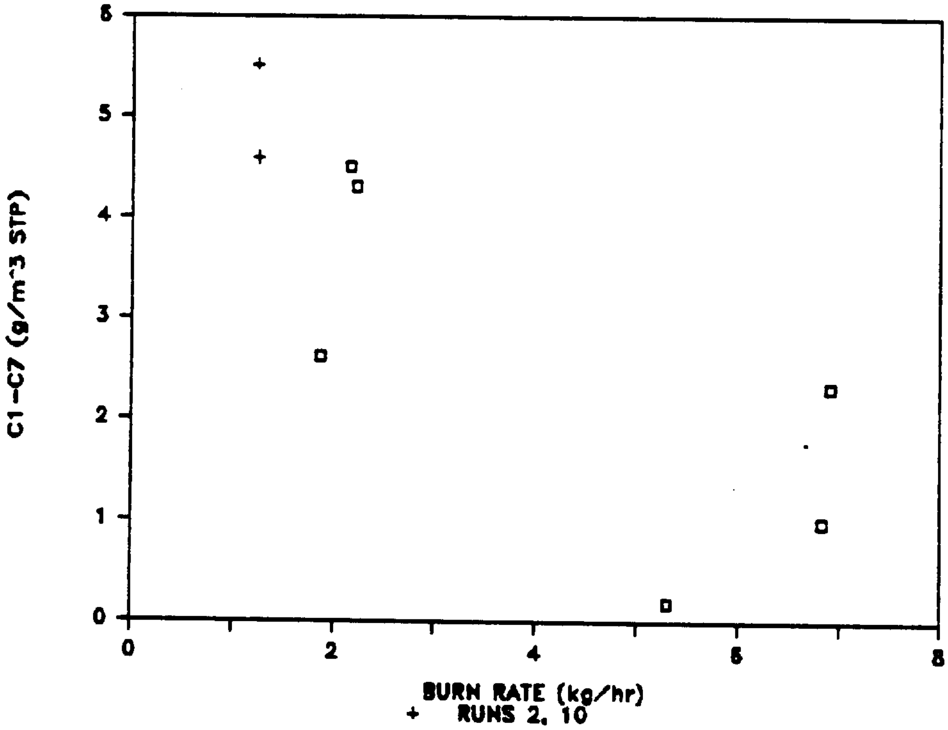

Figure 7.5.2. C_1-C_7 (g/m^3 STP) versus burn rate (kg/hr).

TABLE 7.6.1 STATISTICALLY SIGNIFICANT RESULTS WITH A MEASURE OF THE MAIN EFFECT FROM EACH PARAMETER

Test Parameter	Burn Rate (kg/hr)		Wood Moisture %		Wood Load (kg)		Wood Type	
From To	1.88 → 6.56 kg/hr		33.2 → 16.9 %		8.3 → 14.0 kg		Pine → Oak	
	CI	ME	CI	ME	CI	ME	CI	ME
Total GC/MS PAH (g/m^3)				-0.02				
Total GC/MS (g/hr)		+1.31						
Napthalene (mg/m^3)			90%	-14.20				
(mg/hr)		+864.67		-670.5				
(mg/kg dry wood)		-56.31						
Acenaphthylene (mg/m^3)				-1.95				
(mg/kg wet wood)								-24.5
(mg/kg dry wood)								-11.71
Fluorene (mg/m^3)				-0.64				-0.55
(mg/kg wet wood)								-9.46
(mg/kg dry wood)		-6.05						
Phenanthrene (mg/m^3)								-4.51
(mg/hr)		+136.0						
(mg/kg wet wood)								-22.92
(mg/kg dry wood)								-10.57
Anthracene (mg/m^3)				-0.37				
(mg/kg wet wood)								-4.51
Fluoranthene (mg/m^3		+0.71						
(mg/m)		+52.1						
Pyrene (mg/m^3)		+0.58						
(mg/hr)		+42.7						
(mg/kg dry wood)			90%	-1.35				-1.00
Chrysene (mg/m^3)		+0.21						
(mg/hr)		+14.28						
(mg/kg dry wood)		+0.35				+0.34		

TABLE 7.6.1 STATISTICALLY SIGNIFICANT RESULTS WITH A MEASURE OF THE MAIN EFFECT FROM EACH PARAMETER (continued)

Test Parameter		Burn Rate (kg/hr)		Wood Moisture %		Wood Load (kg)		Wood Type	
From	To	1.88 → 6.56 kg/hr		33.2 → 16.9 %		8.3 → 14.0 kg		Pine → Oak	
		CI	ME	CI	ME	CI	ME	CI	ME
Benzo(b)fluoranthene									
(mg/m^3)			+0.23						
(mg/hr)			+14.99						
(mg/kg wet wood)		90%	+2.27						
(mg/kg dry wood)			+0.48						
Benzo(a)pyrene									
(mg/m^3)			+0.11						
(mg/hr)			+7.31						

+, i = Indicates the direction of the main effect. Where no CI is given, the main effect is just below a 90% Confidence Level.

CI = Confidence Interval.

ME = Main Effect.

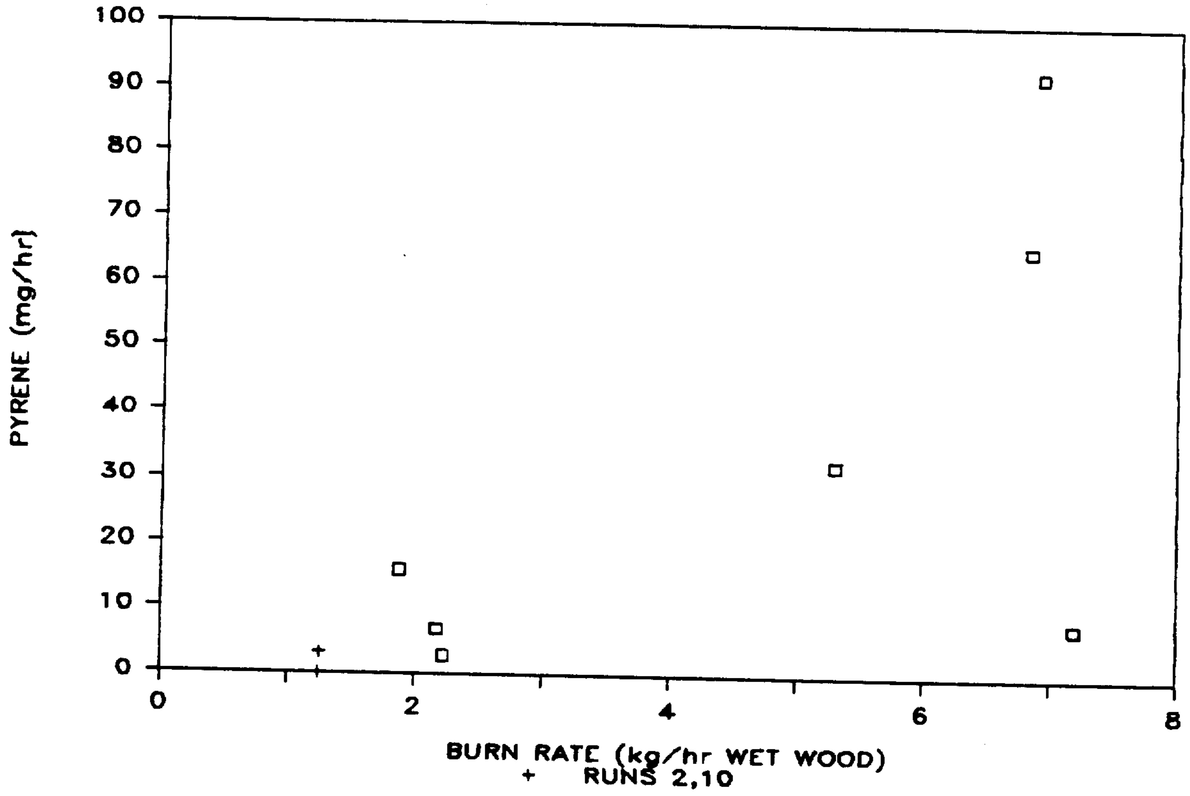

Figure 7.6.1. Pyrene emission rates (mg/hr) versus burn rate (kg/hr wet wood).

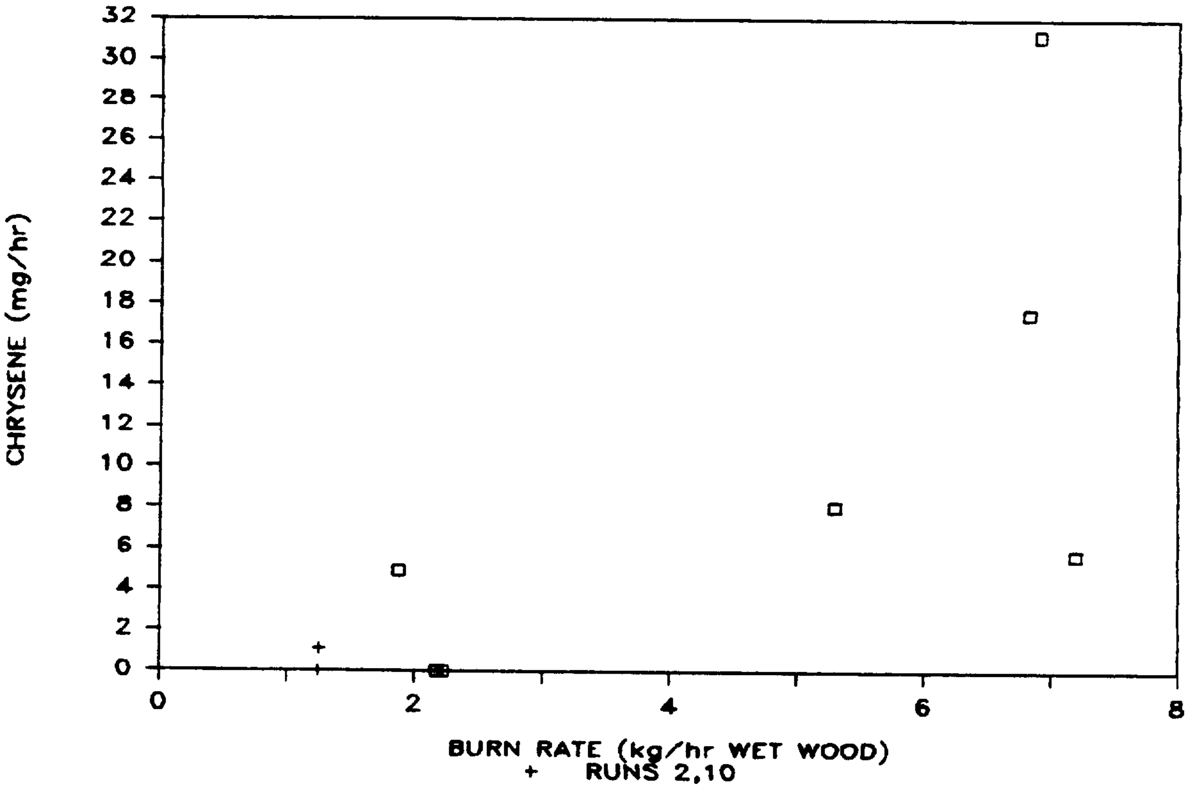

Figure 7.6.2. Chrysene emission rates (mg/hr) versus burn rate (kg/hr wet wood).

Benzo(b) fluoranthene concentration, emission rate, and emission factors also increased with an increase in burn rate. Unlike all other main effects thus far discussed from the burn rate, the emission factor for benzo (b) fluoranthene increases significantly, above the 90% confidence limit. Figure 7.6.3 illustrates this increase. Again, a data point near zero at a high burn rate is due to a sample preparation error.

Benzo(a) pyrene (BaP) is currently one of the most suspect PAH's in chemical carcinogenic studies. The concentration, as well as the emission rate of BaP increases with an increase in burn rate. Figures 7.6.4 and 7.6.5 illustrate the increases of BaP concentration and emission rates respectively, with increases in burn rates. Again, a suspect data point exists due to a sample preparation error. This error causes the confidence interval for these main effects to be just below the 90% level, but a trend is still visible.

Wood moisture content, when decreased, decreased the naphthalene concentration of the flue gas. This effect is statistically significant at the 90% confidence interval. Figure 7.6.6 illustrates this effect. Napthalene emission rates were also reduced by reducing the wood moisture content. Likewise, the concentrations of acenaphthylene, fluorene, and anthracene were also reduced. These effects occurred just below the 90% confidence interval. The emission rate of pyrene was decreased as wood moisture decreased. This effect was significant at the 90% confidence interval.

The change of wood type exhibited some notable main effects, but all were just below the 90% confidence interval. In changing from pine to oak, acenaphthylene, and phenanthrene emission factors, both wet and dry, decreased. For anthracene and pyrene, dry wood emission factors decreased, and for fluorene and anthracene the wet wood emission factors decreased. Fluorene and phenanthrene concentrations decreased. All noted main effects of changing wood from pine to oak decreased the PAH emissions discussed.

A PAH spot dilution test was performed, however, the resulting concentrations were not accurate enough to produce any statistically significant results in the test design. The results of the spot dilution test are only accurate to within an order of magnitude of each other.

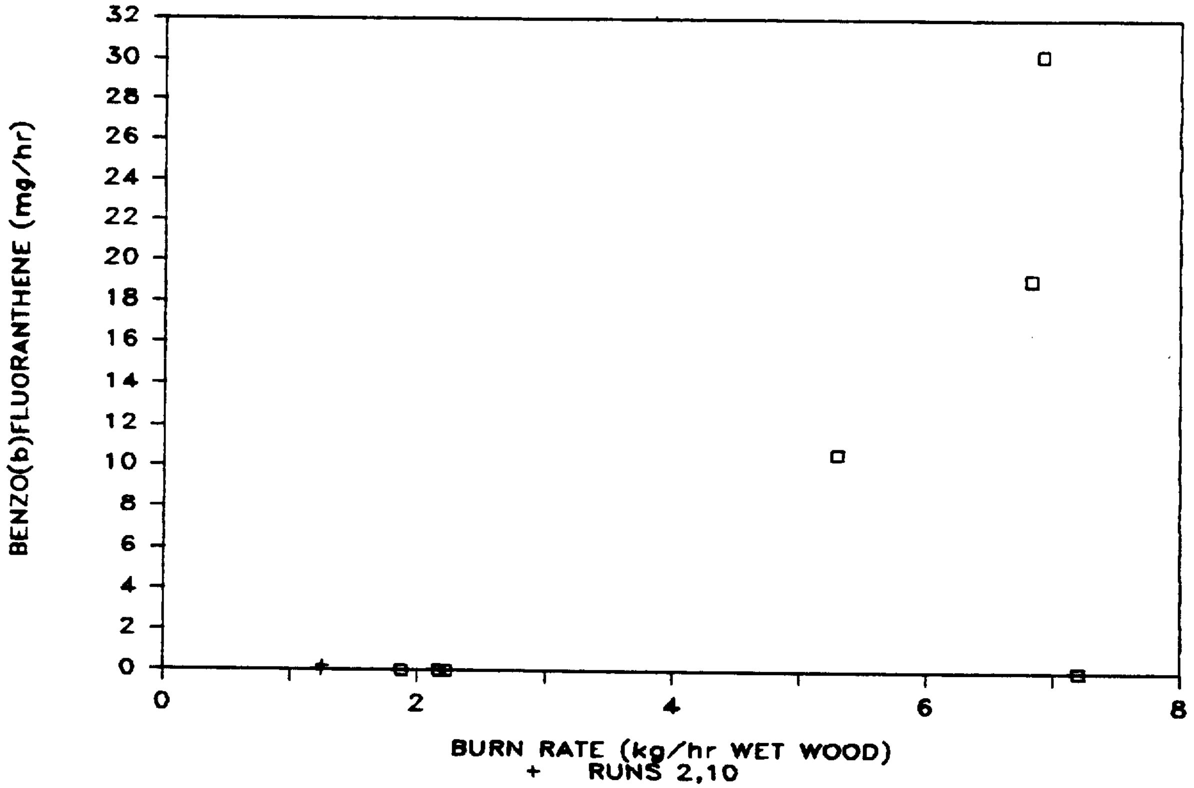

Figure 7.6.3. Benzo(b) fluoranthene emission rates (mg/hr) versus burn rate (kg/hr wet wood).

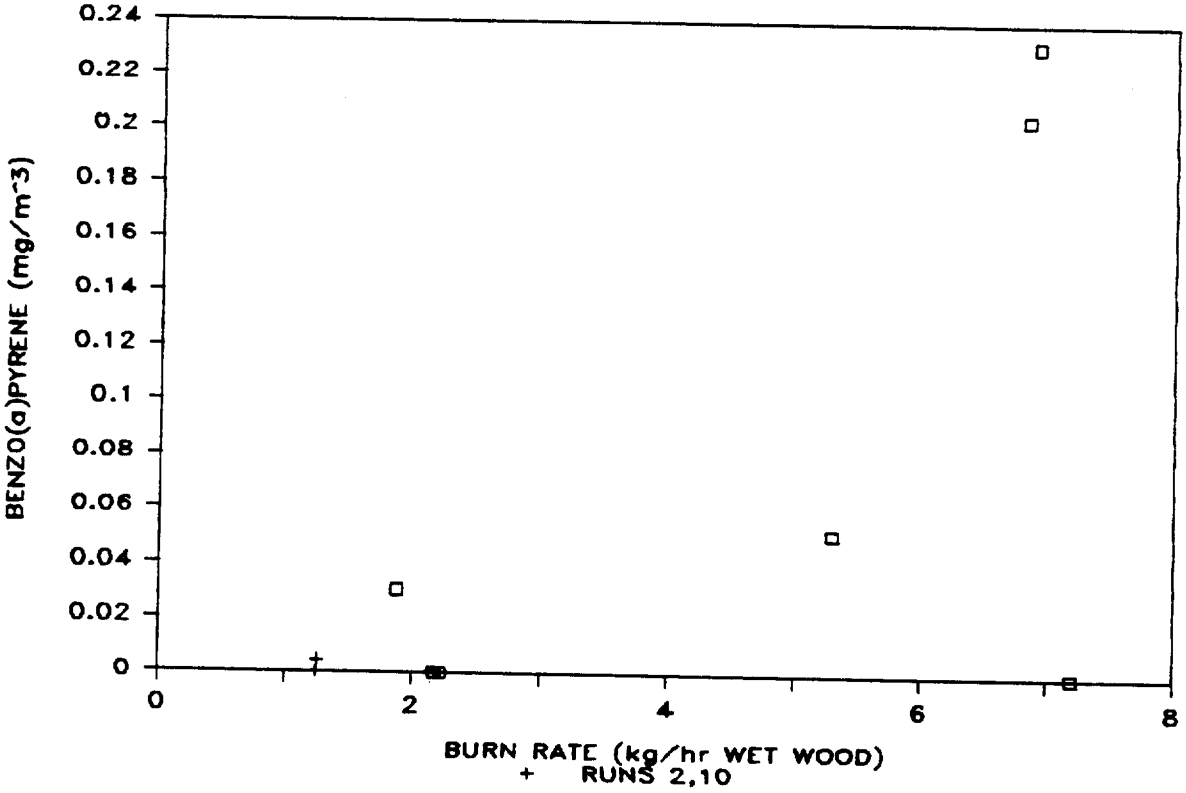

Figure 7.6.4. Benzo(a)pyrene concentration (mg/m^3) versus burn rate (kg/hr wet wood).

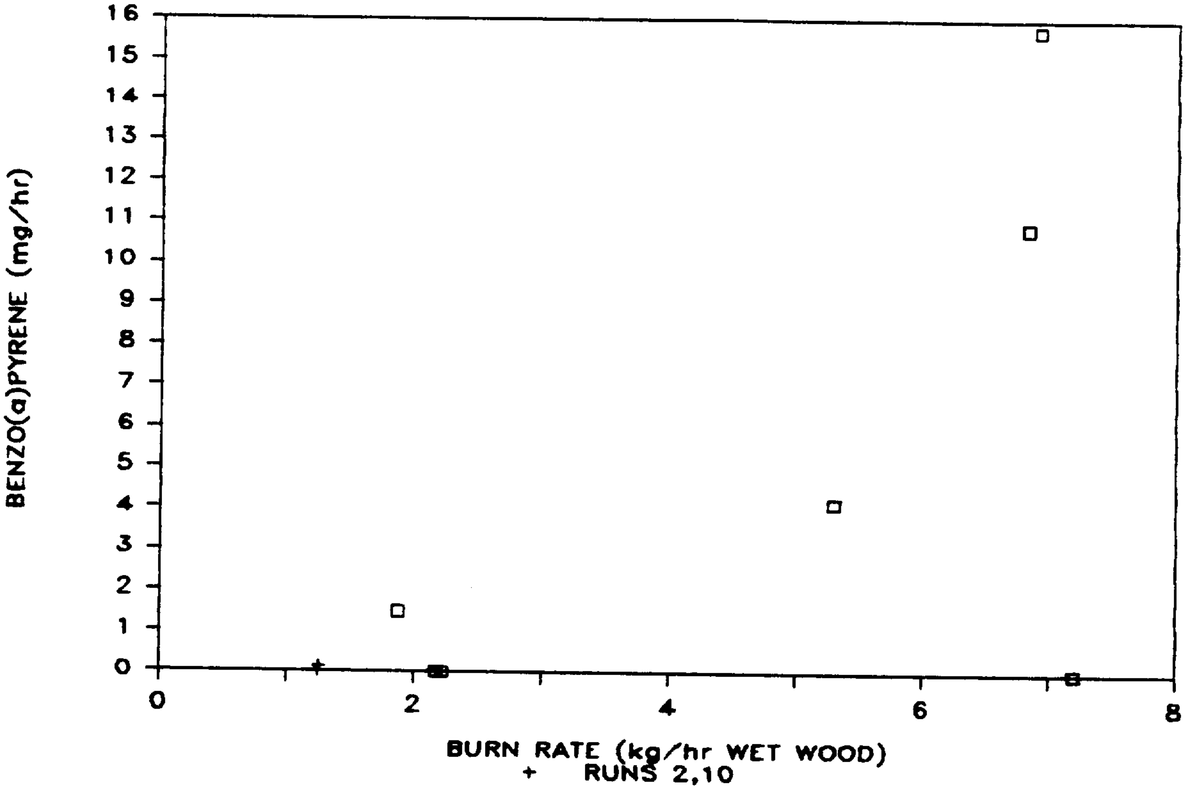

Figure 7.6.5. Benzo(a)pyrene emission rate (g/hr) versus burn rate (kg/hr wet wood).

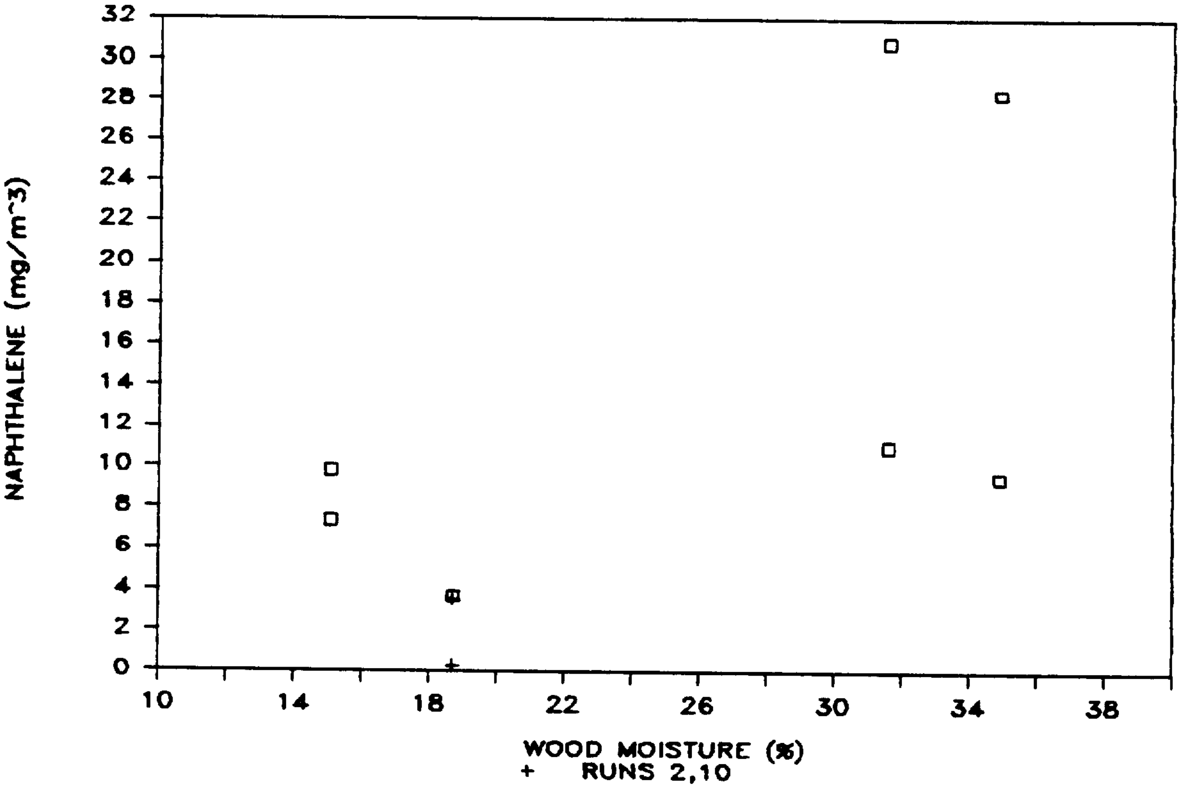

Figure 7.6. 6. Naphthalene concentration (mg/m^3) versus wood moisture (%).

7.7 CARBON MONOXIDE

Carbon monoxide (CO) emission factors decreased with a corresponding increase in burn rate. This effect is significant at a 90% CI and the main effect was a decrease of 111.5 g/kg. Figure 7.7.1 shows the effect of burn rate on CO emission factors. The high moisture tests seem to group below the low moisture tests for CO emission factors as plotted against burn rate. This is probably due to an overall dilution by water in the high moisture wood tests.

Increasing wood load had the effect of increasing CO emission rates, however, this effect was below the 90% CI. Similarly, higher burn rates lowered CO concentrations, however, the effect was also below the 90% CI.

The significant decrease of CO emission factors from higher burn rates can be attributed to an increase in combustion efficiency due to more available oxygen to the fire.

7.8 CARBON DIOXIDE

Carbon dioxide (CO_2) concentrations and emission rates were increased with an increase in burn rates. These effects were significant at a 95% CI. The main effect on CO_2 concentration was an increase of 29.3 g/m^3, and on the emission rate it was an increase of 5238 g/hr. Decreasing wood moisture also caused an increase in CO_2 emission rates, however, this effect was not significant above a 90% CI. Figure 7.8.1 shows the effect of lower burn rates on CO_2 emission rates. There is a distinct decrease in emission rates for high moisture tests than low moisture. This could be due to dilution of the flue gas with water from the high moisture wood. However, since the rate of CO_2 emissions are changing, it may be because low moisture wood burns more readily. The difference in the effect of wood moisture seems to be greater at high burn rate conditions. Figure 7.8.2 plots CO_2 emission rates with wood moisture. Again, decreasing wood moisture shows an increase in CO_2 emission rates, and there seems to be more of an effect on the high burn rate tests.

Decreasing wood moisture did have a 95% CI statistically significant effect of increasing CO_2 emission factors. As Figure 7.8.3 shows, decreased moisture increased CO_2 emission factors. When wood with a higher moisture content is burned, the flue gas may be diluted with water from that wood.

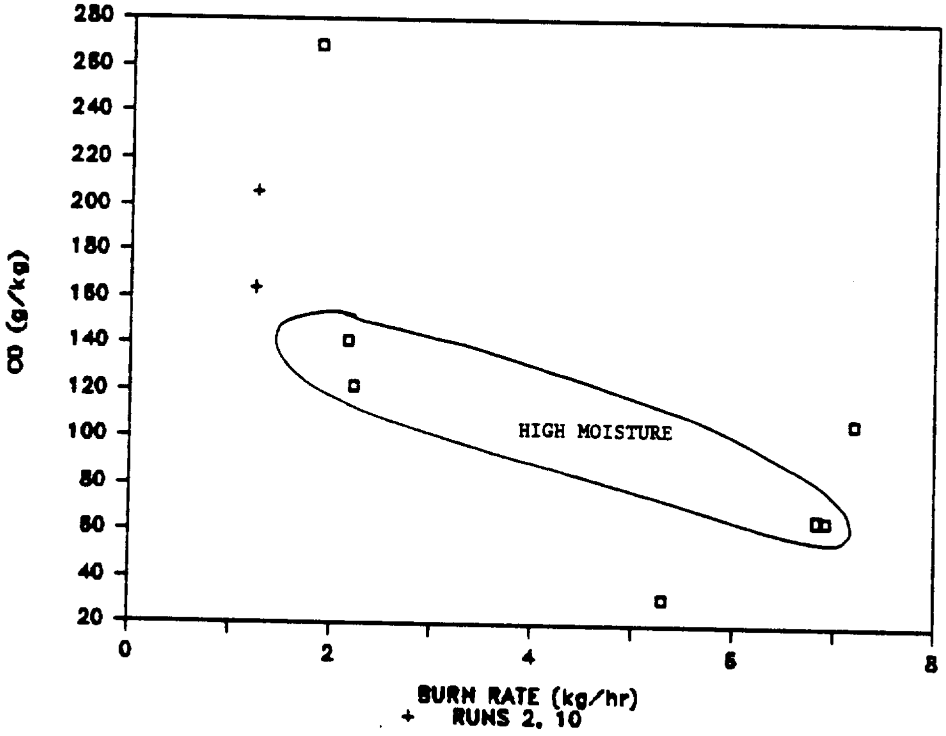

Figure 7.7.1. CO (g/kg) versus burn rate (kg/hr).

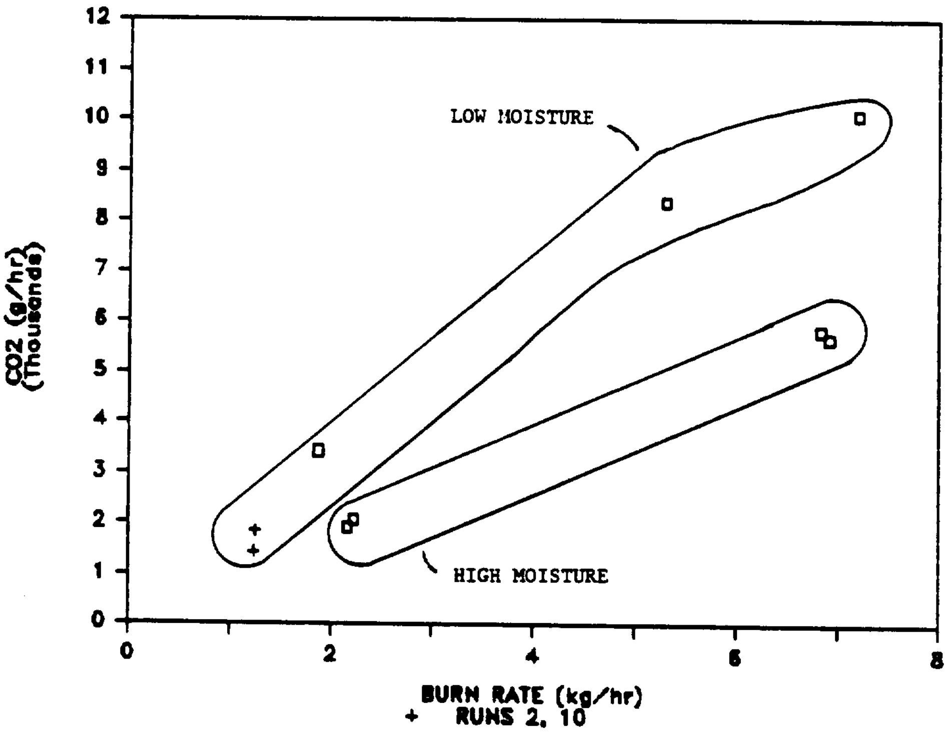

Figure 7.8.1 CO_2 (g/hr) versus burn rate (kg/hr).

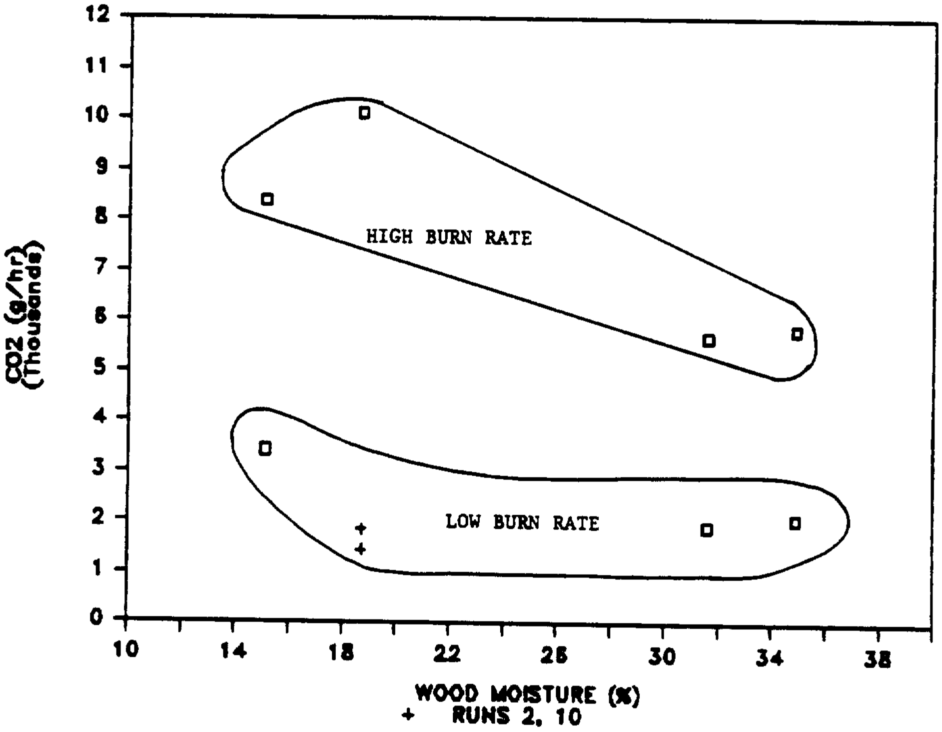

Figure 7.8.2. CO_2 (g/hr) versus wood moisture (%).

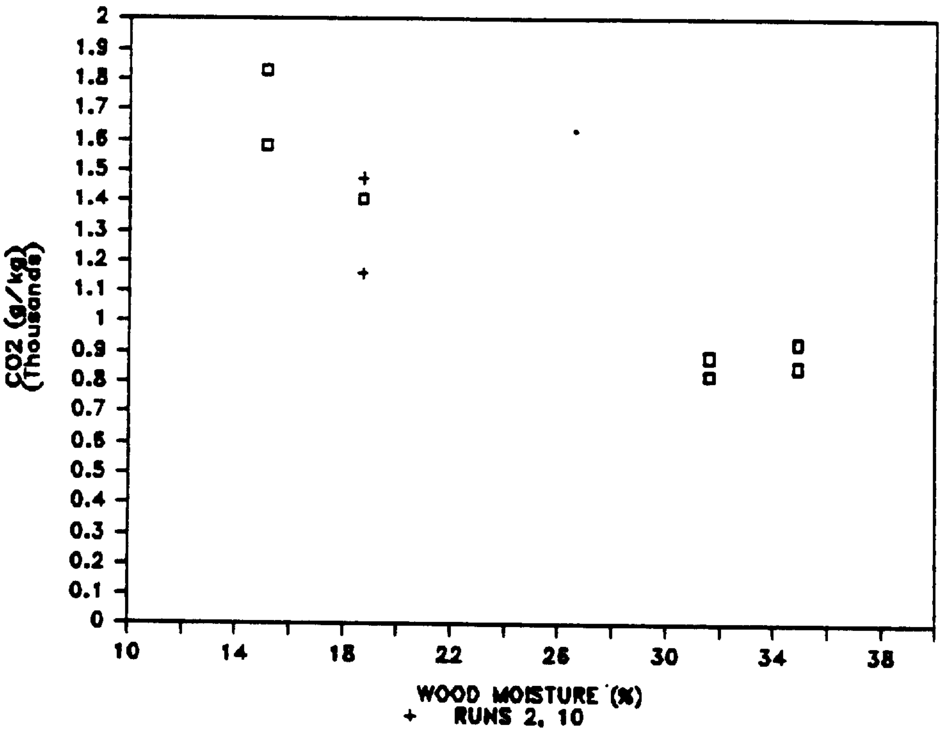

Figure 7.8.3. CO_2 (g/kg) versus wood moisture (%).

7.9 ELEMENTAL RESULTS

An ICAP elemental analyses was performed by ACUREX on RTI ash samples and the glass fiber particulate filters collected from each woodstove test. The entire ACUREX analytical procedure and raw data results are provided in the ACUREX report contained in Appendix D.

7.9.1 Carbon Free Ash Elemental Results

Table 7.9.1 contains a list of elements which were found to change significantly as weight percent of carbon free ash with respect to changes in stove operating parameters. Confidence intervals, the magnitude of the main effect, and the direction of the main effect are also given.

Not surprising, wood specie seemed to have the most statistically significant effects on the elemental composition of the carbon free ash. As the wood used changed from pine to oak, the weight percent of calcium increased by +18.1%, magnesium decreased -1.7% and zinc decreased -0.09%. These effects occurred with a 99% confidence interval. At a 95% confidence interval, the weight percent of manganese decreased by -1.2% while strontium increased by +0.17%. The weight percent of barium increased by +0.06% at a 90% confidence interval as the wood was changed from pine to oak. The iron/potassium ratio exhibited a small decrease of -0.008 which was significant at a 90% confidence interval. A decrease was seen on aluminum weight percent of -0.16, however, this effect was not significant above the 90% confidence interval.

Statistically significant changes in some element weight percents were also found as the wood moisture content of the wood used was decreased from 33.2 weight percent H_2O to 16.9 weight percent H_2O. The weight percent in carbon free ash of barium decreased by -0.10%, whereas, strontium increased by +0.11%. These effects were significant at a 95% confidence interval. At a 90% confidence interval the weight percent of iron increased by +0.07%, magnesium increased by +0.64% and the iron/potassium ratio increased +0.004. An increase in aluminum weight percent of +0.13% was noted as the wood moisture content was decreased, however, this effect was not significant at the 90% confidence interval.

TABLE 7.9.1. STATISTICALLY SIGNIFICANT RESULTS WITH A MEASURE OF THE MAIN EFFECT ON SPECIFIC ELEMENTS IN CARBON FREE ASH SAMPLES FROM EACH PARAMETER

TEST PARAMETER	BURN RATE (kg/hr)		WOOD MOISTURE %		WOOD LOAD (kg)		WOOD TYPE	
FROM TO	1.88 → 6.56 kg/hr		33.2 → 16.9 %		8.3 → 14.0 kg		Pine→Oak	
	CI	ME	CI	ME	CI	ME	CI	ME
Aluminum %				+0.126				-0.158
Barium %			95%	-0.103			90%	+0.065
Calcium %		-0.973					99%	+18.107
Iron %			90%	+0.072				
Magnesium %			90%	+0.642			99%	-1.713
Manganese %							95%	-1.223
Strontium %			95%	+0.108			95%	+0.168
Zinc %							99%	-0.091
Iron/Potassium ratio (Fe/k)			90%	+0.004			90%	-0.008

+,- Indicates the direction of the main effect. Where there is no CI, the main effect fell just below a 90% Confidence Interval.

CI = Confidence Interval

ME = Main Effect

7.9.2 Element Emissions Collected on Particulate Filters

Table 7.9.2 contains a list of elements with statistically significant changes in emission concentrations (mg/m^3), emission rates (mg/hr), and wet and dry emission factors (mg/kg wet wood) and (mg/kg dry wood). Confidence intervals, the magnitude of the main effect, and the direction of the main effect are also given.

The stove operating parameters of wood type and burn rate have most of the statistically significant effects on the elemental emissions listed. Wood moisture content exhibited a statistically significant effect on the emission of only one element, calcium, which decreased in concentration and emission factor as wood moisture decreased.

As the burn rate increased from 1.88 kg/hr to 6.56 kg/hr, the potassium emission rate increased +135.5 mg/hr and the sulfur emission rate increased +64.68 mg/hr. Also, the potassium dry wood emission factor increased +11.77 mg/kg dry wood. These increases were significant at a 95% confidence interval. The emission rates of zinc, +11.64 mg/hr, and cadmium +0.21 mg/hr also increased, but this was not significant above a 90% confidence interval. As the burn rate increased, the emission concentrations (mg/m^3) of potassium +1541.9, manganese +9.0, sulfur +867.44, and zinc +158.8 also increased. Also, the emission rate of manganese increased +1.01 mg/hr. All of these effects were significant at a 90% confidence interval.

Only one emission factor was significantly affected by an increase in burn rate. The sulfur emissions factor was increased by +7.52 (mg/kg wet wood) at a 95% confidence interval. The emission factor for barium showed a decrease of -0.034 mg/kg dry wood with an increase in burn rate, however, this effect was not significant above a 90% confidence interval.

Changing the wood from pine to oak had some statistically significant effects on several elemental emissions. Most notably, all potassium emissions increased, while manganese and zinc emission decreased. At a 99% confidence interval, the potassium emission factor increased by +20.02 mg/kg wet wood. The wet wood emission factors for manganese and zinc decreased, however, by -0.27 and -2.05 mg/kg wet wood, respectively. The dry wood emission factors for manganese and zinc also decreased by -0.11 and -0.63 mg/kg dry wood,

TABLE 7.9.2. STATISTICALLY SIGNIFICANT RESULTS WITH A MEASURE OF THE MAIN EFFECT ON SPECIFIC ELEMENTS EMISSIONS COLLECTED ON PARTICULATE FILTERS FROM EACH PARAMETER

TEST PARAMETER	BURN RATE (kg/hr)		WOOD MOISTURE %		WOOD LOAD (kg)		WOOD TYPE	
FROM TO	1.88 → 6.56 kg/hr		33.2 → 16.9 %		8.3 → 14.0 kg		Pine→Oak	
	CI	ME	CI	ME	CI	ME	CI	ME
Barium (mg/kg drywood)		-0.034						
Cadmium ($\mu g/m^3$)			90%	-4.88				
(mg/hr)		+0.207				-.106		
(mg/kg wetwood)			90%	-0.04				
(mg/kg drywood)			90%	-0.02				
Potassium ($\mu g/m^3$)	90%	+1541.9					95%	+1852.9
(mg/hr)	95%	+135.5					90%	+97.89
(mg/kg wetwood)	95%	+11.77					99%	+20.02
(mg/kg drywood)							90%	+9.75
Manganese ($\mu g/m^3$)	90%	+8.98					95%	-16.02
(mg/m)	90%	+1.01					90%	-1.02
(mg/kg wetwood)							95%	-0.27
(mg/kg drywood)							90%	-0.11
Sulfur ($\mu g/m^3$)	90%	+867.44						
(mg/hr)	90%	+64.68						
(mg/kg wetwood)	90%	+7.52						+5.25
Zinc ($\mu g/m^3$)	90%	+158.84						-136.44
(mg/hr)		+11.64						
(mg/kg wetwood)							90%	-2.05
(mg/kg drywood)							90%	-0.63
Iron/Potassium (Fe/K)	NO SIGNIFICANT CORRELATIONS							

+,- Indicates the direction of the main effect. Where there is no CI given, the main effect fell just below a 90% Confidence Interval.

CI = Confidence Interval

ME = Main Effect

respectively, while the dry wood emission factor for potassium increased +9.75 mg/kg dry wood. These changes were significant at the 90% confidence interval. Also, at a 90% confidence interval, the potassium emission rate increased by +97.89 mg/hr while the manganese emission rate decreased by -1.02 mg/hr. Similarly, potassium concentrations increased by +1852.9 mg/m^3 while manganese concentrations decreased by -16.0 mg/m^3. These effects were significant at 95% confidence interval.

An increase in sulfur wet wood emission factors of +5.25 mg/kg wet wood was noted, as well as a decrease in zinc concentration -136.4 mg/m^3 and zinc emission rate -9.97 mg/hr, however, these were not significant above a 90% confidence interval.

A decrease in wood moisture content only affected cadmium emissions at a significant level. As wood moisture content decreased from 33.2 wt% to 16.9 wt%, cadmium concentrations decreased by -4.9 mg/m^3 and emission factors decreased by -0.04 g/kg wet wood and -0.02 mg/kg dry wood. These decreases were significant at a 90% confidence interval. A decrease of -0.11 mg/hr in cadmium emission rate was seen due to wood load, but was not significant above a 90% confidence interval.

7.10 HYDROCARBONS DETECTED BY FID

The data obtained from the FID on the continuous flue gas analyses system was insufficient. The FID frequently went off-scale and the results obtained were of no use in the statistical test design.

7.11 BIOASSAY RESULTS

Table 7.11.1 presents the statistically significant results for mutagenic activity. As expected, the analyses conducted with activation (+S9) showed higher activity and produced the strongest correlations. For example, the XAD extract mutagenicity correlated at better than 95% with burn rate (higher at higher burn rates). The combined activity of the filter and XAD extracts also correlated at better than 95% although the filter extract showed only a weak correlation (<90%). These strong correlations (see Figure 7.11.1 and 7.11.2) occurred when the mutagenicity is expressed in units of Mrev/hr (millions of revertants per hour) meaning that as one increases burn rate, the mutagenic activity of the emissions released to the atmosphere increases. This is in

TABLE 7.11.1 STATISTICALLY SIGNIFICANT RESULTS WITH A MEASURE OF THE MAIN EFFECT ON MUTAGENIC ACTIVITY OF FILTER AND XAD EXTRACTS AND THE COMBINED (SUM OF EXTRACT OF FILTER AND XAD) MUTAGENICITIES

Test Parameter		Burn Rate (kg/hr)		Wood Moisture %		Wood Load (kg)		Wood Type	
From	To	1.88 → 6.56 kg/hr		33.2 → 16.9 %		8.3 → 14.0 kg		Pine→Oak	
		CI	ME	CI	ME	CI	ME	CI	ME
With Activation									
XAD									
(Mrev/hr)		95%	+ 12.89						
Combined									
(Mrev/hr)		95%	+ 15.39						-8.1
(Mrev/kg wet wood)									-2.69
Without Activation									
XAD									
(krev/m^3)							+ 80.68		
(Mrev/hr)			+ 6.09						
(Mrev/kg dry wood)							- 1.27		-1.28
Combined									
(krev/m^3)							- 102.85		

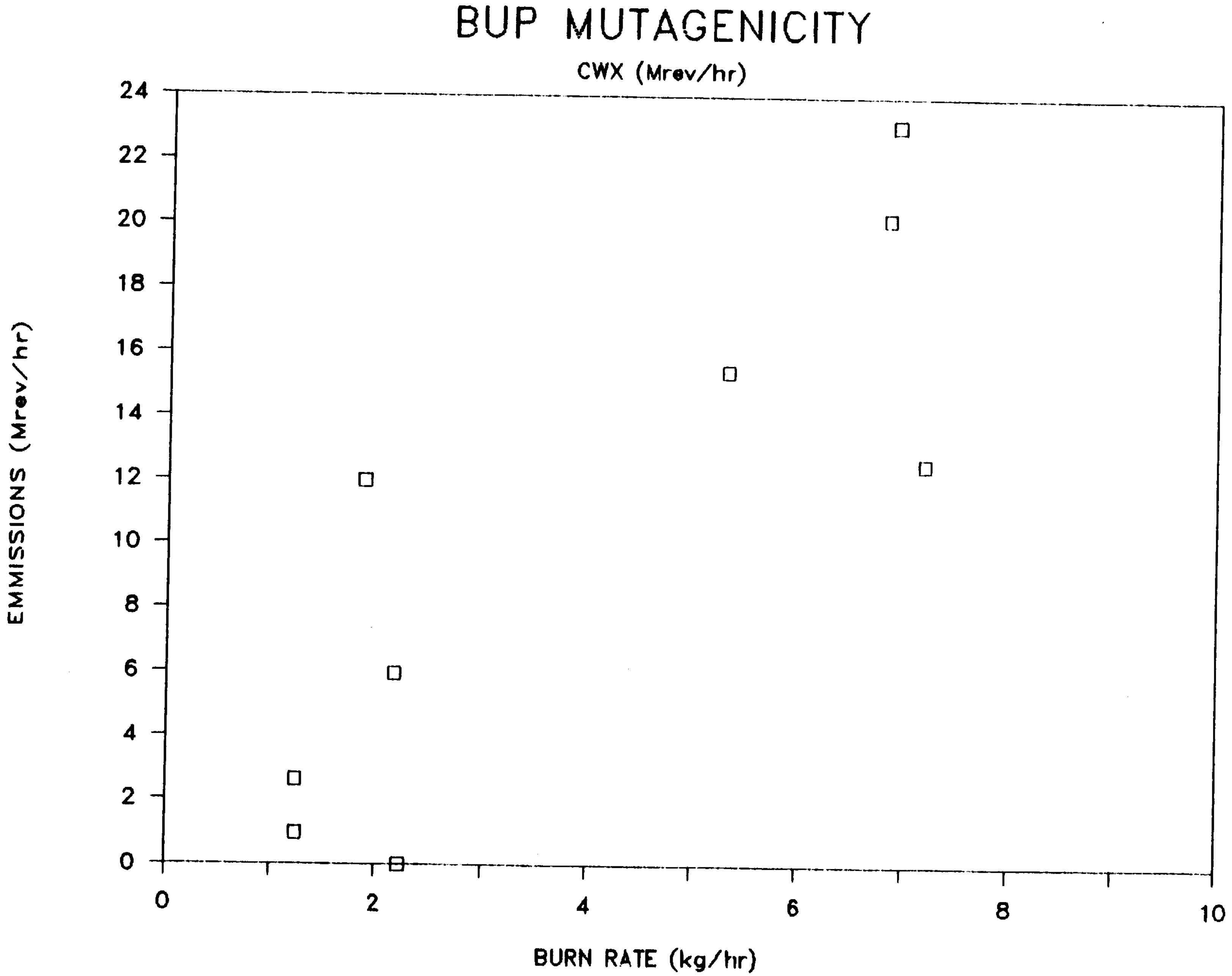

Figure 7.11.1. CWX sample BUP (+S9) emission rate (Mrev/hr) versus burn rate (kg/hr).

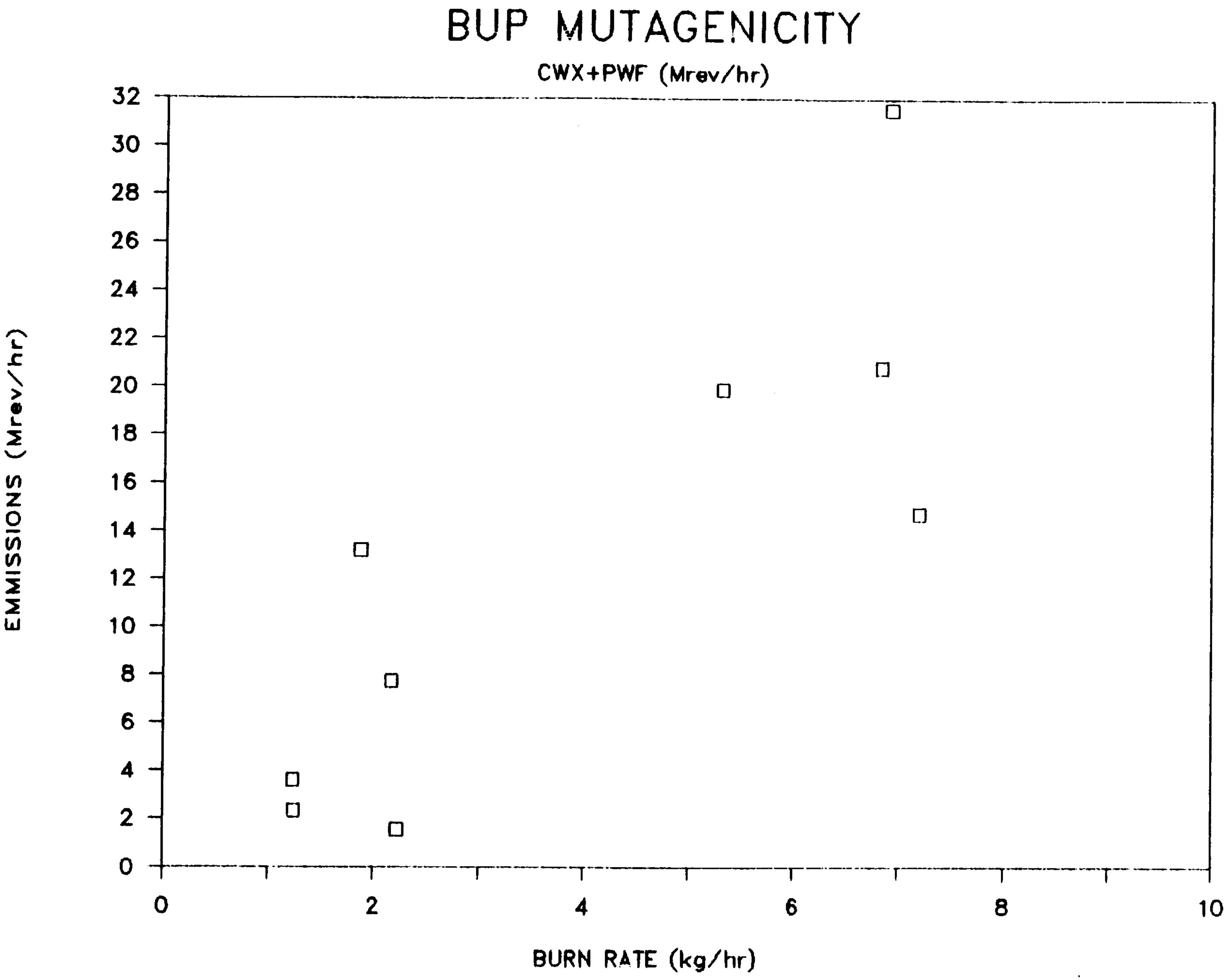

Figure 7.11.2. CWX and PWF sample BUP (+S9) mutagenicity rate (Mrev/hr) versus burn rate (kg/hr).

spite of the fact that the hourly emission rates for particulates and total organics showed 95 to 99% negative correlations with burn rate (see Figure 7.4.7). At a level just below the 90% confidence interval the combined filter and XAD result showed a correlation with wood type, with pine producing more mutagenic emissions than oak as shown in Figure 7.11.3.

The bioassays performed without activation (-S9) produced several correlations just below the 90% confidence interval. Here again, burn rate correlated with XAD mutagenicity in Mrev/hr, as shown in Figure 7.11.4. Wood load, the weight of the initial load of wood placed in the stove at the start of a test, showed a potential negative correlation for the XAD and combined filter and XAD mutagenicities with the emissions expressed in krev/m^3 (Figures 7.11.5 and 7.11.6, respectively), and for the XAD extract only, when the emission units are Mrev/kg dry wood. The latter case also showed a potential correlation with wood type, pine emissions again more mutagenic than oak emissions. Data from the bioassay tests is presented in Table 7.11.2.

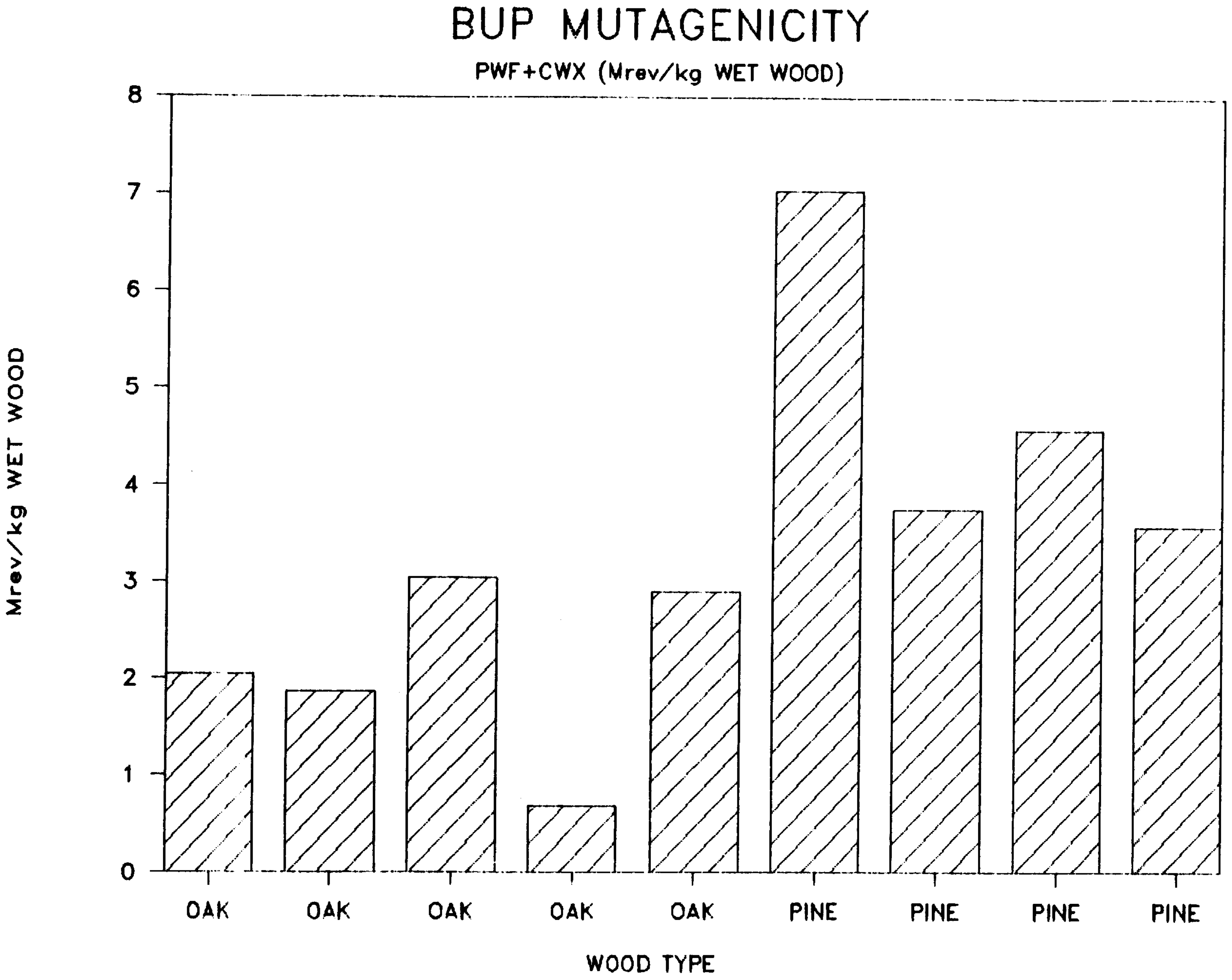

Figure 7.11.3. PWF and CWX sample BUP (+S9) mutagenicity factor (Mrev/kg) versus wood type).

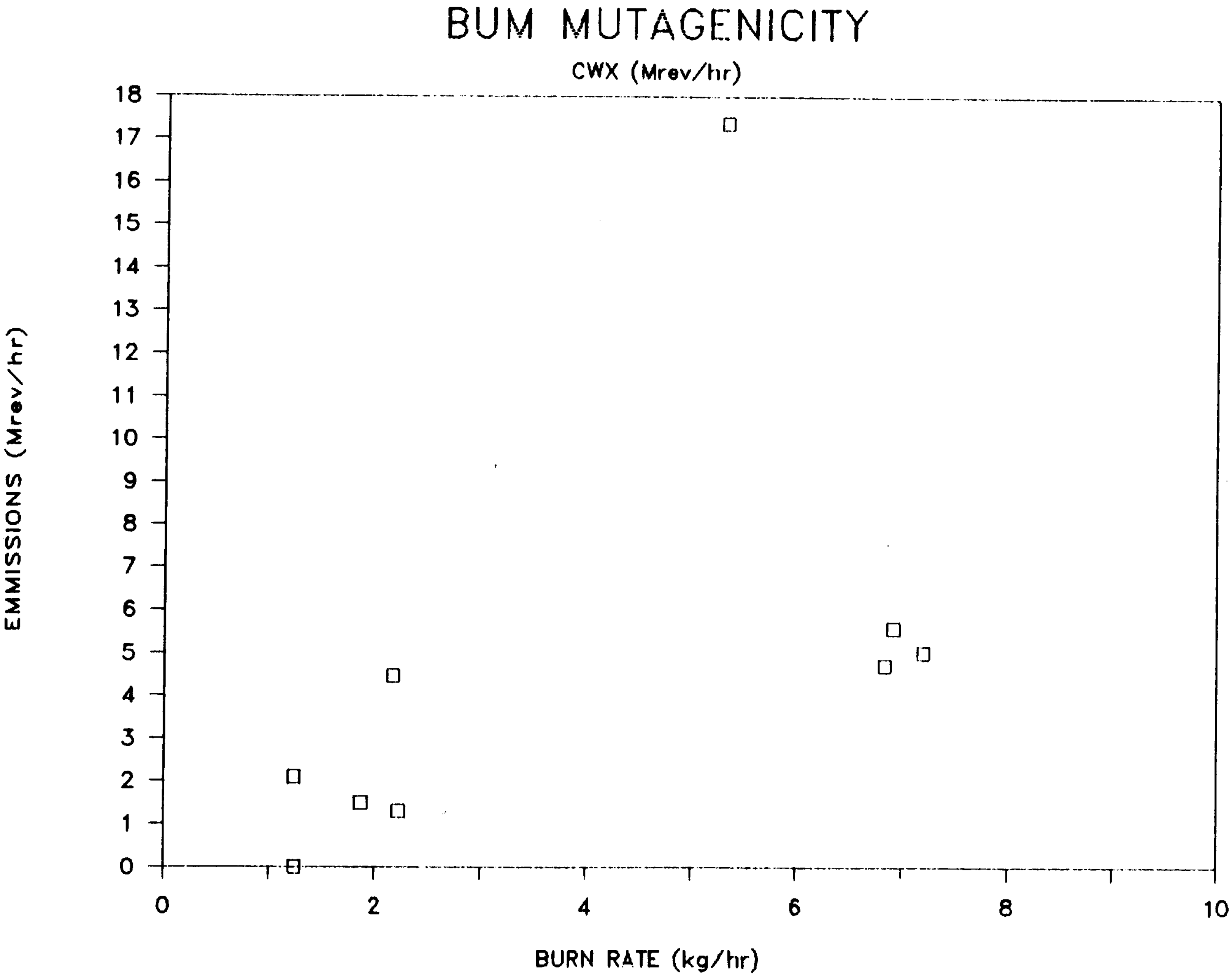

Figure 7.11.4. CWX BUM (-S9) sample mutagenicity emission rate (Mrev/hr) versus burn rate (kg/hr).

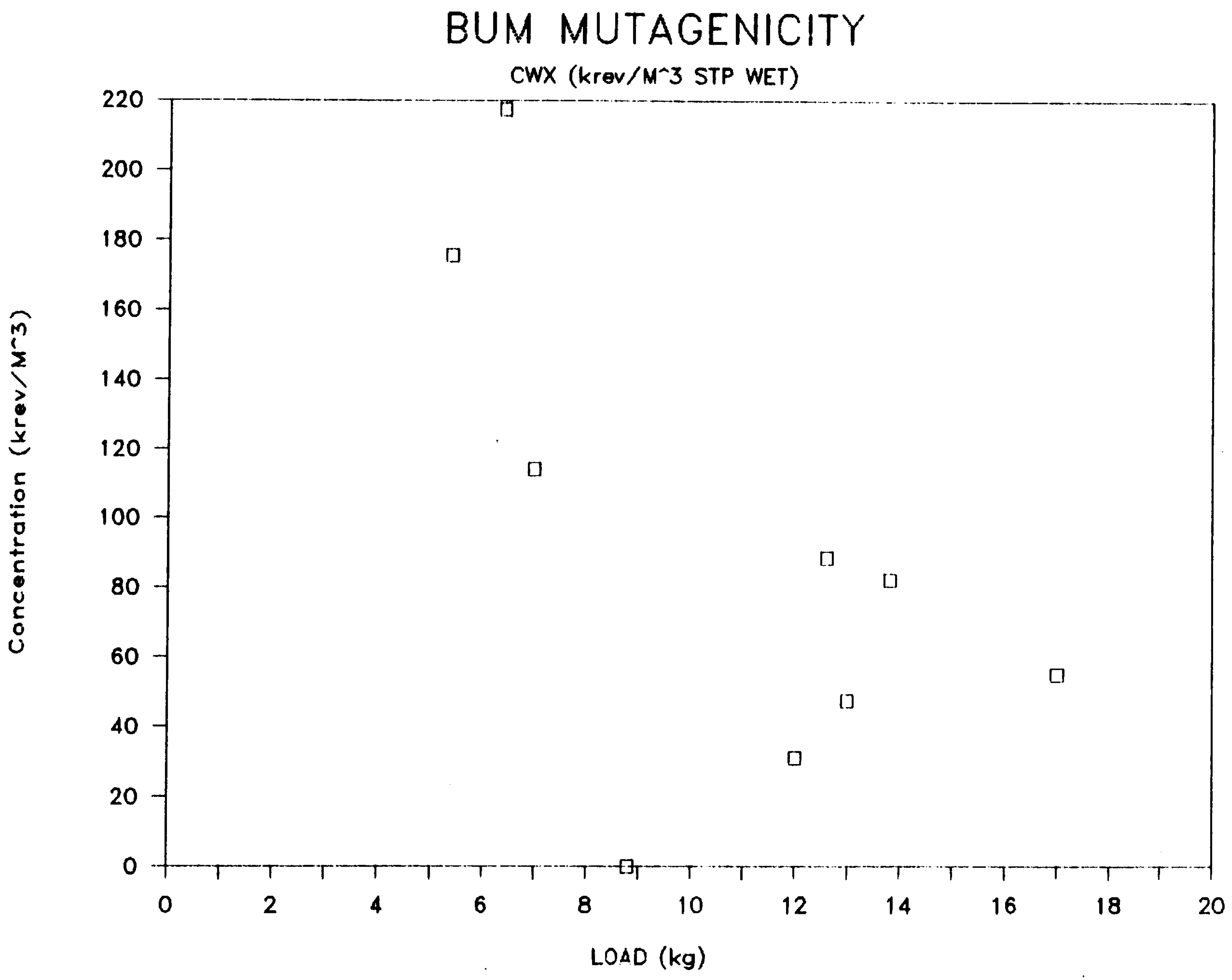

Figure 7.11.5. CWX BUM (-S9) sample mutagenicity concentration (krev/m^3) versus wood load (kg).

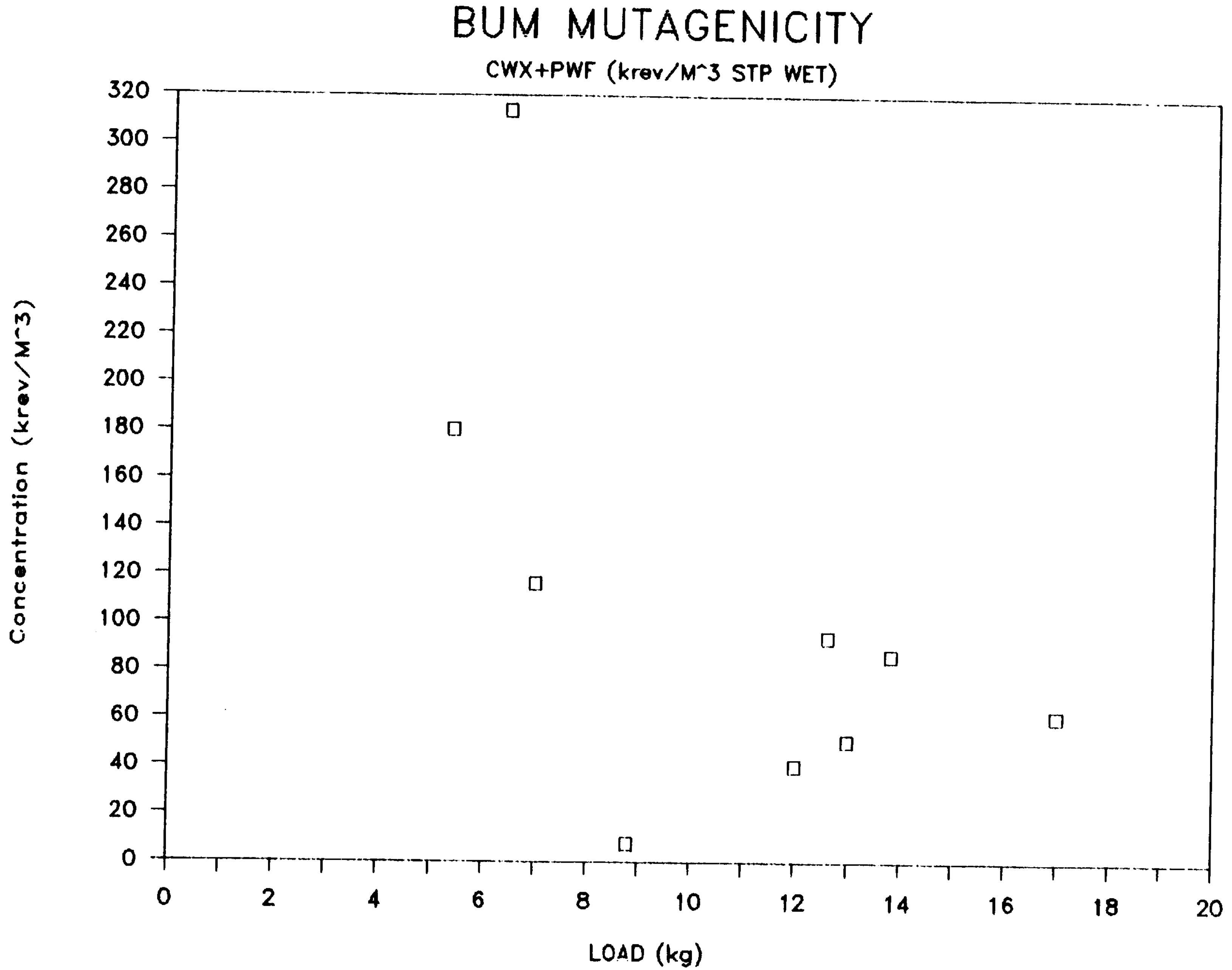

Figure 7.11.6. CWX and PWF BUM (-S9) mutagenicity concentration (krev/m^3) versus wood load (kg).

TABLE 7.11.2. BIOASSAY RESULTS

														-S9		+S9		-S9		+S9	
IACP No.	Task	GBB No.	µg/m³	Assay	Strain	BUMD1	BUMD2	BUPD1	BUPD2	BUM AV	STD	BUP AV	STD	BMMD1	BMMD2	BMPD1	BMPD2	BMM AV	STD	BMP AV	STD
IACP85RS0E01767	24	IACP852401	0.93	Plate	TA98	0.10		0.25		0.10	0.00	0.25	0.00	0.09		0.23		0.09	0.00	0.23	0.00
IACP85RS0G01766	24	IACP852402		Plate	TA98	0.12	0.22	0.81	0.50	0.17	0.05	0.66	0.16	0.11	0.20	0.75	0.47	0.15	0.05	0.61	0.14
IACP85RS0E01769	24	IACP852403	2.57	Plate	TA98	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IACP85RS0G01759	24	IACP852404		Plate	TA98	0.00	0.03	0.19	0.00	0.02	0.01	0.12	0.07	0.00	0.09	0.49	0.00	0.04	0.04	0.25	0.25
IACP85RS0E01770	24	IACP852405	0.61	Plate	TA98	0.00	0.00	0.00	0.09	0.02	0.02	0.09	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.03	0.03
IACP85RS0G01760	24	IACP852406		Plate	TA98	0.00	0.02	0.21	0.11	0.02	0.01	0.16	0.05	0.00	0.01	0.13	0.07	0.01	0.01	0.10	0.03
IACP85RS0E01771	24	IACP852407	2.63	Plate	TA98	0.11	0.17	0.62	0.58	0.14	0.03	0.60	0.02	0.28	0.44	1.62	1.52	0.36	0.08	1.57	0.05
IACP85RS0G01761	24	IACP852408		Plate	TA98	0.44	0.82	1.31	1.37	0.63	0.19	1.34	0.03	1.15	2.15	3.46	3.61	1.65	0.50	3.53	0.08
IACP85RS0E01772	24	IACP852409	2.48	Plate	TA98	0.00	0.00	0.07	0.10	0.01	0.00	0.08	0.02	0.00	0.00	0.17	0.25	0.00	0.00	0.21	0.04
IACP85RS0G01762	24	IACP852410		Plate	TA98	0.00	0.00	0.22	0.13	0.06	0.06	0.17	0.05	0.00	0.00	0.55	0.32	0.00	0.00	0.43	0.11
IACP85RS0E01773	24	IACP852411	2.93	Plate	TA98	1.66	3.88	2.13	2.78	2.77	1.11	2.46	0.33	4.86	11.36	6.24	8.16	8.11	3.25	7.20	0.96
IACP85RS0G01763	24	IACP852412		Plate	TA98	24.66	44.37	17.52	22.58	34.52	9.85	20.05	2.53	72.25	130.00	51.33	66.16	101.13	28.88	58.75	7.41
IACP85RS0E01774	24	IACP852413	1.38	Plate	TA98	0.00	0.08	0.30	0.28	0.07	0.02	0.29	0.01	0.00	0.11	0.41	0.39	0.06	0.06	0.40	0.01
IACP85RS0G01764	24	IACP852414		Plate	TA98	0.00	0.05	0.61	1.07	0.03	0.02	0.84	0.23	0.00	0.07	0.85	1.47	0.03	0.03	1.16	0.31
IACP85RS0E01775	24	IACP852415	3.05	Plate	TA98	0.00	0.11	0.00	0.00	0.06	0.06	0.08	0.01	0.00	0.34	0.00	0.00	0.17	0.17	0.00	0.00
IACP85RS0G01765	24	IACP852416		Plate	TA98	0.00	0.03	0.15	0.13	0.01	0.01	0.14	0.01	0.00	0.08	0.46	0.41	0.04	0.04	0.43	0.03
IACP85RS0E01776	24	IACP852417	1.52	Plate	TA98	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IACP85RS0G01777	24	IACP852418		Plate	TA98	0.00	0.00	0.20	0.17	0.01	0.01	0.18	0.02	0.00	0.00	0.30	0.25	0.00	0.00	0.28	0.02
IACP85RS0E01812	24	IACP852419	1.33	Plate	TA98	0.00	0.04	0.00	0.00	0.04	0.00	0.05	0.03	0.00	0.05	0.00	0.00	0.02	0.02	0.00	0.00
IACP85RS0G01778	24	IACP852420		Plate	TA98	0.00	0.00	0.17	0.29	0.01	0.00	0.23	0.06	0.00	0.00	0.22	0.39	0.00	0.00	0.31	0.08
IACP85RZ0Y02264	24	IACP852421	*	Plate	TA98	0.00	0.00	0.00	0.00	0.03	0.02	0.06	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IACP85R90X00709	24	IACP852422		Plate	TA98																
IACP85RQZP02697	24	IACP852423		Plate	TA98																
IACP85RQ0X00713	24	IACP852424		Plate	TA98																
IACP85RQ0X00717	24	IACP852425		Plate	TA98																
IACP85RQ0P00716	24	IACP852426		Plate	TA98																
IACP85RQ0X00712	24	IACP852427		Plate	TA98																
IACP85RQZP02698	24	IACP852428		Plate	TA98																

BUMD1 = Bernstein slope
rev/µg dissolved organic
(-)S9 activation
Day 1

BUPD1 = Bernstein slope
rev/µg
(+)S9 activation
Day 1

BMMD1 = Bernstein slope
rev/m³ air/µg
(-)S9
Day 1
BMP = (+S9)

*Methylene chloride.

8.0 CONCLUSIONS

For the purpose of discussion, three types of emissions are defined. Concentrations are mass of component per cubic meter of stack gas STP wet (g/m^3), emission factors are mass of component per mass of wet wood burned (g/kg), and emission rates are mass of component emitted per hour (g/hr). All reported effects are the result of the analyses of variance performed by the half-factorial statistical test design.

8.1 BURN RATE

A. The effects of increasing burn rate (kg wood burned/hr) at a 90% or better confidence limit are:

1. The stove and stack gas temperatures increase significantly, as much 140° C and 170° C, respectively. Maintaining higher temperatures may contribute to better combustion efficiency, and thus, lower total organic, particulate, and carbon monoxide emissions
2. Carbon dioxide emissions are increased while carbon monoxide emissions are decreased
3. Particulate matter (probe wash and filter catch) concentration and emission factors decrease. At high burn rates, particulate concentrations and emission factors are lower, but the stack flow rate is higher; at low burn rates, particulate concentrations and emission rates are higher, but the stack flow is lower. These effects tend to cancel, such that wood load has the most significant effect on particulate emission rates
4. Gravimetric compounds (> 300° b.p.) emissions decrease
5. TCO (100°-300° C) b.p. emissions decrease
6. Total extractable organic emissions decrease
7. C_1-C_7 concentration and emission factors decrease
8. H_2O emission rates increase but H_2O emission factors decrease
9. Benzo(b) fluoranthene emission factor (mg/kg wet wood) increases
10. Potassium emissions increase
11. Manganese concentration and emission rate increase
12. Sulfur emissions increase

13. Zinc concentration increases

14. Mutagenic activity as measured by TA98+S9 increases

B. The effects of increasing burn rate (kg wood burned/hr) at just under a 90% confidence limit are:

1. Naphthalene, phenanthrene, fluoranthene, pyrene, chrysene, benzo(b) fluoranthene, and benzo(a) pyrene, emission rates all increase.

2. Naphthalene and fluorene emission factors (mg/kg wood) decrease

3. Chrysene and benzo(b) fluoranthene emission factors increase

4. Benzo(a) pyrene concentration increases

5. TA98-S9 mutagenic activity increases

8.2 WOOD MOISTURE

A. The effects of decreasing wood moisture percent at a 90% or better confidence limit are:

1. Lower stack gas moisture concentration, but particulate emission factor increases as well as CO_2 emission factor.

2. Napthalene concentration decreases.

3. Pyrene emission factor decreases.

4. Cadmium emissions decrease.

5. The weight percent of barium in the ash decreases while the weight percent of aluminum, iron, magnesium, and strontium increase.

6. The Fe/K ratio in the ash increases.

8.3 WOOD TYPE

A. The effects of changing the wood from pine to oak at a 90% or better confidence limit are:

1. Potassium emissions decrease.

2. Manganese emissions decrease.

3. Zinc emission factor decreases.

4. The weight percent in ash of barium, calcium, and strontium increase.

5. The weight percent in ash of aluminum, manganese, magnesium, and zinc decreased.

6. The iron to potassium ratio decreases.

B. Effects of changing the wood from pine to oak just under a 90% or better confidence limit are:

   1. Acenaphthylene, phenanthrene, anthracene, and pyrene emission factors decrease.

   2. Particulate emission factor increases.

   3. Gravimetric and TCO concentrations and emission rates decrease.

   4. Total extractable organic concentration decreases.

   5. Mutagenic activity as measured by TA98+S9 and -S9 decreases.

8.4 WOOD LOAD

A. The effects of increasing wood load at 90% or better confidence limit are:

   1. Stack flow increases.

   2. Particulate emission rate increases.

B. Effects of increasing wood load just under a 90% confidence limit are:

   1. Mutagenic activity (TA98-S9) decreases.

9.0 DATA QUALITY ASSURANCE/QUALITY CONTROL AND CALCULATIONS

9.1 PROCEDURES USED TO ASSESS DATA PRECISION, ACCURACY, AND COMPLETENESS

For each major measurement parameter, the completeness, precision, and accuracy of the measurement data has been compiled. Completeness is a measure of the number of acceptable samples or datapoints actually obtained divided by the number which were planned. Ways in which a sample can become "incomplete" or voided included not collecting the sample, sampling incorrectly, losing or breaking the sample in shipment, improper sample preservation, or consuming the whole sample in a voided analysis.

Precision of measurements are assessed on the basis of range (R) or relative range (RR) for analysis of replicate pairs. R and RR are defined as follows:

$$R = \text{maximum} - \text{minimum value}$$

$$RR = (100\ R/\bar{X}) \tag{9-1}$$

Accuracy is assessed as bias (B) or percent bias (%B) for the analysis of performance evaluation samples. B and %B are defined as follows:

$$B = \bar{X} - T$$

$$\%B = 100\%\ (\bar{X} - T)/T \tag{9-2}$$

where:

$\bar{X}$ = the average value of a set of measurements

T = the reference value of the standard

Completeness is defined as a percent by the amount of valid data (D_v) collected and the amount of data planned (D_p).

$$C\% = \frac{D_v}{D_p} \times 100\ . \tag{9-3}$$

Table 9.1.1 lists projected objectives for precision accuracy and completeness with actual achieved precision accuracy and completeness.

TABLE 9.1.1. PRECISION ACCURACY AND COMPLETENESS RESULTS

Measurement	Projected objective			Actual results		
	Precision	Accuracy	Completeness	Precision	Accuracy	Completeness
Gravimetric	± 20%	± 0.01 mg	100%	2.7 ± 3.4%	± 0.01 mg	100%
Total Chromatographic HC	± 15%	± 15%	100%	10.6 ± 10.8	< 10.4%	100%
Total FID HC[a]	± 1% full scale	± 1%	100%	--	--	0[a]
C_1 - C_7 HC	± 10%	± 20%	100%	11% Dup. inj. 25% Dup. test.	12.8 ± 2.2%	89%
PAH[b]	± 10%	± 20%	100%	C	C	100%
Elemental[c]			100%			50%
CO conc.	± 1% full scale	± 1% full scale	100%	± 1% full scale	± 1% full scale	100%
CO_2 conc.	± 1% full scale	± 1% full scale	100%	± 1% full scale	± 1% full scale	100%
O_2 conc.	± 1% full scale	± 1% full scale	100%	± 1% full scale	± 1% full scale	100%
Retene[d]	--	--	100%	--	--	0%
Levoglucosan[e]	--	--	50%	--	--	0%
Wood moisture	± 1%	6-20%; ± 0.5%	100%	± 1%	6-20% ± 0.5%	100%
(Moisture meter)		20-30%; ± 2%			20-30%; ± 2%	

[a] FID results were rejected.

[b] PAH QA/QC results are in Radian reports in Appendix A and B.

[c] Elemental QA/QC results are in Acurex ICAP report in Appendix D.

[d] Retene analyses was not performed.

[e] Levoglucosan analyses was not performed.

9.2 TOTAL CHROMATOGRAPHABLE ORGANICS

Total chromatographable organics (TCO) analyses were performed on all methylene chloride PWF and CWX samples for each woodstove test. A detailed description of the TCO procedures followed is given in Appendix C. Individual standards were prepared from pure heptane (C_7), decane (C_{10}),dodecane (C_{12}), tetradecane (C_{14}), and hexadecane (C_{16}). C_7 and C_{16} retention times (RT) are used solely as markers to bracket the 100° C to 300° C hydrocarbon range. The TCO procedure specified heptadecane (C_{17}), as the upper RTmarker, however, C_{16} was used for this analyses. The peak areas for C_{16} were included in the calculations. This slight variation on the procedure should not significantly effect the TCO results.

Precision was measured by performing duplicate injections on known standards as well as all samples analyzed. Initially, duplicate injections were made of individual C_{10}, C_{12}, and C_{14} standards prepared at 20 mg/L. The relative ranges of the C_{10}, C_{12}, and C_{14}, duplicates at 20 mg/L were 14%, 3.4%, and 0% respectively. Several standard mixtures were prepared with C_{10} + C_{12} + C_{14} concentrations totaling 59.8, 119.5, 239.1, and 522.9 mg/L. Each hydrocarbon was approximately the same concentration within each standard. Each standard mixture was injected twice and an average area was calculated for each hydrocarbon. The average areas of each hydrocarbon were then added to obtain an area for each standard mixture. The relative ranges for C_{10}, C_{12}, and C_{14}, standard mixture duplicate injections are given below:

Total Mixture Concentration (mg/L) (C_{10} + C_{12} + C_{14})	Relative Range of Total Standard Areas
59.8	1.0%
119.5	1.2%
239.1	3.6%
522.9	19.0%

Although the relative range for the highest standard concentration (522.9 mg/L) was 19%, the calibration point for that concentration fit nicely on the calibration curve generated. The points of the calibration curve produced a linear correlation coefficient of 0.996.

Precision was also measured by performing duplicate injections on all samples analyzed. Total TCO for each woodstove test is the combined total of the PWF and CWX analyses. The PWF samples typically contained very low amounts of hydrocarbon compared to the CWX portions. This effect is not surprising since the PWF (probe wash and filter) is from the heated portion of the sampling train (>200° C) and the CWX (condenser wash; XAD) is from the cooled organic collecting portion of the train. PWF TCO values were all calculated on the lower end of the calibration curve due to their lower organic content, and the average relative range for duplicate injections was 35.6 ± 17.8%. Contributions of the PWF to the total TCO concentration were typically less than 1% of the total, therefore, this seemingly wide relative range has little effect on the total values of TCO reported.

Greater than 99% of the TCO was contributed by the CWX portions for each test. The analytical values generated by the GC chromatograms were typically in the mid-ranges of the generated calibration curve. Five of the nine relative ranges for the duplicate analyses were under 5%; one was 13%, and three were in the 20% range. Those duplicates in the 20% relative range were the most concentrated samples which had been diluted to give areas which were on the uppermost portion of the calibration curve. This probably accounts for the higher relative range for those three duplicate results. The precision objective was 15%. The average relative range for the entire CWX analyses consisting of ten sets of duplicates was 10.6 ± 10.8%. The high standard deviation measured here is due primarily to the three analyses which provided a relative range at the 20% level. Since the remaining seven relative ranges were less than 15%, the precision objective was satisfied for most of the TCO analyses. Time and budgetary constraints prevented continued dilution and re-analyses of the three 20% relative range outliers, however, the data is still useful in the statistical test design since the overall trend would still show a higher TCO for those runs compared to others even though the precision is slightly less.

Accuracy of the TCO analyses was assessed by injecting a known standard mixture of the C_{10}, C_{12}, and C_{14} hydrocarbons each day prior to sample analyses. Percent bias given in equation (9-2) is used to evaluate accuracy. On six occasions, a 60 mg/L TCO standard was used. Those six analyses provided a 5.4% bias for accuracy. On one occasion, a 240 mg/L TCO standard was used which was analyzed to within 10.4%. On another occasion, a 480 mg/L TCO standard was used and provided a bias of 1.4%. The accuracy objective of data quality was 15%. These analyses document an acceptable measure of accuracy and are well within the 15% accuracy objective as given by the TCO procedure in Appendix C.

9.3 GRAVIMETRIC ANALYSES

Gravimetric analyses were performed according to procedures outlined in Appendix C. The results of the gravimetric analyses are added to the results of the TCO analyses for each run. This provides total extractable organic (TEO) results for each test.

For gravimetric analyses, a known aliquot (between 1-5 ml depending on the degree of concentration) of the concentrated samples is placed in a weighed, desiccated aluminum pan. It is placed in a hood and covered until dry, usually 24-48 hours. It is then desiccated for 8-10 hours and reweighed for the mass of the residue. All weighings were preformed on a recently calibrated Mettlar HR51A analytical balance. The samples which were analyzed gravimetrically included the concentrated methylene chloride condenser wash, XAD-2 extract (CWX-CH_2Cl_2), the concentrated methylene chloride probe wash, filter extract (PWF-CH_2Cl_2), the methanol probe wash, and the methanol condenser wash. For each woodstove test, the total of these four samples constituted the gravimetric mass. Blank solvents and several duplicates were also analyzed.

The gravimetric values were corrected by subtracting the blank results within each set of analyses. Two duplicate gravimetric analyses were performed to assess precision in each category of samples as previously described here. The duplicates analyzed had the following percent agreement: 99.9, 99.6, 99.6, 98.8, 89.0, 99.8, 96.7, and 94.4%. All fell well within the specified 80% agreement range specified by the procedure which is described in Appendix C. The average precision was 97.2 ± 3.8%. The accuracy of the HR51A analytical balance is ±0.01 mg.

9.4 C_1-C_7 HYDROCARBONS

Considerable problems were encountered in obtaining C_1-C_7 hydrocarbon analyses. First, a sample was not available from the first woodstove test number 50403. A teflon sampling pump which was purchased just for C_1-C_7

sampling became fouled and failed early in the test. In subsequent tests, bag samples were taken from the bypass on a Beckman 400 FID which sampled via a heated stainless steel line to the stove. Bag samples were collected in 44 liter gas sampling bags which were purchased from Calibrated Instruments, Inc. The sample interval varied from one to two hours, and occurred during the "steady state" burn rate of the Modified Method 5 sampling period. Upon completion of sample collection, the bags were labeled and sent directly to IEA for same day analyses. The bags were not heated prior to analyses.

Results were obtained from IEA after the sample from the final woodstove test was analyzed. RTI found the initial report obtained from IEA to be in error. IEA then sent RTI a revised report which also was found to be in error. RTI then obtained all analytical raw data from IEA and performed the analytical calculations.

C_1-C_7 gas samples were measured with gas chromatography-FID. The GC column was 0.19% Picric acid on Carbopac C. The chromatographic temperature conditions are not known to RTI. The FID was calibrated with 5 ml of a gas standard obtained from Supelco. The standard contained 100 ± 5 ppm each of methane, ethane, propane, butane, pentane, and hexane. Sample volumes were also 5 ml. Response factors were calculated from the standard injections and were used to calculate the C_1-C_7 hydrocarbon concentrations in the sample. It is regretable that only a one point calibration was performed and that only a single column retention time was available for sample identification, but this was the extent of the analytical procedure. Retention times were assigned on the basis of the standard injections. After each standard peak, peaks were assigned to the next higher aliphatic standard since the n-chained aliphatics generally all have higher boiling points than their isomers. So, for example, peaks between the butane and pentane standard peak were all assigned to pentane. This does not preclude the possibility of some isomers being included in the wrong class. It was not the intention of this analyses to provide an extremely accurate account of individual C_1-C_7 hydrocarbon species. Rather, a broader analyses of hydrocarbon classes (i.e., all C_6) was desired. Given the simplified method of instrument calibration and compound identification, an even broader analyses was performed and a sum of the C_1-C_7 hydrocarbons was used in the statistical analyses of these emissions. Missing data from the first woodstove test was estimated for the analyses of variance in the half-factorial design by using a statistically valid technique. A much more stringent correlation is required to show the cause and the main effect using this technique. The ANOVA analyses reported on the C_1-C_7 hydrocarbons indicate correlations between test variables and emissions even with a more stringent requirement for correlation. The data obtained from this analyses is valid to the point of showing trends of total C_1-C_7 hydrocarbon emissions with respect to stove operating parameters.

Precision was estimated by duplicate sample analyses and by sampling a duplicate woodstove test. Three sample injections were performed on sample 50515 and the average percent standard deviation between the three injections was 11%. Samples 50411, 50417, 50424, and 50528 were analyzed in duplicate. Percent differences between injections were generally low for the lower hydrocarbons C_1, C_2, C_3, and increased as the carbon number increased. A substantial decrease in concentration occurs as the number of carbons increase. The concentrations of the higher molecular weight hydrocarbons are low enough that even a small change in the duplicate analytical results of a particular compound could make a large percent difference for that compound. However, the contribution made by the higher molecular weight aliphatics to the total C_1-C_n7 is minimal and the percent changes reflect very little change in the total C_1-C_7 concentration. Duplicate woodstove tests provided a measure of repeatability between tests. A percent difference of 25% was obtained between duplicate woodstove tests (numbers 2 and 10).

Accuracy was assessed by injecting the standard C_1-C_7 each day prior to analyses. The average standard deviation of a known concentration from the analyzed concentration was 12.8 ± 2.2%. Actual C_1-C_7 raw data is shown in Table 9.4.1. Duplicate injection results are shown in Table 9.4.2.

9.5 POLYCYCLIC AROMATIC HYDROCARBONS

A capillary GC/MS analyses was performed by Radian Corporation under EPA Contract No. 68-02-3994 entitled, "Analyses of Woodstove Samples," on cleaned composite sample extracts from each woodstove test. The composite samples consisted of PWF methylene chloride and CWX methylene chloride portions of the MM5 sampling train. Composite samples were generated in volumetric proportions to the amount of each PWF and CWX sample obtained from each test.

TABLE 9.4.1. C_1 - C_2 RAW DATA USED.

RUN # 50411

	STD AREA	C (ug/ml)	RF	SAMP A1	SAMP A2	CONC 1	CONC 2	AVE CONC	%DIFF
METHANE C1	2.864	0.0725	7.903	78.220	115.497	1.98	2.92	2.45	-38%
ETHANE C2	5.218	0.1359	7.600	45.414	32.852	1.18	0.86	1.02	32%
PROPANE C3	8.147	0.1992	8.178	12.639	25.390	0.31	0.62	0.47	-67%
BUTANE C4	10.868	0.2626	8.277	10.672	23.692	0.26	0.57	0.42	-76%
PENTANE C5	##	0.3261	7.311	2.962	16.137	0.08	0.44	0.26	-138%
HEXANE C6	14.235	0.3894	7.311	10.341	5.700	0.28	0.16	0.22	58%
HEPTANE C7	##	##	7.311	2.581		0.07	0.00		
TOTAL						4.16	5.57		

RUN # 50417

	STD AREA	C (ug/ml)	RF	SAMP A1	SAMP A2	CONC 1	CONC 2	AVE CONC	%DIFF
METHANE C1	3.696	0.0725	10.199	112.102	107.387	2.20	2.11	2.15	4%
ETHANE C2	7.339	0.1359	10.001	41.497	40.179	0.77	0.74	0.76	3%
PROPANE C3	11.462	0.1992	11.506	30.689	28.699	0.53	0.50	0.52	7%
BUTANE C4	15.220	0.2626	11.592	30.183		0.52			
PENTANE C5	18.008	0.3261	11.044	17.965		0.33			
HEXANE C6	20.140	0.3894	10.344	9.247		0.18			
HEPTANE C7	##	##	10.344	5.733		0.11			
TOTAL						4.64			

RUN # 50424

	STD AREA	C (ug/ml)	RF	SAMP A1	SAMP A2	CONC 1	CONC 2	AVE CONC	%DIFF
METHANE C1	2.056	0.0725	7.001	10.231	10.114	0.26	0.26	0.26	1%
ETHANE C2	8.307	0.1359	12.226	31.600	25.390	0.52	0.42	0.47	22%
PROPANE C3	11.127	0.1992	11.169	2.937	2.594	0.05	0.05	0.05	12%
BUTANE C4	13.629	0.2626	10.380	6.090	1.621	0.12	0.03	0.07	116%
PENTANE C5	15.168	0.3261	9.303	11.990	0.872	0.26	0.02	0.14	173%
HEXANE C6	##	0.3894	9.754	7.253	7.573	0.15	0.16	0.15	-4%
HEPTANE C7	##	##	9.754			0.00	0.00		
TOTAL						1.35	0.92		

RUN # 50501

	STD AREA	C (ug/ml)	RF	SAMP A1	CONC 1
METHANE C1	3.173	0.0725	8.756	53.704	1.23
ETHANE C2	9.625	0.1359	14.166	57.933	0.82
PROPANE C3	12.336	0.1992	12.383	12.450	0.20
BUTANE C4	14.759	0.2626	11.241	9.462	0.17
PENTANE C5	16.497	0.3261	10.118	11.083	0.22
HEXANE C6	##	0.3894	9.754	8.927	0.18
HEPTANE C7	##	##	9.754	0.000	0.00
					2.82

RUN # 50508

	STD AREA	C (ug/ml)	RF	SAMP A1	SAMP A2	CONC 1	CONC 2	AVE CONC	%DIFF
METHANE C1	3.274	0.0725	9.034	5.173	4.997	0.11	0.11	0.11	3%
ETHANE C2	6.482	0.1359	9.540	3.564	3.438	0.07	0.07	0.07	4%
PROPANE C3	10.023	0.1992	10.061	0.522	0.495	0.01	0.01	0.01	5%
BUTANE C4	13.256	0.2626	10.096	0.415	0.389	0.01	0.01	0.01	6%
PENTANE C5	15.455	0.3261	9.479	0.097	0.099	.00	.00	.00	-2%
HEXANE C6	18.924	0.3894	9.720	0.833	0.876	0.02	0.02	0.02	-5%
HEPTANE C7	##	##	9.720	0.401	0.529	0.01	0.01	0.01	-28%
						0.24	0.23		

TABLE 9.4.1 (Continued)

	RUN #	50515									
	STD AREA	C (ug/ml)	RF	SAMP A1	SAMP A2	SAMP A3	CONC 1	CONC 2	CONC3	AVE CONC	%STDEV
METHANE C1	4.435	0.0725	12.238	67.628	62.349	85.704	1.11	1.02	1.40	1.17	14%
ETHANE C2	8.347	0.1359	12.285	46.636	44.006	59.725	0.76	0.72	0.97	0.82	14%
PROPANE C3	12.374	0.1992	12.421	10.706	10.308	13.276	0.17	0.17	0.21	0.18	12%
BUTANE C4	14.691	0.2626	11.189	7.803	7.362	9.044	0.14	0.13	0.16	0.14	9%
PENTANE C5	15.553	0.3261	9.539	4.230	3.918	4.72	0.09	0.08	0.10	0.09	8%
HEXANE C6	16.368	0.3894	8.407	11.661	10.502	13.812	0.28	0.25	0.33	0.29	11%
HEPTANE C7	**	**	8.407	2.405	2.102	2.543	0.06	0.05	0.06	0.06	8%
							2.60	2.41	3.24		

	RUN #	50522			
	STD AREA	C (ug/ml)	RF	SAMP A1	CONC 1
METHANE C1	3.829	0.0725	10.566	118.938	2.25
ETHANE C2	7.458	0.1359	10.977	45.740	0.83
PROPANE C3	11.624	0.1992	11.668	36.916	0.63
BUTANE C4	15.449	0.2626	11.766	33.368	0.57
PENTANE C5	18.430	0.3261	11.303	27.665	0.49
HEXANE C6	20.615	0.3894	10.588	13.980	0.26
HEPTANE C7	**	**	10.588	5.914	0.11
					5.15

	RUN #	50605			
	STD AREA	C (ug/ml)	RF	SAMP A1	CONC 1
METHANE C1	3.690	0.0725	10.182	121.288	2.38
ETHANE C2	7.354	0.1359	10.823	41.672	0.77
PROPANE C3	11.505	0.1992	11.549	59.783	1.04
BUTANE C4	15.473	0.2626	11.784	32.031	0.54
PENTANE C5	18.445	0.3261	11.312	18.201	0.32
HEXANE C6	20.641	0.3894	10.601	8.038	0.15
HEPTANE C7	**	**	10.601	1.569	0.03
					5.23

	RUN #	50612			
	STD AREA	C (ug/ml)	RF	SAMP A1	CONC 1
METHANE C1	3.995	0.0725	11.024	164.972	2.99
ETHANE C2	8.070	0.1359	11.877	48.688	0.82
PROPANE C3	12.669	0.1992	12.717	82.549	1.30
BUTANE C4	17.023	0.2626	12.965	37.690	0.58
PENTANE C5	20.090	0.3261	12.321	24.485	0.40
HEXANE C6	22.186	0.3894	11.395	11.522	0.20
HEPTANE C7	**	**	11.395	3.116	0.05
					6.35

TABLE 9.4.2. C_1 - C_2 DUPLICATE INJECTIONS

		STD AREA	%STDEV	RF	STDEV	CONC 1
METHANE C1	AVE	3.5		9.753		11.01
	STD	0.5	14%	1.385	14%	26.42
ETHANE C2	AVE	7.6		11.153		7.28
	STD	1.2	16%	1.731	16%	18.54
PROPANE C3	AVE	11.3		11.295		1.93
	STD	1.3	12%	1.332	12%	4.03
BUTANE C4	AVE	14.5		11.032		1.31
	STD	1.6	11%	1.252	11%	2.74
PENTANE C5	AVE	17.2		10.192		0.76
	STD	1.7	10%	1.406	14%	1.41
HEXANE C6	AVE	19.0		9.764		1.69
	STD	2.6	14%	0.000	0%	4.29
HEPTANE C7						0.33
						0.79

Sample calculations are provided for Test Number 4 in Section 9.9. The important aspect of sample preparation in this manner is that volumetric ratio of the amount of CWX to PWF present in separate vials be retained in the composite sample. Thus, for Test Number 4, 14 ml each of CWX and PWF were present initially, so the composite sample consisted of a 1:1 mixture of the two. Composite samples were then cleaned by RTI via EPA Method 610 silica gel column procedures. The volume of column eluate was recorded, and known aliquot volumes were sent to Radian Corporation for capillary GC/MS PAH analyses.

No audit sample was sent to Radian by RTI, however, a solvent blank was sent. No PAH compounds were found in the blank solvent. Quality assurance, quality control for the RTI PAH sample analytical determinations are described in the Final Draft of Radian's report entitled, "Analysis of Woodstove Emissions Samples," EPA Contract 68-02-3994, Work Assignment Number 38. Excerpts from that report which are relevant to the PAH TCO, PAH GRAV, and PAH GC/MS analyses performed on the RTI samples under that contract by Radian appear in Appendix B. The data obtained from Radian for Gravimetric, TCO, and Capillary GC/MS PAH results on RTI cleaned composite samples appears in Appendix A.

9.6 ELEMENTAL ICAP ANALYSES

All analytical quality control procedures are discussed for the ICAP elemental analyses in the Acurex report contained in Appendix D.

9.7 SYSTEM AND DATA QUALITY AUDITS

During the woodstove testing program, RTI conducted an internal audit on the operation of the woodstove and the test system. The RTI internal systems audit was performed by Mike Messner, who is RTI's Quality Assurance Officer for this project. The systems audit is contained in Appendix F.

A Systems audit and Audit of Data Quality was performed by Dave Taylor of S-cubed. Judy Ford and Gary Johnson of the Environmental Protection Agency were also present during the S-cubed systems audit.

Several points were raised in the audit of Data Quality and are outlined below with a description of the corrective action taken.

1. RTI should indicate the criteria used to distinguish the different molecular weight species in the C_1-C_7 hydrocarbon analyses.

   The C_1-C_7 analytical procedures and methods of data interpretation are presented in Sections 6.2 and 9.4 of this report. Section 9.4 details the analytical problems encountered and the final method of data interpretation for these results.

2. RTI should report, if available, the GC's linear concentration range for the C_1-C_7 hydrocarbon analyses.

   The linear concentration range of the GC used at IEA for the C_1-C_7 hydrocarbon analyses was not available. Discussion associated with C_1-C_7 analyses are found in Section 9.4 of this report.

3. An explanation should be provided, if possible, for the wide variation on some runs between C_1-C_7 duplicates.

   See Section 9.4.

4. The report should address the off-scale standard peaks in the TCO analysis and indicate whether this impacted the results. Ideally, either a curve that is completely on scale should be obtained, and the linear range of the detector should be demonstrated so that the calibration used in the TCO calculations can be verified.

   There were no "off-scale" standard peaks in the TCO analyses. The recorder on the Sigma 10 console was not attenuated to allow the peaks to be recorded in full on paper, however, the signal to the integrator was well within the linear range of the instrument, and the whole peak was integrated. This can be demonstrated from the calibration curve which was produced which has a correlation coefficient of 0.996. Section 9.2 and Appendix C discuss the QA/QC for TCO analyses and the analytical procedures.

5. RTI should document their TCO method and check that the use of C_{10}, C_{12}, and C_{14} standards give comparable results to using C_8, C_{12}, and C_{16} standards.

   Sections 9.2 and Appendix C document the procedures used and the data quality objectives.

6. The PAH analyses should be documented in detail, especially the QA/QC checks, so that the quality of the data can be evaluated by all readers of the final report.

   The PAH analyses is documented in the Radian report contained in Appendices A and B. Excerpts are also available in Appendix B which document the QA/QC procedures used by Radian under the contract which analyzed the RTI samples.

9.8 PRECISION OF A DUPLICATE WOODSTOVE TEST

An attempt was made to show the repeatability of a woodstove test. Woodstove tests No. 2 and No. 10 were duplicate tests as shown in the summary of data collected in Section 7.1. Where applicable, percent differences are listed in the last column in each Table. Runs 2 and 10 were placed near the beginning and the end of the project test timetable. For some conditions, there is a large percent difference between the two runs. One possible explanation for some large percent differences is that "refinement" of testing procedures had occurred during the course of the experiment. Overall, the differences do not appear to be outside a normal range of experimental error. Many different factors may influence the performance of a woodstove from one day to another. Longer or shorter sample times, whether or not particulate filters were clogged and changed during a test, or the difference in relative humidity of ambient air from one test to another are just a few examples which may affect the repeatability of a woodstove test.

The four stove operating variables chosen for this half-factorial experimental design were controlled very closely. The statistical analyses of each variable on an emission or operating characteristic in this test design also allows for a measure of experimental error. Each ANOVA Table has a measure of error associated with the change in a measurement as well as a measure of change associated with an operating parameter. The error term is discussed in detail in Section 5. The difference in repeatability of a woodstove test is a part of the overall statistical analyses of the test matrix. The duplicate tests provided in this report serve as an example of the magnitude of percent difference which can be observed when operating a woodstove. Even with the observed differences in duplicate tests, the statistical test plan controlling four important variables can still be used to show the effects of changes in emissions due to changes in those variables.

9.9 CALCULATIONS USED WITH AN EXAMPLE FROM TEST NO. 4

CALCULATIONS:

Standard Temperature and Pressure (STP) is 20° C, 1 atm

DRY GAS VOLUME SAMPLED DURING METHOD 5:

$$V_{G,STP} = V_m \gamma \left(\frac{T_{STP}}{T_m}\right) \left(\frac{P_{BAR} + \frac{\Delta H}{0.535}}{P_{STP}}\right) C_1$$

$V_{G,STP}$ = Dry gas volume sampled during Method 5, m^3 STP

V_m = Gas volume measured by dry test meter, ft^3

γ = Average dry test meter temperature, °R

P_{BAR} = Barametric pressure, mm Hg

ΔH = Average pressure differential across orifice meter, inches of H_2O

C_1 = Conversion factor 0.028317 $m^3 ft^3$

T_{STP} = 527.7 °R

P_{STP} = 760 mm Hg

VOLUME OF WATER COLLECTED DURING METHOD 5 SAMPLING:

$$V_{W,STP} = \frac{nRT}{P} = \frac{\left(\frac{W_{H_2O}}{MW_{H_2O}}\right)(R)(T_{STP})}{P_{STP}}$$

$V_{W,STP}$ = Volume of water collected during Method 5 sampling, as a gas at STP

W_{H_2O} = Weight of H_2O collected during Method 5, includes condensate and impingers, g

W_{H_2O} = Molecular weight of water, 18.015 g/mol

R = Gas constant, $8.206 \times 10^{-5} \frac{m^3\ atm}{mol\ ^\circ K}$

T_{STP} = 293.2 °K

P_{STP} = 1 atm

MOISTURE CONTENT OF FLUE GAS:

$$X_{H_2O} = \frac{V_{W,\ STP}}{V_{W,STP} + V_{G,STP}}$$

X_{H_2O} = Water fraction in flue gas

FLUE GAS FLOW RATE:

$$F_{FG,STP} = V_{FG}\ A_{CS} \left(\frac{T_{STP}}{T_{STK}} \right) \left(\frac{P_{BAR}}{P_{STP}} \right) C_2$$

$F_{FG,STP}$ = Flue gas flow rate at STP, m^3/min

V_{FG} = Velocity of flue gas, ft/min

A_{CS} = Cross sectional area of flue, 0.3491 ft^2

T_{STK} = Flue gas temperature, °K

T_{STP} = 293.2 °K

C_2 = 0.02317 m^3/ft^3

P_{BAR} = Barametric pressure, mm Hg

P = 760 mm Hg

BURN RATE:

$$BR = W_w/t_{m5}$$

BR = Burn rate during Method 5 sampling, kg/hr

W_w = Weight of wood burned during Method 5, kg

T_{m5} = Method 5 sampling time, hr

METHOD 5 SAMPLE RATE:

$$SR_{m5} = V_{G,STP}/t_{m5}$$

SR_{m5} = Sample rate during Method 5, m^3 STP/min

$V_{G,STP}$ = Gas volume sampled during Method 5, m^3 STP

t_{m5} = Method 5 sample time, min

C_1-C_7 CALCULATIONS:

RESPONSE FACTORS:

$$RF_i = \frac{A_{i,s}}{C_{i,s}V}$$

RF_i = Response factor for i, area/µg

$A_{i,s}$ = Measured area of i th peak, area

$C_{i,s}$ = Concentration of i th component in standard, µg/ml

V = Injected volume of standard, ml

i = C_1, C_2, C_3, C_4, C_5, C_6

CONCENTRATION:

$$C_i = \frac{A_i}{RF_i V}$$

C_i = Concentration of component, μg/ml

A_i = Measured area of ith peaks, area

RF_i = Response factor for i, area/μg

V = Injected volume of sample, ml

EMISSIONS IN g/m^3 STP:

CO, CO_2, O_2, HC, H_2O

Molar Gas Volume at 20° C

$$\left(\frac{V}{n}\right) = \frac{RT_{STP}}{P_{STP}} = \frac{\left(8.205 \times 10^{-5} \frac{m^3\ atm}{mol\ °K}\right)\left(293.2\ °K\right)}{1\ atm} = 0.02406\ \frac{m^3}{ml}$$

CO, CO_2, O_2

$$C_i = \frac{\left(MW_i\right)}{\left(\frac{V}{n}\right)_{STP}} \left(\frac{\%i}{100}\right)\left(1-X_{H_2O}\right)$$

i = CO, CO_2, O_2

C_i = Concentration of i in flue gas, g/m^3 STP

MW_i = Molecular weight of i

%i = % of i in dry gas, average over Method 5

X_{H_2O} = mole fraction water in flue gas

$\left(\frac{V}{n}\right)_{STP}$ = molar gas volume at STP, 0.2406 $\frac{m^3}{mol}$

H_2O

$$C_{H_2O} = \frac{\left(MW_{H_2O}\right)}{\left(\frac{V}{n}\right)_{STP}} X_{H_2O}$$

C_1-C_7 HYDROCARBONS

$$C_{C_1\ C_7} = (C_1\ C_7)\ (1-X_{H_2O})$$

$C_1\ C_7$ = total C_1 - C_7 hydrocarbons, g/m^3

PARTICULATES:

$$C_{PART} = \frac{\left(P_F + P_P\right)}{\left(V_{G,STP}\right)} \left(1-X_{H_2O}\right)$$

P_F = Weight of particulates collected on filter, g

P_P = Weight of particulates collected on probe, from CH_2Cl_2 and CH_3OH wash, g

TOTAL CHROMATOGRAPHABLE ORGANICS (TCO):

$$C_{PART} = \frac{\left(C_{L,i}\right)\left(V_{L,\ i}\right)}{\left(V_{G,STP}\right)} \left(1-X_{H_2O}\right)$$

i = CWX (Condenser Wash and XAD), PWF (Probe Wash and Filter)

$C_{L,i}$ = Concentration of TCO in liquid sample, i, g/ml

$V_{L,i}$ = Volume of liquid sample i, ml

GRAVIMETRIC HYDROCARBONS (GRAV):

$$C_{GRAV,i} = \frac{\left(\frac{W_{Res,\ A}}{VA}\right) V_{L,i}}{\left(V_{G,STP}\right)} \left(1-X_{H_2O}\right)$$

i = CWX, PWF

$W_{Res,A}$ = Weight of residue from an aliquot (V_A) from sample i, g

V_A = Volume of aliquot from $V_{L,i}$, ml

$V_{L,i}$ = Volume of liquid sample i, ml

TOTAL EXTRACTABLE ORGANICS (TEO):

$$C_{TEO} = \left(C_{TCO} + C_{GRAV}\right)_{PWF} + \left(C_{TCO} + C_{GRAV}\right)_{CWX}$$

INDIVIDUAL PAH COMPOUNDS (mg/m^3

$$C_{i,PAH} = \frac{W_{i,\ PAH}}{(10^3)V_{C,ANA}} \frac{V_{C,COL}}{V_{COMP}} \frac{V_{CWX\ +\ PWF}}{V_{G,STP}} 1-X_{H_2O}$$

$C_{i,PAH}$ = Concentration of PAH compound in flue gas, mg/m^3

i = PAH compound

$W_{i,PAH}$ = mass of PAH compound in $V_{C,ANA}$, μg

$V_{C,ANA}$ = Volume of cleaned composite sample analyzed, ml

$V_{C,COL}$ = Volume of cleaned composire sample after cleanup, ml

$V_{CWX+\ PWF}$= Combined volume of CWX + PWF samples, ml

V_{COMP} = Volume of composite sample cleaned, ml

TOTAL GCMS PAH

$$C_{GCMS} = \Sigma\, C_{i,PAH}$$

ELEMENTAL ANALYSIS OF COLLECTED PARTICULATE

$$C_{i,ELE} = \frac{W_{i,ELE}}{V_{G,STP}} \quad X_{H_2O}$$

$C_{i,ELE}$ = Concentration of metal element in flue gas ($\mu g/m^3$

$W_{i,ELE}$ = Mass of element measured in collected particulate, μg

PAH SPOT TEST:

$$C_{PAH,i} = \frac{\left(100\ \frac{\mu g}{ml} \times\ 10^{n-1}\right)\left(V_L\right)}{\left(10^6\right)\left(V_{G,STP}\right)} \left(1-X_{H_2O}\right)$$

i = CWX, PWF

$100\ \frac{\mu g}{ml}$ = Assumed detection limit for PAH glow

n = Number of successive 1:10 dilutions required for disappearance of PAH glow

V_L = Volume of liquid sample, ml

EMISSIONS IN g/hr:

$$R_i = C_i \bullet F_{FG,STP} \bullet (60\ \text{min/hr})$$

R_i = Emission rate g/hr

C_i = Concentration of i in flue gas, g/m^3 STP

$F_{FG,STP}$ = Flue gas flow rate, m^3/min

i = CO, CO_2, O_2, HC, H_2O, C_1-C_7, PART, PAH

EMISSIONS IN g/kg WOOD:

$$E_i = R_i / BR$$

E_i = Emission factor, g/kg wood burned

R_i = Emission rate, g/hr

BR = Burn rate, kg/hr

i = CO, CO_2, O_2, HC, H_2O, C_1-C_7, PART, PAH

CALCULATIONS FOR MUTAGENICITY DATA

$$\text{Reported concentration} \left(\frac{\text{Reversions}}{\mu g}\right) \times \left(g_{GRAV} + g_{TCO}\right) \times 10^{6} \frac{\mu g}{g}$$

$$= \text{Total number of reversions in collected sample}$$

$$\frac{\left(\text{Total reversions}\right)}{m^{3}\ \text{STP gas sampled}} = \text{Reversions}/m^{3}\ \text{STP Wet (in flue gas)}$$

$$(\text{Reversions}/m^{3}\ \text{STP wet}) \times (\text{Flue flow } m^{3}\ \text{STP/hr}) = \text{Reversions/hr}$$

$$\frac{\text{Reversions/hr}}{\text{Burn Rate kg/hr}} = \text{Reversions/kg wood burned}$$

SAMPLE CALCULATIONS, RUN NO. 50424, TEST NO. 4
UNCURED OAK, LOW WOOD LOAD, HIGH BURN RATE

V_m, measured dry gas volume sampled = 100.04 ft^3

T_m, average dry testmeter temperature = 106 °F

P_{BAR}, barametric pressure = 754 mm Hg

DH, average Δ pressure across orifice meter = 0.75 inches H_2O

W_{H_2O}, weight of water collected = 265.3 g

V_{FG}, velocity of flue gas = 161 ft/min

T_{STK}, flue gs temperature = 249 °C

W_w, weight of wood burned = 25.0 kg

t_{m5}, Method 5 sample time = 219.5 min = 3.658 hrs

%CO_2, average during Method 5 sampling = 6.8%

%CO, average during Method 5 sampling = 0.83%

%O_2, average during Method 5 sampling = 14.7%

C_1-C_7, total C_1-C_7 hydrocarbons = 1.14 mg/L = 1.14 g/m^3

P_F, filter particulates = 0.2365 g

P_p, probe wash particulats = 0.2542 g

W_{TCO}, PWF + CWX = total TCO hydrocarbons = 0.4892 g

W_{GRAV}, n^{P}WF + CWX = total grave hydrocarbons = 1.4416 g

$W_{PAH\ TCO}$ = 12.40 mg

$W_{PAH\ GRAV}$ = 11.25 mg

$W_{NAPHTHALENE,\ PAH}$ = 475.9 μg

$V_{C,ANA}$ = 30.0 ml

$V_{C,COL}$ = 38.0 ml

V_{COMP} = 1.0 = 1.0 = 2.0 ml

$V_{CWX\ +\ PWF}$ = 14.0 + 14.0 = 28.0 ml

$$W_{POTASSIUM,\ ELE} = 1.3884\ \mu g$$

$$V_{G,STP} = (100.4)(1.0)\left(\frac{527.7}{106 + 459.7}\right)\left(\frac{\begin{array}{c}\underline{0.75}\\754 + 0.535\end{array}}{760}\right)\ 0.028317$$

$$V_{G,STP} = 2.636\ m^3$$

$$V_{W,STP} = \frac{\frac{265.3}{18.015}\ (8.206 \times 10^{-5})\ (293.2)}{1.00}$$

$$V_{W,STP} = 0.354\ m^3$$

$$X_{H_2O} = \frac{0.354}{0.354 + 2.636}$$

$$X_{H_2O} = 0.1189 \text{ or } 11.89\%$$

$$F_{FG,STP} = (161)(0.3491)\left(\frac{293.2}{249 + 273.2}\right)(0.02817)\left(\frac{754}{760}\right)$$

$$F_{FG,STP} = 0.894\ m^3/min$$

$$BR_{m5} = 25.0/3.658$$

$$BR_{m5} = 6.83\ kg/hr$$

$$SR_{m5} = 2.636/219.5$$

$$SR_{m5} = 0.0120\ m^3/min$$

$$C_{CO_2} = \left(\frac{44.01}{0.02406}\right)\left(\frac{6.8}{100}\right)\ (1-0.1189)$$

$$C_{CO_2} = 109.6\ g/m^3$$

$$C_{CO} = \left(\frac{28.01}{0.02406}\right)\left(\frac{0.83}{100}\right)\ (1-0.1189)$$

$$C_{CO} = 8.5\ g/m^3$$

$$C_{O_2} = \left(\frac{32.00}{0.02406}\right)\left(\frac{14.7}{100}\right)\ (1-0.1189)$$

$$C_{O_2} = 172.3\ g/m^3$$

$$C_{H_2O} = \frac{18.015}{0.02406} (0.1189)$$

$$C_{H_2O} = 89.0 \text{ g/m}^3$$

$$C_{C_1-C_7} = 1.14 (1-0.1189)$$

$$C_{C_1-C_7} = 1.00 \text{ g/m}^3$$

$$C_{PART} = \frac{(0.2365 + 0.2542)}{2.636} (1-0.1189)$$

$$C_{PART} = 0.16 \text{ g/m}^3$$

$$C_{TCO,\ PWF\ +\ CWX} = \frac{(0.4892)}{2.636} (1-0.1189)$$

$$C_{TCO,\ PWF\ +\ CWX} = 0.1635 \text{ g/m}^3$$

$$C_{GRAV,\ PWF\ +\ CWX} = \frac{(1.4416)}{2.636} (1-0.1189)$$

$$C_{GRAV,\ PWF\ +\ CWX} = 0.4819 \text{ g/m}^3$$

$$C_{TEO} = 0.1635 + 0.4819 = 0.645 \text{ g/m}^3$$

$$C_{NAPHTHALENE,\ PAH} = \frac{4756.9\ (38.0)\ (28)}{10^3(30.0)(2.))(2.636)} (1-0.1189)$$

$$= 28.19 \text{ mg/m}^3$$

$$C_{POTASSIUM,\ ELE} = \frac{13884}{2.636} (1-0.1189)$$

$$= 4641\ \mu\text{g/m}^3$$

$$C_{SPOT\ PAH,\ CWX} = \frac{560000}{10^6\ (2.636)} (1-0.1189)$$

$$C_{SPOT\ PAH,\ CWX} = 0.1872 \text{ g/m}^3$$

$$C_{SPOT\ PAH,\ PWF} = \frac{140000}{10^6\ (2.636)} (1-0.1189)$$

$C_{\text{SPOT PAH, PWF}}$ = 0.0047 g/m^3

$C_{\text{SPOT PAH TOTAL}}$ = 0.1872 + 0.0047 = 0.192 g/m^3

CONVERSION OF CONCENTRATIONS TO EMISSION RATES:

$$R_i = C_i \bullet (0.89) \bullet (60) = 53.4 \bullet C_i$$

EMISSION OF EMISSION RATES TO EMISSION FACTORS:

$$E_i = R_i \ / \ 6.83$$

[illegible]

i	C_i (g/m^3)	R_i (g/hr)	E_i (g/kg wood)	
CO_2	109.6	5353	857	
CO	8.5	454	66.5	
O_2	172.3	9200	1350	
H_2O	89.0	4750	695	
C_1-C_7	1.00	53	7.8	12
Particulate	0.16	8.5	1.24	
TCO, PWF + CWX	0.1635	8.7	1.27	
GRAV, PWF + CWX	0.4819	25.7	3.76	
TEO	0.645	34.4	5.04	
Napthalene	0.0282	1.51	0.22	
Potassium	0.00464	0.25	0.036	

Ei wet • 1.53 = Ei dry

REFERENCES

1. Federal Register, Vol. 50, No. 149, Friday, August 2, 1985, pp. 31504.

2. Trefil, J. Sawing Away at OPEC. Science 80, Vol. 1, No. 5, 1980, pp. 16-18.

3. Imhuff, R. E., and J. A. Manning. Tennessee Valley Authority, Muscle Shoals, Alabama, and William A. Cook and Timothy L. Hayes, Battelle Columbus Laboratories, Columbus, Ohio. Preliminary Report on a Study of the Ambient Impact of Residential Wood Combustion in Petersville, Alabama. In: Proceedings of the International Conference on Residential Solid Fuels, 1981. pp. 520.

4. Allwine, Jr., K. J. Pacific Northwest Laboratory Assessment of the Long-Range Transport of Residential Woodstove Fine Particulate Emissions for Two Future United States Energy Scenarios. In: Proceedings of the International Conference of Residential Solid Fuels, 1981. pp. 404-413.

5. Meyer, R. H. The Contribution of Residential Wood Combustion Local Airshed Pollutant Concentrations. In: Proceedings of the International Conference on Residential Solid Fuels, 1981. pp. 386-394.

6. Butcher, S. S., and E. M. Sorenson. "A Study of Woodstove Particulate Emissions," Journal of the Air Pollution Control Asso., Vol. 29, No. 7, July 1979, pp. 724-728.

7. Peters, J. A. POM Emissions from Residential Woodburning: An Environmental Assessment. Monsanto Research Corporation. In Proceedings of the International Conference on Residential Solid Fuels, 1981. pp. 267-288.

8. Ramdahl, Thomas. "Retene-a Molecular Marker of Wood Combustion in Ambient Air." Nature. Vol. 306, No. 5943. pp. 580-582.

9. Horning, J. F. et al. Woodsmoke Analysis: Vaporization Losses of PAH from Filters, and Levoglucosan as a Distinctive Marker for Woodsmoke. A paper delivered at the Eighth International Symposium on Polynuclear Aromatic Hydrocarbon, Battelle Memorial Institute, Columbus, Ohio, October 26-28, 1983.

10. Truesdale, R. S. et al. "Characterization of Emissions from the Combustion of Wood and Alternative Fuels in a Residential Woodstove." EPA-600/7-84-094 (PB85-105336), U.S. Environmental Protection Agency, September 1984.

11. Lipfert, F. W. An Assessment Methodology for the Quality Impact of Residential Wood Burning. In: Proceedings of the International Conference on Residential Solid Fuels, 1981. pp. 415-434.

APPENDIX A

PAH CAPILLARY GC/MS RESULTS FROM RADIAN ON RTI CLEANED COMPOSITE SAMPLES

DCN No.: 86-203-023-38-08
Radian No. 203-023-38

ANALYSIS OF RTI WOODSTOVE MM5 SAMPLES

EPA Contract No. 68-02-3994

Prepared for:

U.S. Environmental Protection Agency
Air and Energy Environmental Research Laboratory
Research Triangle Park, NC 27711

Submitted by:

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January 31, 1986

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INTRODUCTION

A total of eleven samples for analysis were received from Bob McCrillis (EPA) on January 6, 1986. The samples consisted of Modified Method 5 Woodstove extracts to be analyzed for GRAV (gravimetric analysis), TCO (Total Chromatographable Organics), and qualitative/quantitative determination of polynuclear organic materials (POMs) using capillary GC/MS techniques. The samples had previously been extracted, concentrated, and cleaned up via column chromatography by Research Triangle Institute (RTI) on EPA Contract No. 68-02-3992.

EXPERIMENTAL PROCEDURE

The eleven woodstove samples received from Bob McCrillis (EPA) were systematically logged into Radian's Master Logbook. Initially, the samples were carefully removed from their original 50 mL amber bottles and the volumes precisely measured. The samples were then analyzed for TCO, but all samples were too dilute judging from the TCO calculations. Therefore, the samples were concentrated to a final volume of 5.0 mL using KD concentrators. The TCO analyses were repeated on all samples (at 5.00 mL volume), and the calculated TCO values showed all samples except four to be within the acceptable range for GC/MS analysis. These four were further concentrated, reanalyzed for GC/TCO, and found to be within range fro GC/MS analysis. The calculated TCO values are listed in Table 1. The samples were next spiked with internal standards, D_{10}-phenanthrene and D_{12}-chrysene, and submitted for POMs analysis by capillary GC/MS. The results of the GC/MS analysis are listed in Table 2. Finally, the remaining sample volumes were used to determine the GRAV values and these are listed in Table 3. The supporting GC/MS data including sample chromatograms are listed.

Table 1. TOTAL CHROMATOGRAPHABLE ORGANICS (TCO)

RADIAN SAMPLE I.D. #	AREA COUNTS	AREA COUNTS	MEAN AREA CTS.	PERCENT DIFF.	TCO MG/ML	FINAL VOLUME (mL)	TOTAL MG
11244	797483 *		797483.0		4.08	5.00	20.4
11245	109355	121837	115596.0	10.8	0.417	5.00	2.09
11246	713651	700722	707186.5	1.83	3.67	1.50	5.50
11247	482939	513530	498234.5	6.14	2.47	5.00	12.4
11248	454344	482850	468597.0	6.08	2.32	5.00	11.6
11249	93964	97929	95946.5	4.13	0.00	1.73	0.00
11250	280808	278937	279872.5	0.669	1.30	5.00	6.50
11251	448261 *		448261.0		2.21	5.00	11.0
11252	54918	57979	56448.5	5.42	0.00	1.50	0.00
11253	313897	331842	322869.5	5.56	1.53	5.00	7.66
11254	128370	125920	127145.0	1.93	0.00	1.60	0.00

* Sample not analyzed in duplicate.

TABLE 2. WOODSTOVE TARGET COMPOUND QUANTITIES IN TOTAL MICROGRAMS

ION	COMPOUND	RADIAN SAMPLE # 11244	11245	11246	11247	11248	11249	11250
94	phenol				5.0			
128	naphthalene	1952.0	2682.0	78.7	4756.9 *	602.7	1.9	651.3
152	acenaphthylene	360.6	231.6	3.4	493.6	32.2		112.3
154	acenaphthene	41.7	11.3	0.9	35.2	9.2		10.5
166	fluorene	192.8	71.2	4.0	143.3	47.3		36.5
173	nitronaphthalene							
178	phenanthrene	383.4	498.3	7.0	651.6	89.0		108.5
178	anthracene	81.7	55.8	1.5	106.2	19.2		21.1
174	acridine							
167	carbazole				1.0			
202	fluoranthene	77.4	188.3	0.9	222.3	16.1		36.3
194	phenanthrol							
202	pyrene	65.7	146.7	1.0	207.0	17.1		28.7
228	benzo(a)anthracene	19.5	29.4		42.3	3.2		6.6
228	chrysene	20.3	36.7		55.4	5.4		9.7
252	benzo(b)fluoranthene		48.2		60.7			9.4
252	benzo(k)fluoranthene	13.2			10.1			
252	benzo(a)pyrene	6.1	18.8		34.4			4.9
263	3-methylcholanthrene							
276	benzo(g,h,i)perylene				15.4			
278	dibenzo(a,h)anthracene							
276	indeno(1,2,3cd)pyrene		6.6		19.5			

* This number is taken from a 1:4 dilution of the original sample as naphthalene was saturated in the initial sample.

TABLE 2. WOODSTOVE TARGET COMPOUND QUANTITIES IN TOTAL MICROGRAMS

ION	COMPOUND	RADIAN SAMPLE # 11251	11252	11253	11254	DUPLICATE 11246	DUPLICATE 11254
94	phenol		NO COMPOUNDS DETECTED				
128	naphthalene	544.6		120.5	47.4	79.6	46.5
152	acenaphthylene	25.5		21.6	3.7	3.5	3.7
154	acenaphthene	9.2				1.0	
166	fluorene	43.2		9.5	1.1	4.3	1.2
173	nitronaphthalene						
178	phenanthrene	75.3		23.2	7.9	6.6	7.7
178	anthracene	17.2		4.2	0.8	1.3	0.9
174	acridine						
167	carbazole						
202	fluoranthene	16.3		3.4	1.5	0.7	1.5
194	phenanthrol						
202	pyrene	17.0		3.0	1.1	0.7	1.1
228	benzo(a)anthracene	3.8					
228	chrysene	6.3			0.8		0.8
252	benzo(b)fluoranthene	2.7					
252	benzo(k)fluoranthene						
252	benzo(a)pyrene	1.5					
263	3-methylcholanthrene						
276	benzo(g,h,i)perylene						
278	dibenzo(a,h)anthracene						
276	indeno(1,2,3cd)pyrene						

All other QC information will be the same as for the first 20 woodstove samples.
(Corelation coefficient, five point calibration, etc.)

TABLE 3. GRAVIMETRIC WEIGHTS

RADIAN SAMPLE I.D. #	RTI #	INITIAL RESIDUE WT. (mg/mL)	DILUTION FACTOR	FINAL RESIDUE WT. TOTAL (mg/mL)	AVERAGE * RESIDUE WT. TOTAL (mg/mL)
11254	50403	0.50	1.6	0.80	
11251	50411	0.87	1.0	0.87	1.40
11251	50411	1.94	1.0	1.94	
11248	50411A	1.16	1.0	1.16	1.16
11248	50411A	1.16	1.0	1.16	
11247	50424	2.05	1.0	2.05	2.25
11247	50424	2.45	1.0	2.45	
11244	50501	5.29	1.0	5.29	5.48
11244	50501	5.68	1.0	5.68	
11245	50508	1.17	1.0	1.17	1.18
11245	50508	1.20	1.0	1.20	
11250	50515	0.82	1.0	0.82	0.85
11250	50515	0.88	1.0	0.88	
11253	50522	0.78	1.0	0.78	0.80
11253	50522	0.82	1.0	0.82	
11246	50605	1.51	1.5	2.26	
11249	50612	0.26	1.73	0.45	
11252	60103	0.32	1.5	0.48	

TABLE 4. WOODSTOVE GC/MS QUALITY CONTROL SAMPLE DAILY RESPONSE FACTORS

ION	COMPOUND	RESPONSE FACTOR: F860035	F860049	F860061	F860068	F860077	MEAN	S. D.	% CV
128	naphthalene	1.902	1.686	1.619	1.527	1.578	1.662	0.131	7.9
178	phenanthrene	1.248	1.261	1.266	1.261	1.293	1.266	0.015	1.2
202	fluoranthene	1.085	1.002	1.139	1.219	1.062	1.101	0.073	6.7
202	pyrene	1.191	1.091	1.287	1.409	1.175	1.231	0.109	8.8
228	chrysene	1.353	1.432	1.405	1.376	1.413	1.396	0.028	2.0

These numbers are for the first 20 woodstove samples plus the additional ones analyzed later.

TABLE 5. GC/MS INSTRUMENTAL CONDITIONS

Instrument:	Finnigan MAT 5100
Column:	30m DB-5 wide bore (0.32mm), thick film (1 u) fused silica capillary
GC Program:	45° (4 min), 290°C at 10°/min, hold at 290°C
Emission Current:	0.3 mA
Electron Energy:	70 eV
Separator Oven Temperature:	290°C
Transfer Line Temperature:	290°C
Injector Temperature:	290°C
Manifold Temperature:	105°C
Injection Mode:	Splitless 0.6 min, then 10:1 split
Scan Cycle:	0.95 s scan, 0.05 hold
Column Head Pressure:	8 psi

TABLE 6. TARGET COMPOUNDS FOR QUANTITATIVE ANALYSIS BY GC/MS AND ESTIMATED QUANTIFIABLE LIMITS

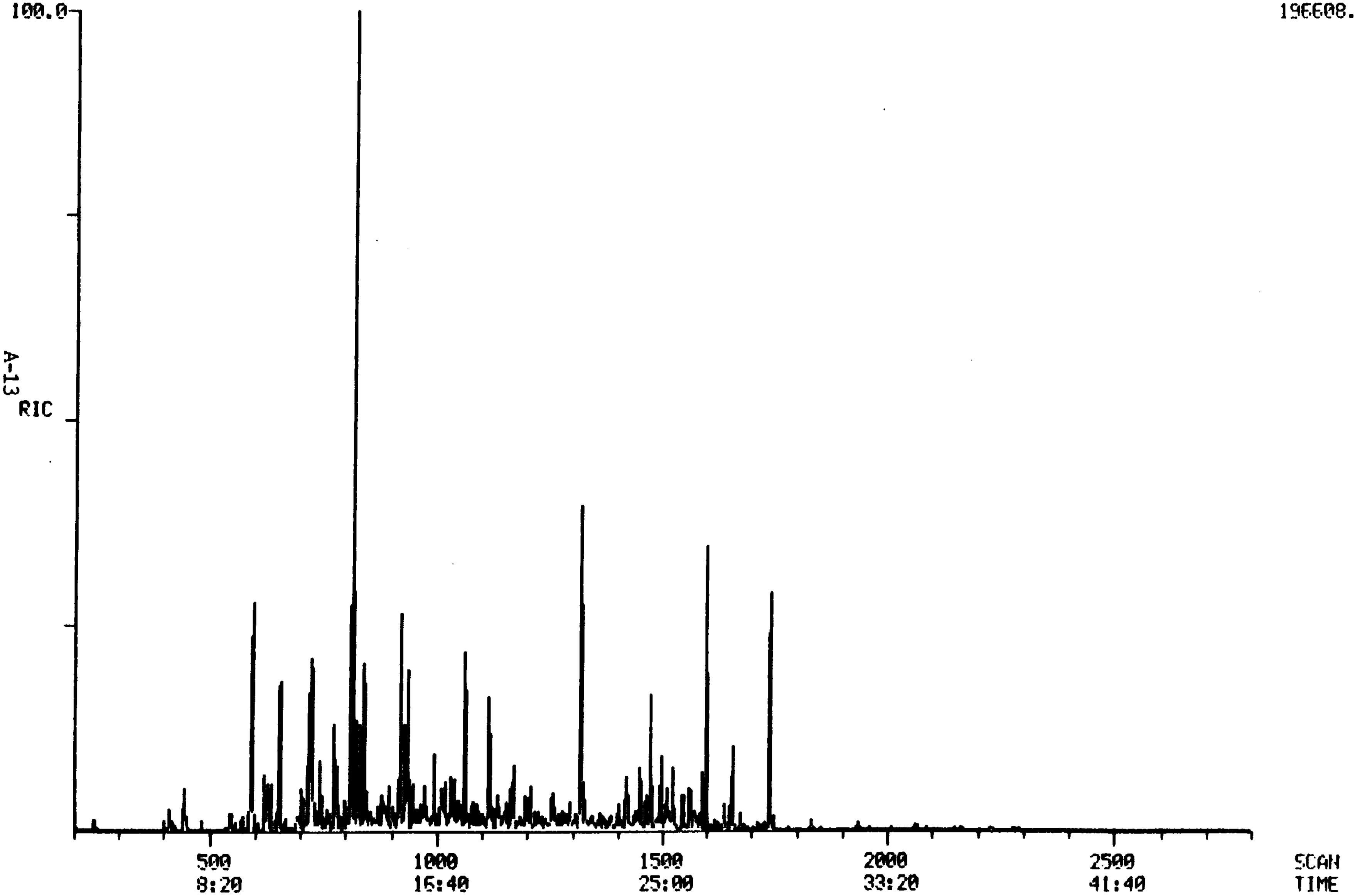
Compound	Quantifiable Limit, ng
phenol	0.8
naphthalene	0.5
acenaphthylene	0.6
acenaphthene	0.9
fluorene	0.9
nitronaphthalene	3.0
phenanthrene	0.7
anthracene	0.6
acridine	0.7
carbazole	0.7
fluoranthene	0.8
phenanthrol	6.0
pyrene	0.7
benzo(a)anthracene	0.8
chrysene	0.9
benzo(b)fluoranthene	1.0
benzo(k)fluoranthene	1.0
benzo(a)pyrene	1.2
methylcholanthrene	3.0
benzo(g,h,i)perylene	1.1
dibenzo(a,h)anthracene	1.4
indeno(1,2,3-cd)pyrene	1.3

CHROMATOGRAMS OF WOODSTOVE SAMPLE EXTRACTS

RIC
01/14/86 16:13:00
SAMPLE: WOODSTOVE RAD # 11244
CONDS.: 1500
RANGE: G 1,2800 LABEL: N 0, 4.0 QUAN: A 0, 1.0 J 0 BASE: U 20, 3

DATA: F860073 #1
CALI: F860017 #7

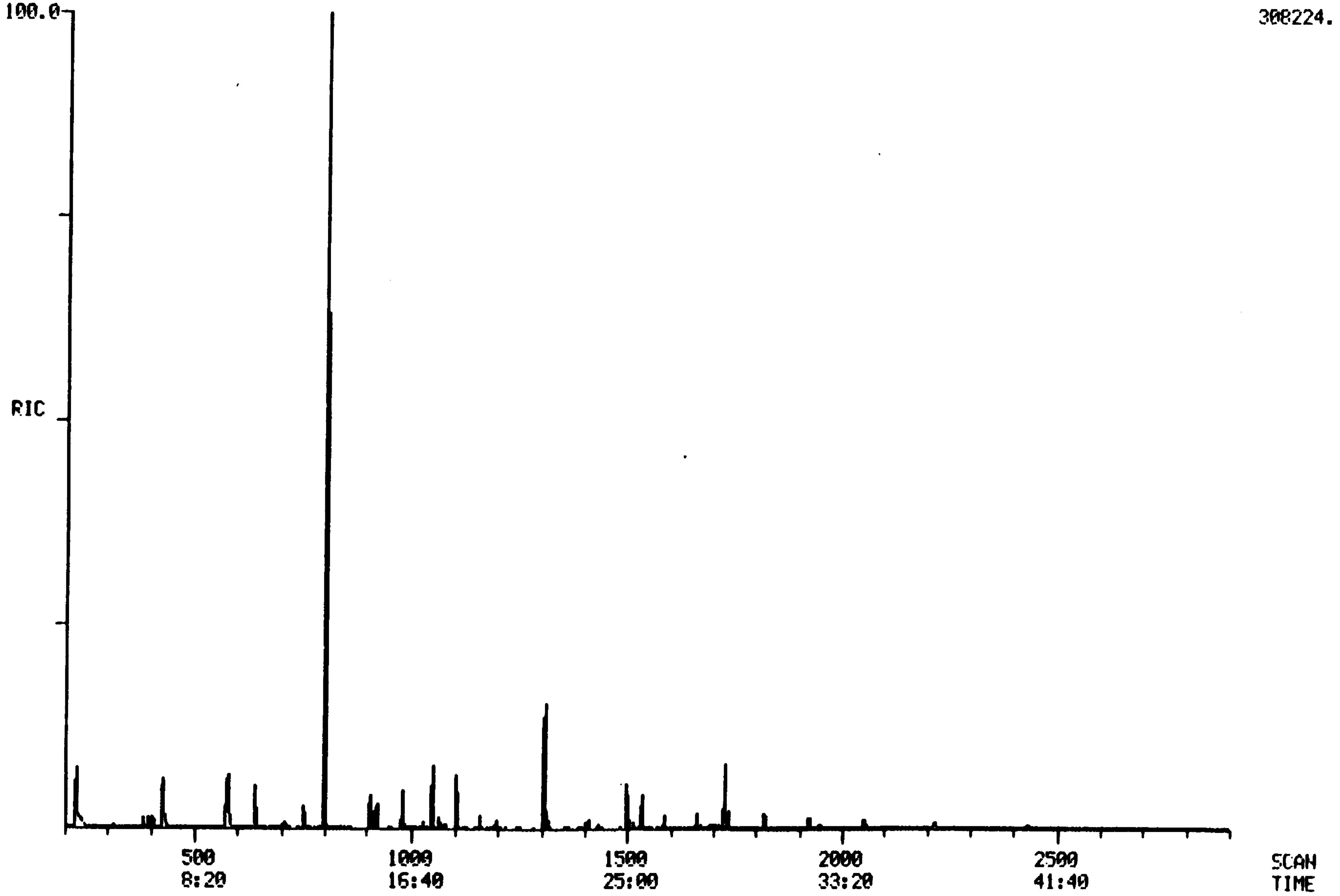
SCANS 200 TO 2800



RIC
01/14/86 13:04:00
SAMPLE: WOODSTOVE RAD#11245
CONDS.: 1500
RANGE: G 1,2900 LABEL: N 0, 4.0 QUAN: A 0, 1.0 J 0 BASE: U 20, 3

DATA: F860071 #1
CALI: F860017 #7

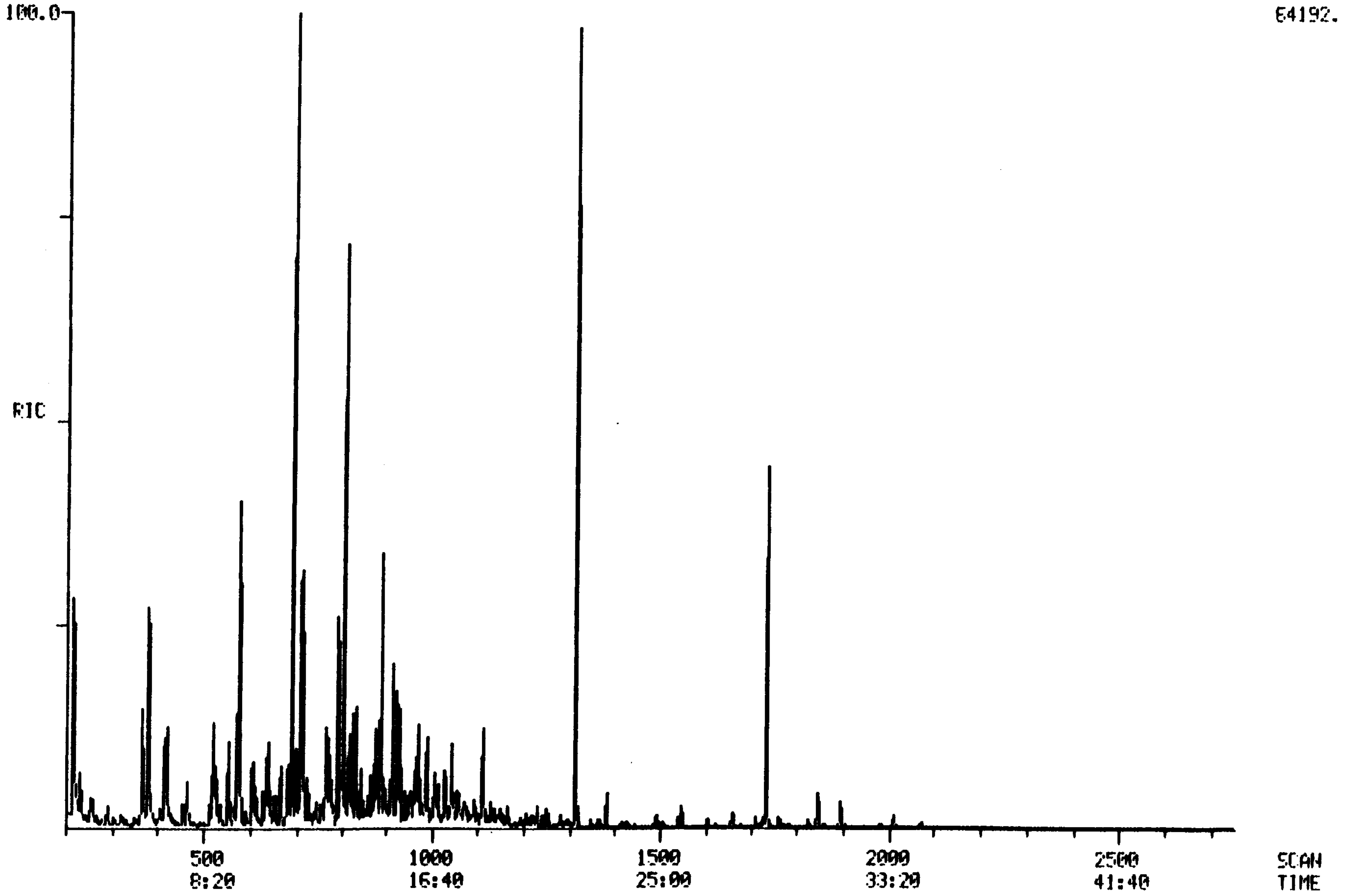
SCANS 200 TO 2900



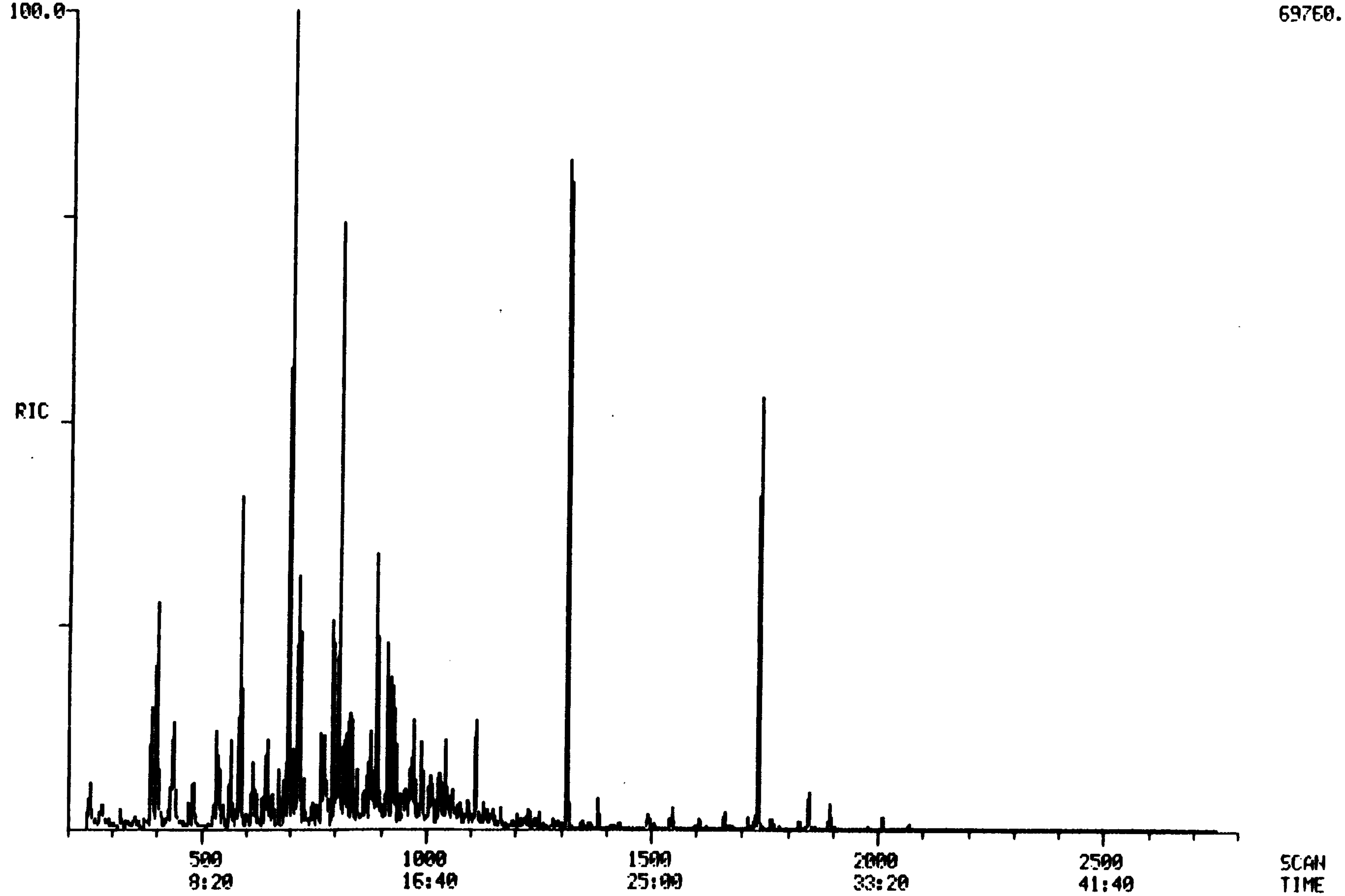
RIC
01/15/86 10:43:00
SAMPLE: WOODSTOVE RAD # 11246
CONDS.: 1500
RANGE: G 1,2800 LABEL: N 0, 4.0 QUAN: A 0, 1.0 J 0 BASE: U 20, 3

DATA: F860078 #1
CALI: F860017 #7

SCANS 200 TO 2750



```
RIC                                        DATA: F860079 #1        SCANS  200 TO 2800
01/15/86 11:48:00                          CALI: F860017 #7
SAMPLE: WOODSTOVE RAD # 11246 DUPLICATE
CONDS.: 1500
RANGE: G   1,2800  LABEL: N  0, 4.0  QUAN: A  0, 1.0 J  0  BASE: U 20,  3
```

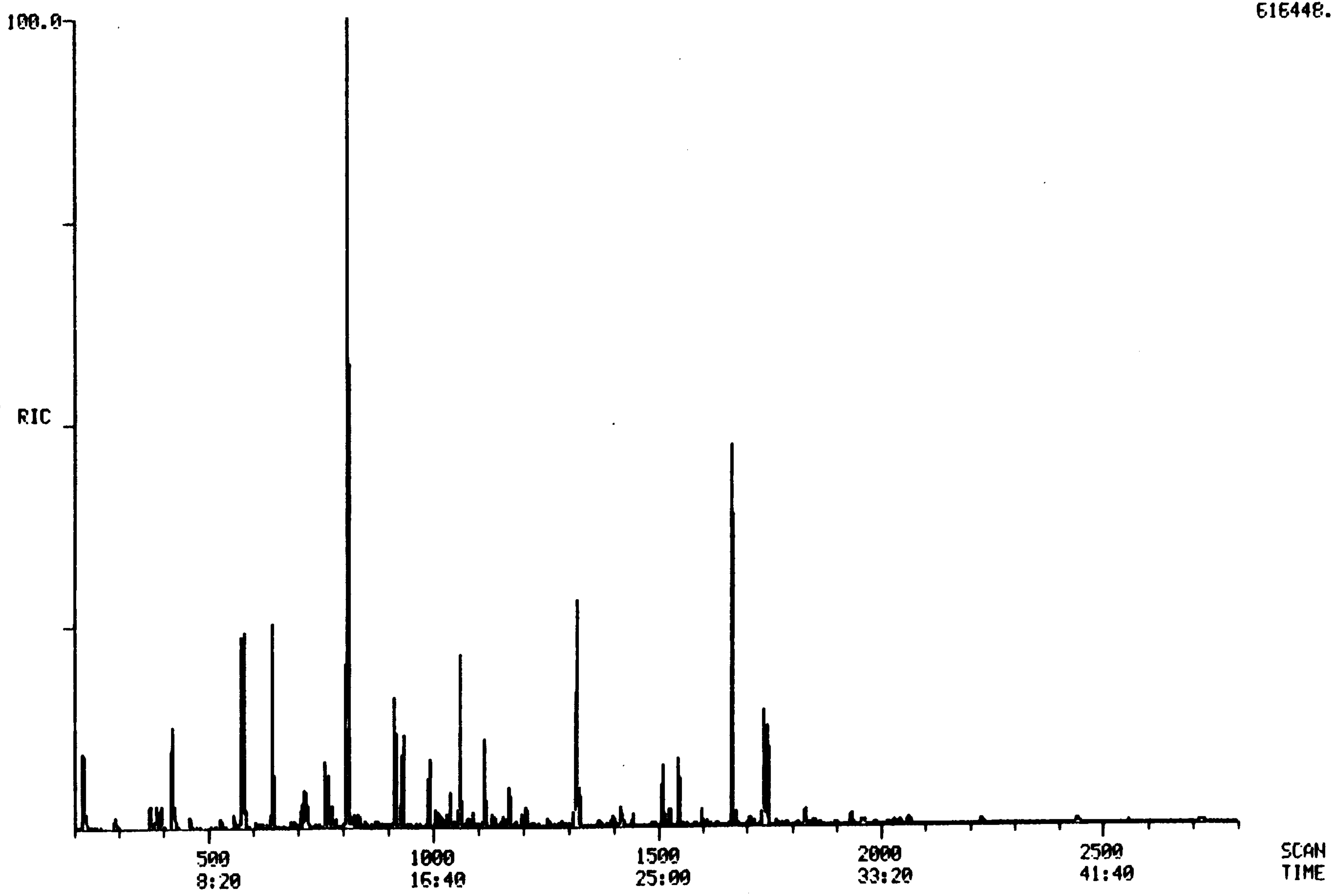


unmatched ar [illegible]
(naphthalene saturated)

RIC
01/13/86 15:36:00
SAMPLE: WOODSTOVE RAD #11247
CONDS.: 1500
RANGE: G 1,2800 LABEL: N 0, 4.0 QUAN: A 0, 1.0 J 0 BASE: U 20, 3

DATA: F860064 #1
CALI: F860017 #7

SCANS 200 TO 2800

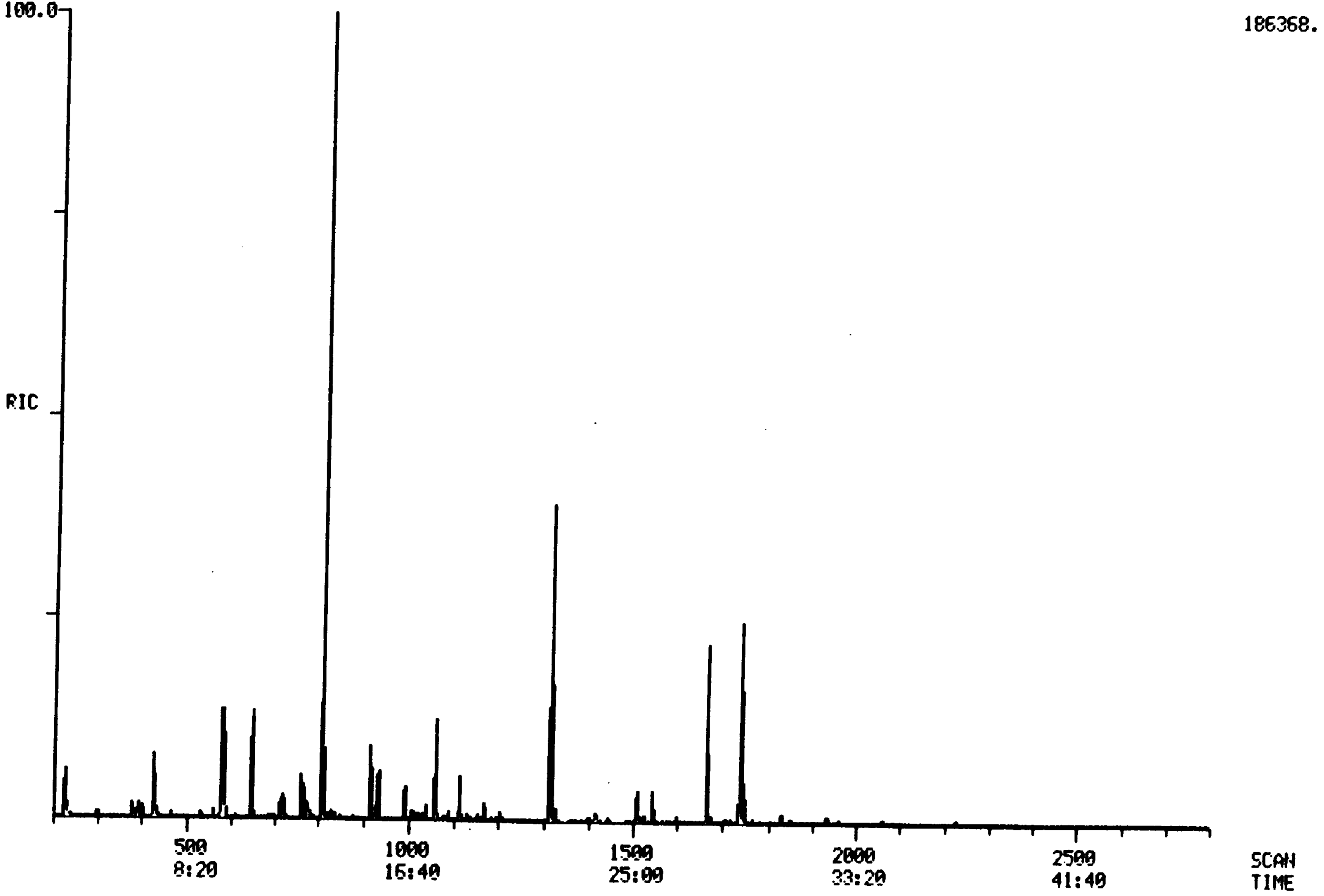


RIC
01/14/86 17:11:00
SAMPLE: WOODSTOVE RAD # 11247
CONDS.: 1500
RANGE: G 1,2800 LABEL: N 0, 4.0 QUAN: A 0, 1.0 J 0 BASE: U 20, 3

DATA: F860074 #1
CALI: F860017 #7

SCANS 200 TO 2800

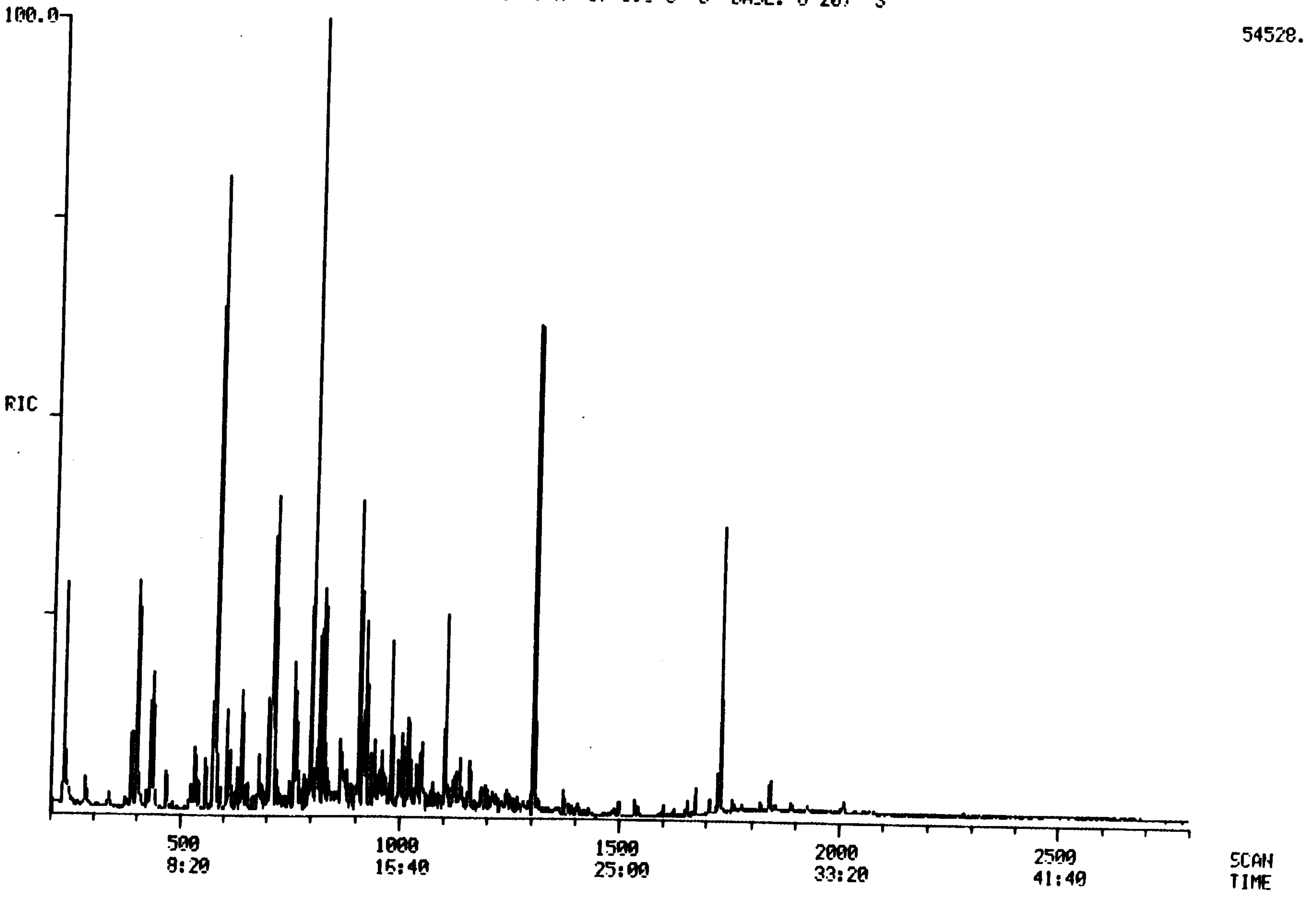
(1:4 dilution
of original sample)



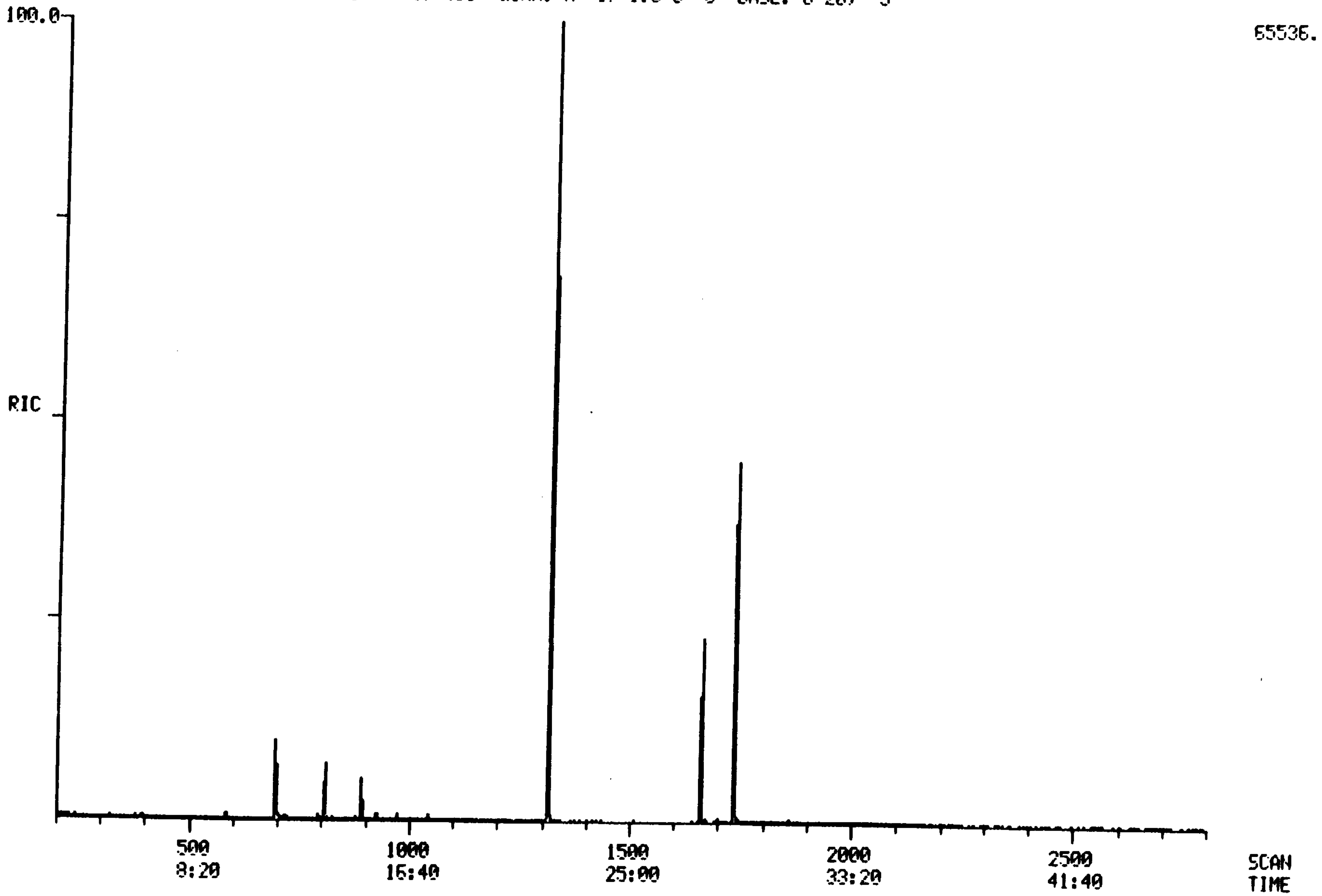
RIC
01/14/86 14:53:00
SAMPLE: WOODSTOVE RAD#11248
CONDS.: 1500
RANGE: G 1,2800 LABEL: N 0, 4.0 QUAN: A 0, 1.0 J 0 BASE: U 20, 3

DATA: F860072 #1
CALI: F860017 #7

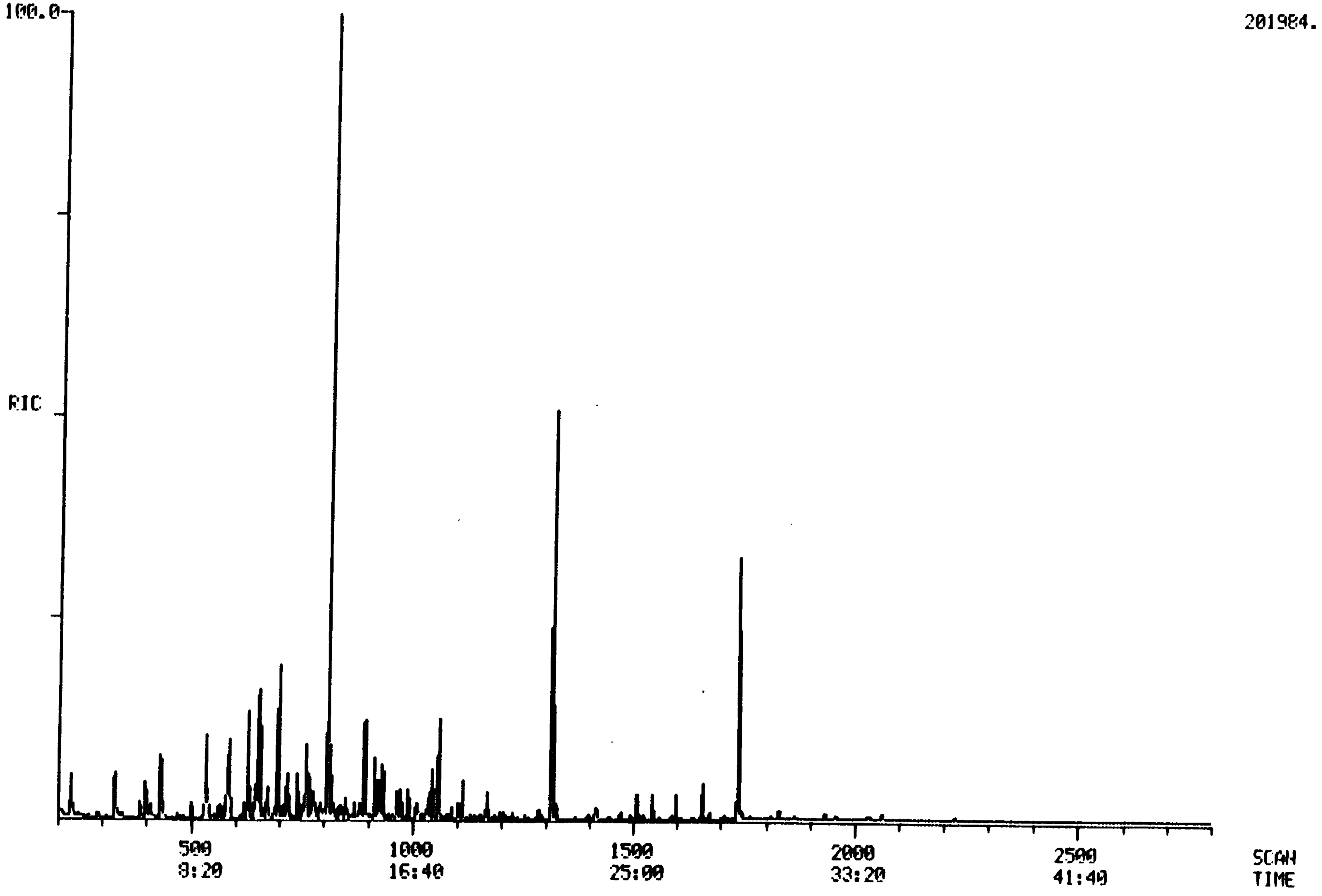
SCANS 200 TO 2800



```
RIC                                            DATA: F860082 #1       SCANS  200 TO 2800
01/15/86 14:41:00                              CALI: F860017 #7
SAMPLE: WOODSTOVE RAD # 11249
CONDS.: 1500
RANGE: G   1,2800  LABEL: N  0, 4.0  QUAN: A  0, 1.0 J  0  BASE: U 20,  3
```



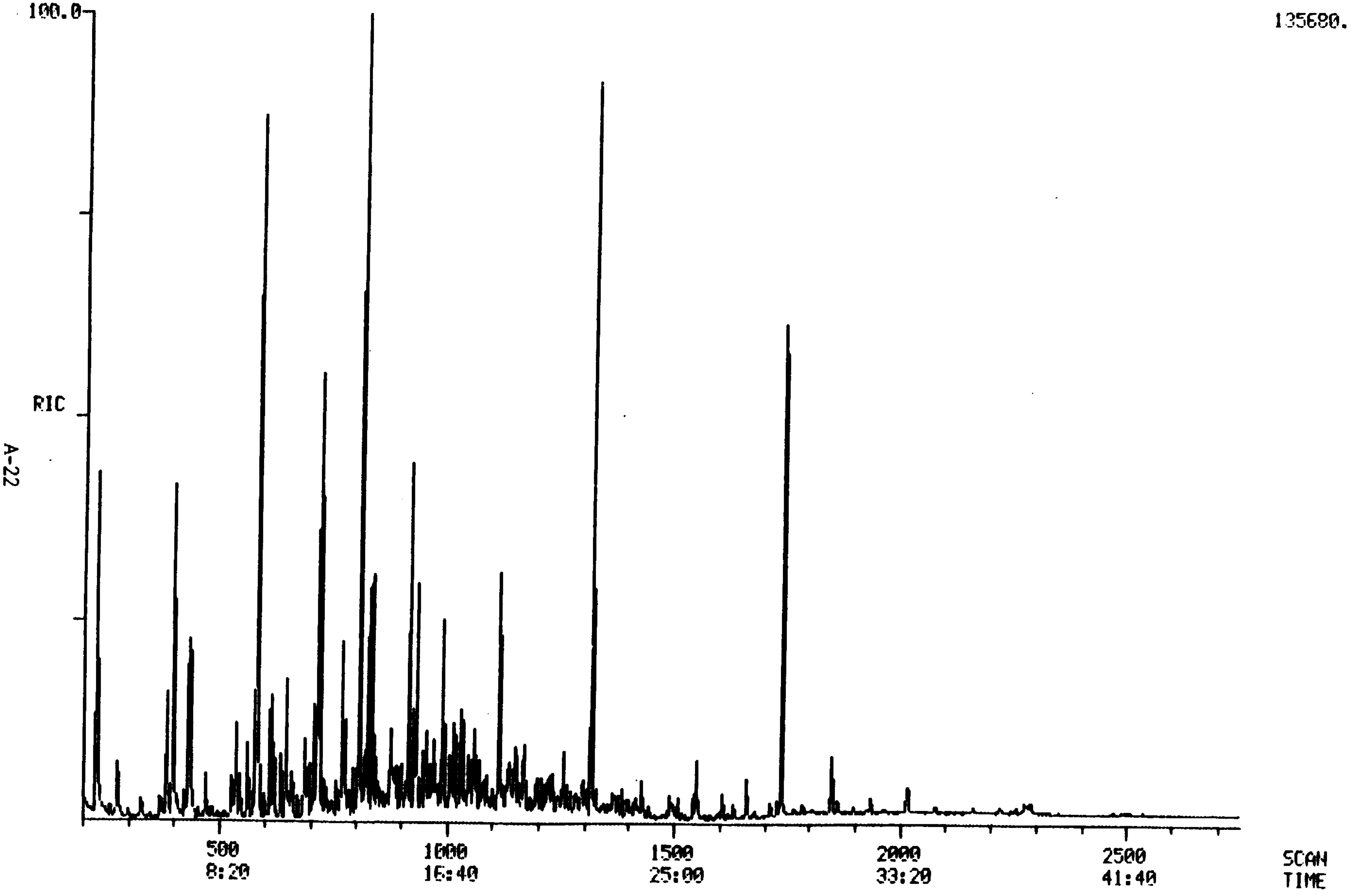
```
RIC                                            DATA: F860069 #1        SCANS  200 TO 2800
01/14/86 10:46:00                              CALI: F860017 #7
SAMPLE: WOODSTOVES RAD # 11250
CONDS.: 1500
RANGE: G   1,2800  LABEL: N  0, 4.0  QUAN: A  0, 1.0 J  0  BASE: U 20,  3
```



RIC
01/13/86 16:37:00
SAMPLE: WOODSTOVE RAD # 11251
CONDS.: 1500
RANGE: G 1,2800 LABEL: N 0, 4.0 QUAN: A 0, 1.0 J 0 BASE: U 20, 3

DATA: F860065 #2611
CALI: F860017 #7

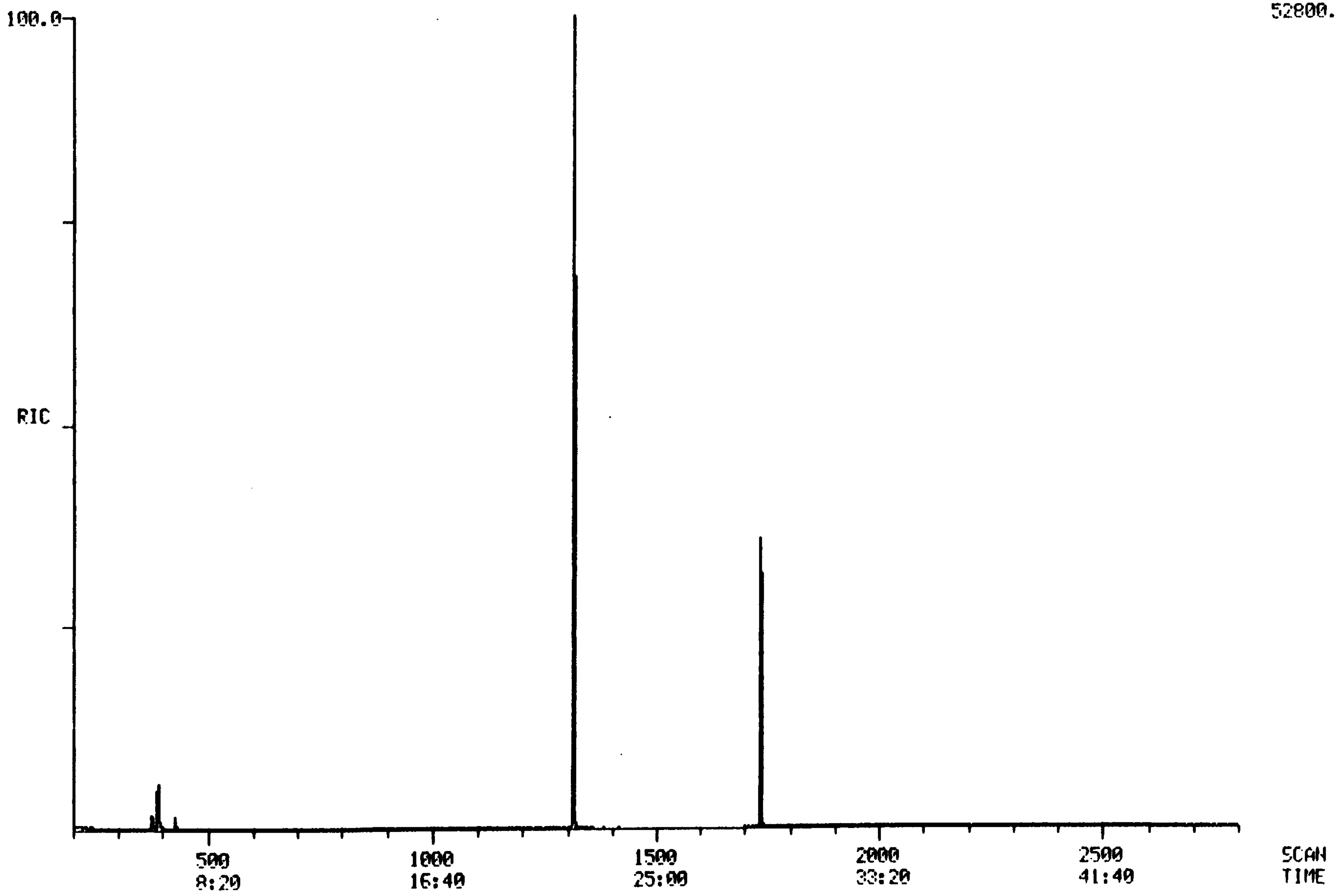
SCANS 200 TO 2750



RIC
01/15/86 15:49:00
SAMPLE: WOODSTOVE RAD # 11252
CONDS.: 1500
RANGE: G 1,2800 LABEL: N 0, 4.0 QUAN: A 0, 1.0 J 0 BASE: U 20, 3

DATA: F860083 #1
CALI: F860017 #7

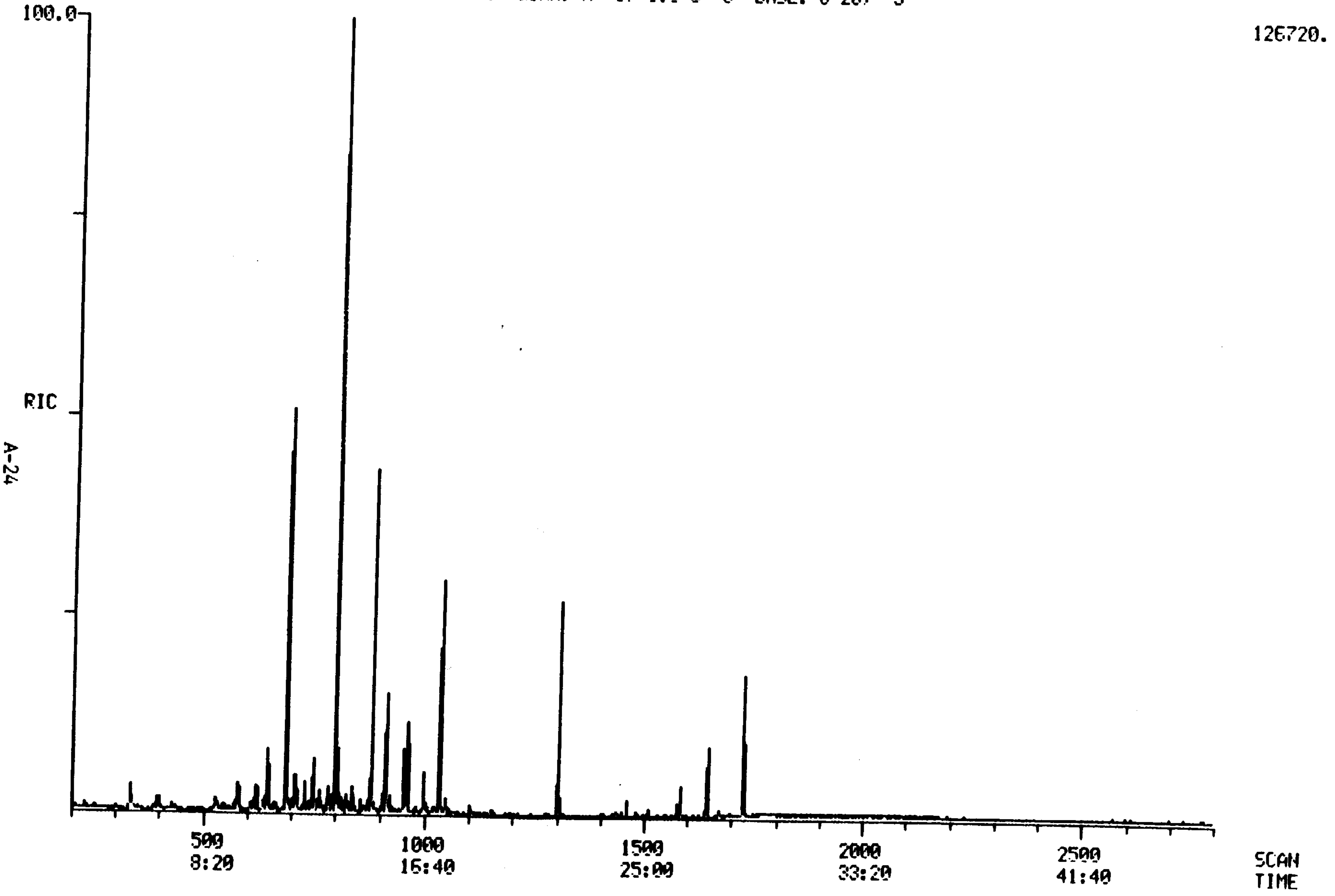
SCANS 200 TO 2800



RIC
01/14/86 12:00:00
SAMPLE: WOODSTOVE RAD# 11253
CONDS.: 1500
RANGE: G 1,2800 LABEL: N 0, 4.0 QUAN: A 0, 1.0 J 0 BASE: U 20, 3

DATA: F860070 #1
CALI: F860017 #7

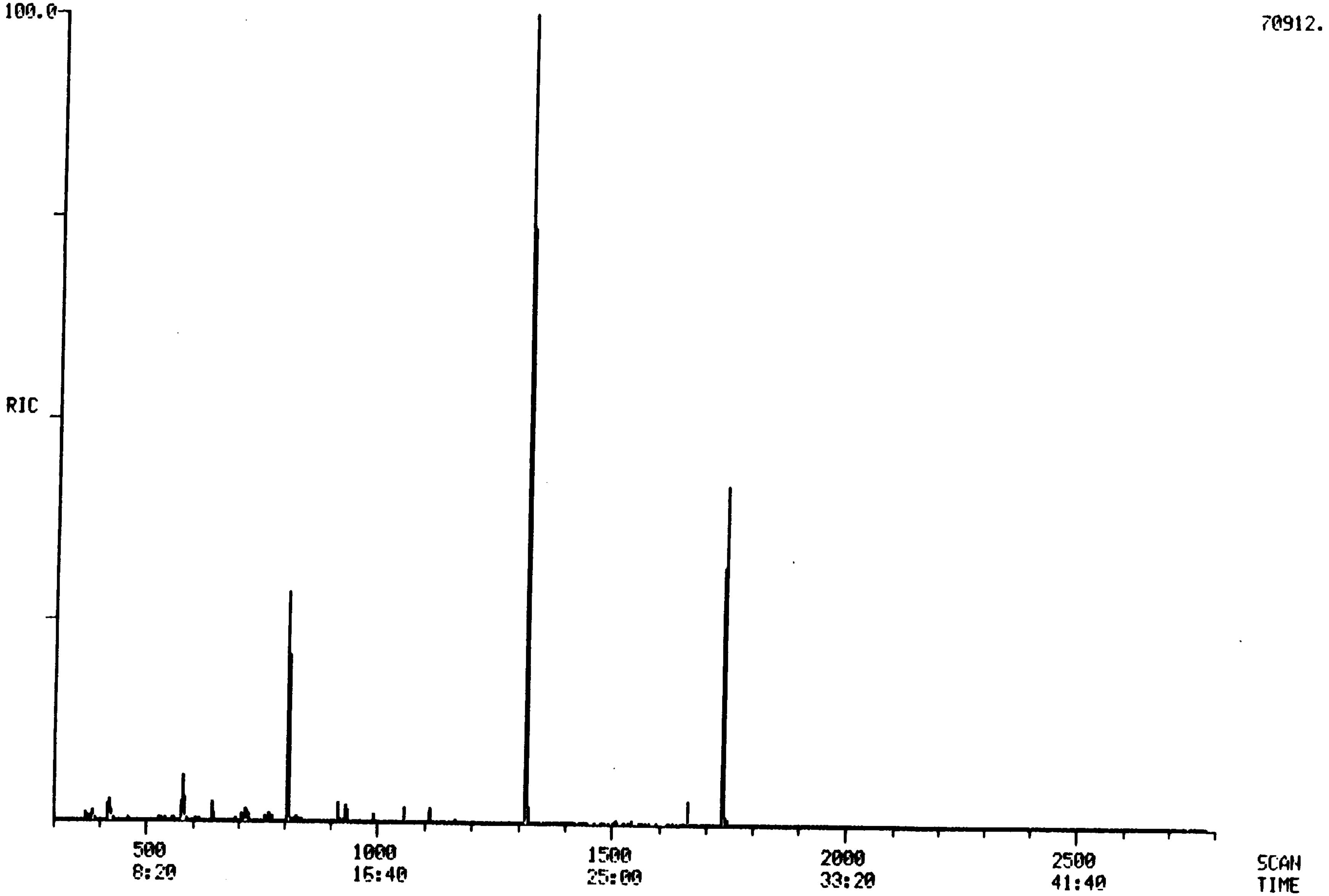
SCANS 200 TO 2800



RIC
01/15/86 12:45:00
SAMPLE: WOODSTOVE RAD # 11254
CONDS.: 1500
RANGE: G 1,2800 LABEL: N 0, 4.0 QUAN: A 0, 1.0 J 0 BASE: U 20, 3

DATA: F860080 #1
CALI: F860017 #7

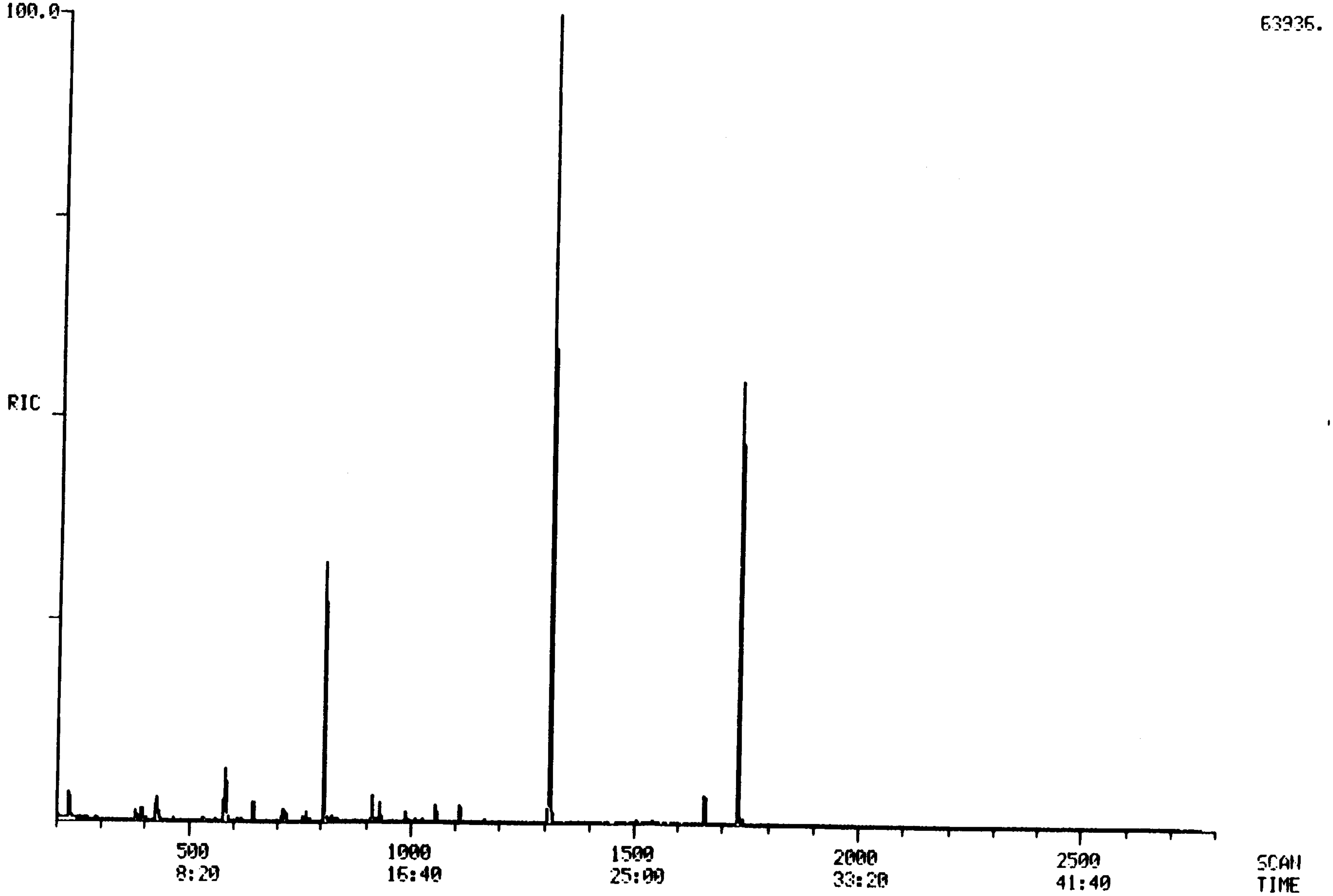
SCANS 300 TO 2800



RIC
01/15/86 13:43:00
SAMPLE: WOODSTOVE RAD # 11254 DUPLICATE
CONDS.: 1500
RANGE: G 1,2800 LABEL: N 0, 4.0 QUAN: A 0, 1.0 J 0 BASE: U 20, 3

DATA: F860081 #1
CALI: F860017 #7

SCANS 200 TO 2800



APPENDIX B

Excerpts from Radian report on

ANALYSIS OF WOODSTOVE EMISSION SAMPLES

FINAL DRAFT

EPA CONTRACT NO. 68-02-3994
WORK ASSIGNMENT NO. 38

THIS APPENDIX SERVES AS QA/QC DOCUMENTATION FOR THE CAPILLARY GC/MS PAH ANALYSES PERFORMED BY RADIAN CORP. ON RTI CLEANED COMPOSITE WOODSTOVE SAMPLES UNDER THIS CONTRACT.

GRAVIMETRIC AND TCO ANALYSES WERE ALSO PERFORMED.

5.0 QUALITY ASSURANCE AND QUALITY CONTROL

Supporting quality control and quality assurance data for the analytical determinations are reported in this section.

5.1 GRAVIMETRIC ANALYSIS

As requested in the QA/QC protocol the accuracy of the gravimetric (GRAV) analysis must be ± 20% of the actual value. Proficiency tests were administered to the analyst using prepared standards containing known amounts of stearic acid, eicosane, and triphenylmethane in a total volume of 100 mL of methylene chloride. The results for the GRAV tests are as follows:

	Actual	Experimental	Accuracy	% CV
GRAV Test 1	1.21 mg/mL	1.20 mg/mL	-0.8%	2.4%
GRAV Test 2	1.21 mg/mL	1.16 mg/mL	-4.1%	
GRAV Test 3	1.04 mg/mL	1.05 mg/mL	1.0%	
GRAV Test 3	1.04 mg/mL	1.10 mg/mL	5.8%	

The results of the GRAV Audit were within the precision and accuracy specification outlined in the SOP. It should be noted that the same analyst performed all GRAV analyses.

A GRAV value for duplicate method blanks was determined for each new lot of solvent and/or set of samples. Also, a reagent blank was analyzed for GRAV every ten samples (listed in Table 4-1). These reagent (solvent) blanks consisted of the same volume of solvent used in analyzing the samples. Any unusually high reagent blanks were noted and the blanks reanalyzed. The reported GRAV values were determined by subtracting the values of the solvent blanks from the samples, including the method blanks.

5.2 TOTAL CHROMATOGRAPHABLE ORGANICS (TCO)

The gas chromatograph (GC) was calibrated using solutions prepared by diluting a stock solution of C_7 to C_{17} hydrocarbons. The stock solution contained approximately 37 mg (C_7 to C_{17})/mL. Linear regression analysis of the calibration curve resulted in a correlation coefficient of 0.9999. C_7 and C_{19} peaks were not included in the regression analysis. One calibration standard in the middle of the linear working range was used as the daily QC standard.

Duplicate injections of the QC standard were performed daily prior to sample analysis. If the QC standard duplicates differed by more than 15% the injections were repeated. If the mean QC standard response differed by more than 15% from the original value obtained, a new standard was prepared and then analyzed. If the new standard failed to meet the criteria, the instrument was recalibrated. A plot of the QC standard results is shown in Figure 5-1.

The GC injector septum was changed daily, along with a column bake-out at 300°C for twenty minutes. If the detector response was not stable after column bake-out, this procedure was repeated until stability was obtained.

Duplicate injections were performed for all samples analyzed. The TCO results from both injections could not differ by more than 15%. The TCO values were calculated by subtracting the appropriate field blanks from the total values.

5.3 GC/MS CALIBRATION AND TUNING DATA

The gas chromatograph/mass spectrometer system was tuned to meet DFTPP criteria every day prior to analysis. Daily analysis was initiated by a check of DFTPP to verify that the instrumental tune was acceptable prior to the analysis of samples. Tuning data are included as Appendix J.

The instrument was calibrated by analysis of five calibration samples at a concentration of 5, 10, 50, 100, and 200 ng/uL. These points were incorporated into a database and the mean, standard deviation, and per cent coefficient of variation calculated. The database is shown in Table 5-1. A linear regression was performed for each of the ions for each compound in the calibration standard, with the

Table 5-1 WOODSTOVES RESPONSE FACTOR DATABASE

Compound	Ion	Mean	SD	% CV	+2SD	-2SD
d_{10}-phenanthrene	188	1.000	0	0	---	---
phenol	94	1.203	0.081	6.7	1.041	1.365
naphthalene	128	1.786	0.238	13.3	1.310	2.262
acenaphthylene	152	1.548	0.198	12.8	1.152	1.944
acenaphthene	154	0.940	0.116	12.3	0.708	1.172
fluorene	166	1.010	0.122	12.1	0.766	1.254
nitronaphthalene	127	0.311	0.025	8.0	0.261	0.361
	173	0.210	0.022	10.4	0.166	0.254
phenanthrene	178	1.273	0.160	12.6	0.953	1.593
anthracene	178	1.537	0.182	11.8	1.173	1.901
acridine	179	1.227	0.075	6.1	1.077	1.377
carbazole	167	1.260	0.080	6.3	1.100	1.420
DFTPP	127	0.080	0.004	5.0	0.072	0.088
	198	0.161	0.009	5.4	0.143	0.179
fluoranthene	202	1.134	0.147	13.0	0.084	1.428
phenanthrol	194	0.177	0.033	18.4	0.111	0.243
pyrene	202	1.167	0.163	14.0	0.841	1.493
d_{12}-chrysene	240	1.000	0	0	---	---
benzo(a)anthracene	228	2.054	0.213	10.4	1.628	2.480
chrysene	228	1.816	0.192	10.6	1.432	2.200
benzo(b)fluoranthene	252	1.687	0.185	11.0	1.317	2.057
benzo(k)fluoranthene	252	1.591	0.185	11.6	1.221	1.961
benzo(a)pyrene	252	1.394	0.148	10.6	1.098	1.690
3-methylcholanthrene	268	0.694	0.092	13.3	0.51	0.878
benzo(g,h,i)perylene	276	1.502	0.167	11.1	1.168	1.836
dibenzo(a,h)anthracene	278	1.192	0.129	10.8	0.934	1.450
indeno(1,2,3,c,d)pyrene	276	1.209	0.151	12.5	0.907	1.511

exception of pyrenequinone, which could not be chromatographed under the analytical conditions used. Correlation coefficients are shown in Table 5-2. The linear plots are included as Appendix K. Calibration checks were performed daily prior to sample analysis. Values for the response factors obtained in the daily calibration checks are shown in Table 5-3, and compared to the database values. The precision of the analysis is illustrated by the eight daily analyses of the same standard (100 mg/uL), with only phenol exhibiting % CV above 20 and all of the rest of the compounds showing % CV less than 15 (Table 5-3).

A check sample containing naphthalene, phenanthrene, fluoranthene, pyrene, and chrysene was analyzed daily. The results of the first two analyses, with relative percent difference, are shown in Table 5-4. Results for the subsequent days are shown in Table 5-5. Duplicate analyses were performed for four samples. These samples were injection duplicates, not process duplicates, since an entire sample (e.g., the entire XAD-2 module) was extracted to prepare the sample. Results are shown in Table 5-6. The GC/MS values for all Blank Runs (field and solvent) were reported separately. All reported GC/MS sample values were reported independently of the blank values.

A peak is observed at approximately 1500 scans in the sample chromatograms. The mass spectrum, shown in Figure 5-2, is characteristic of an unsaturated aldehyde. This compound is not observed in the solvent blanks (Appendix I, Figures I1 and I2) but appears to be an artifact associated with the extraction of XAD-2. Field exposure of the XAD-2 is not essential, since the compound appears also in the chromatograms of the internal audit samples consisting of spiked XAD-2 which was not sent to the field.

5.4 SYSTEMS AND PERFORMANCE AUDIT

A systems and performance audit of the Woodstove Project was performed by Donna Holder as part of the internal Radian quality assurance program. Joann Rice, Nancy Cole and Melinda Dilda provided input for the systems audit. Denny Wagoner, Joan Bursey, Ed Messer and Joann Rice were responsible for coordinating the performance audit analysis.

Table 5-2. LINEAR REGRESSION, WOODSTOVE DATABASE

Compound	Ion	Correlation Coefficient
phenol[a]	94	0.964
naphthalene[a]	128	0.936
acenaphthylene[a]	152	0.930
acenaphthene[a]	154	0.922
fluorene[a]	166	0.923
nitronaphthalene[a]	127	0.928
	173	0.928
phenanthrene[a]	178	0.911
anthracene	178	0.903
acridine[a]	179	0.886
carbazole[a]	167	0.907
fluoranthene[a]	202	0.891
phenanthrol[a]	194	0.924
pyrene[a]	202	0.884
benzo(a)anthracene[b]	228	0.883
chrysene[b]	228	0.875
benzo(b)fluoranthene[b]	252	0.847
benzo(k)fluoranthene[b]	252	0.901
benzo(a)pyrene[b]	252	0.886
3-methylcholanthrene[b]	268	0.874
benzo(g,h,i)perylene[b]	276	0.856
bibenzo(a,h)anthracene[b]	278	0.862
indeno(1,2,3-c,d)pyrene[b]	276	0.853

[a] Relative to d_{10}-phenanthrene.

[b] Relative to d_{12}-chrysene.

Table 5-3. DAILY CALIBRATION CHECKS

Compound	Ion	Database	11/12	11/13	11/14	11/15	11/18	11/19	11/20	11/21	Mean	SD	%CV
phenol	94	1.203	1.092	1.258	1.247	1.214	1.139	1.000	0.673	0.607	1.029	0.255	24.8
naphthalene	128	1.786	1.529	1.677	1.657	1.663	1.681	1.544	1.142	1.118	1.501	0.237	15.8
acenaphthylene	152	1.548	1.395	1.422	1.445	1.411	1.445	1.335	1.158	1.041	1.332	0.151	11.3
acenaphthene	154	0.940	0.849	0.872	0.880	0.881	0.884	0.844	0.747	0.667	0.828	0.079	9.5
fluorene	166	1.010	0.927	0.911	0.943	0.932	0.907	0.889	0.823	0.772	0.888	0.060	6.7
nitronaphthalene	173	0.210	0.227	0.231	0.226	0.230	0.223	0.216	0.198	0.180	0.216	0.018	8.4
phenanthrene	178	1.273	1.178	1.196	1.208	1.221	1.207	1.207	1.189	1.166	1.197	0.018	1.5
anthracene	178	1.537	1.453	1.498	1.478	1.504	1.521	1.529	1.507	1.518	1.501	0.025	1.7
acridine	179	1.227	1.288	1.331	1.302	1.329	1.315	1.346	1.337	1.315	1.320	0.019	1.4
carbazole	167	1.260	1.306	1.374	1.289	1.304	1.346	1.277	1.181	1.171	1.281	0.071	5.6
fluoranthene	202	1.134	1.116	1.150	1.071	1.098	1.174	1.154	1.260	1.261	1.161	0.070	6.0
phenanthrol	194	0.177	0.216	0.262	0.215	0.211	0.205	0.194	0.201	0.210	0.214	0.021	9.6
pyrene	202	1.167	1.118	1.195	1.104	1.128	1.213	1.223	1.341	1.368	1.211	0.099	8.2
benzo(a)anthracene	228	2.054	1.888	1.917	1.883	1.862	1.947	1.844	1.744	1.722	1.851	0.079	4.3
chrysene	228	1.816	1.684	1.683	1.699	1.723	1.670	1.631	1.630	1.639	1.670	0.034	2.0
benzo(b)fluoranthene	252	1.687	1.576	1.557	1.659	1.741	1.645	1.386	1.635	1.830	1.628	0.132	8.1
benzo(k)fluoranthene	252	1.591	1.527	1.411	1.453	1.538	1.355	1.358	1.444	1.703	1.474	0.115	7.8
benzo(a)pyrene	252	1.394	1.381	1.271	1.357	1.411	1.252	1.160	1.307	1.492	1.329	0.104	7.8
3-methylcholanthrene	268	0.694	0.872	0.756	0.802	0.863	0.618	0.616	0.641	0.839	0.751	0.111	14.7
benzo(g,h,i)perylene	276	1.502	1.599	1.353	1.451	1.572	1.208	1.241	1.416	1.696	1.442	0.173	12.0
dibenzo(a,h)anthracene	278	1.192	1.314	1.096	1.170	1.297	0.891	1.007	1.199	1.411	1.173	0.171	14.6
indeno(1,2,3-c,d)pyrene	276	1.209	1.283	1.175	1.186	1.330	1.049	1.006	1.217	1.424	1.209	0.139	11.5

Table 5-5. DAILY PERCENT RECOVERIES (CHECK SAMPLE)

Compound	11/13	11/14	11/15	11/18	11/19	11/20	11/21	Mean	SD	% CV
naphthalene	98	101	100	99	98	73	68	91	14.1	15.5
phenanthrene	102	104	103	103	105	102	102	103	1.2	1.1
fluoranthene	91	94	92	99	98	106	107	98	6.4	6.5
pyrene	97	101	99	107	107	122	122	108	10.4	9.6
chrysene	79	83	83	80	82	79	79	81	1.9	2.3

Table 5-8. QA/QC AUDIT TCO AND GRAV

SAMPLE I.D.#	AREA COUNTS	AREA COUNTS	PERCENT DIFF.	MEAN AREA CTS.	Mg/mL	SAMPLE VOL (mL)	TOTAL mg
10251-B	14000	12124	14.362	13062	+	1	+
Audit 1 (9872)	6222	5800	7.020	6011	0.03 *	1	0.03 *
Audit 2 (9873)	118196	115812	2.038	117004	0.62 *	1	0.62 *
Audit 3 (9874)	499979	454941	9.433	477460	2.54 *	1	2.54 *
Audit 4 (11165)	50314	55860	10.447	53087	0.08 *	5	0.04 *
Audit 5 (11166)	109225	105423	3.543	107324	0.37 *	5	1.85 *
Audit 6 (11167)	311201	322811	3.662	317006	1.50 *	5	7.50 *

\+ Solvent Blank

* Total mg/mL calculated using daily response factor.

GRAV TEST	THEORETICAL mg/mL	EXPERIMENTAL mg/mL	ACCURACY %
1	1.21	1.20	-0.83
2	1.21	1.16	-4.13
3	1.04	1.05	0.96
4	1.04	1.10	5.77

Table 5-7. QA/QC AUDIT GC/MS SAMPLES

TARGET COMPOUND	Audit 1 (9872) True Conc. (ng/uL)	Audit 1 (9872) Measured Conc. (ng/uL)	Audit 1 (9872) Percent Recovery (%)	Audit 2 (9873) True Conc. (ng/uL)	Audit 2 (9873) Measured Conc. (ng/uL)	Audit 2 (9873) Percent Recovery (%)	Audit 3 (9874) True Conc. (ng/uL)	Audit 3 (9874) Measured Conc. (ng/uL)	Audit 3 (9874) Percent Recovery (%)
Phenol	0	Trace	-	200	132.0	66	1,000	725.9	73
Napthalene	0	Trace	-	200	142.1	71	1,000	721.0	72
Acenaphylene	0	0	-	200	161.3	81	1,000	811.9	81
Acenaphthene	0	0	-	200	163.6	82	1,000	821.9	82
Fluorene	0	0	-	200	171.0	86	1,000	824.5	82
Nitronaphthalene	0	0	-	-	-	-	-	-	-
Phenanthrene	0	0	-	200	187.8	94	1,000	861.9	86
Anthracene	0	0	-	200	120.7	60	1,000	714.6	71
Acridine	0	0	-	-	-	-	-	-	-
Carbazole	0	0	-	-	-	-	-	-	-
Fluoranthene	0	0	-	200	130.3	65	1,000	870.8	87
Phenanthrol	0	0	-	-	-	-	-	-	-
Pyrene	0	0	-	200	123.7	62	1,000	854.5	85
Benzo(a)anthracene	0	0	-	200	182.0	91	1,000	869.5	87
Chrysene	0	0	-	200	157.6	79	1,000	824.1	82
Benzo(b)fluoranthene	0	0	-	200	198.3	99	1,000	863.8	86
Benzo(k)fluoranthene	0	0	-	200	185.4	93	1,000	911.0	91
Benzo(a)pyrene	0	0	-	200	208.5	104	1,000	927.3	93
3-methylcholanthrene	0	0	-	-	-	-	-	-	-
Benzo(g,h,i)perylene	0	0	-	200	211.6	106	1,000	921.1	92
Dibenzo(a,h)anthracene	0	0	-	200	222.2	111	1,000	992.7	99
Indeno(1,2,3-cd)pyrene	0	0	-	200	227.3	114	1,000	946.9	95

continued

Table 5-7. QA/QC AUDIT GC/MS SAMPLES

TARGET COMPOUND	Audit 4 (11165)			Audit 5 (11166) *			Audit 6 (11167) +		
	True Conc. (ng/uL)	Measured Conc. (ng/uL)	Percent Recovery (%)	True Conc. (ng/uL)	Measured Conc. (ng/uL)	Percent Recovery (%)	True Conc. (ng/uL)	Measured Conc. (ng/uL)	Percent Recovery (%)
Phenol	0	0	-	201.3	127.2	63.2	2013	1378	68.4
Napthalene	0	0	-	300.0	336.0	112	1000	1054	105
Acenaphylene	0	0	-	300.0	266.3	88.8	1000	970.0	97.0
Acenaphthene	0	0	-	300.0	262.1	87.4	1000	787.8	78.8
Fluorene	0	0	-	300.0	287.7	95.9	1000	1065	107
Nitronaphthalene	0	0	-	201.4	262.1	130	2014	1574	78.2
Phenanthrene	0	0	-	300.0	292.9	97.6	1000	1079	108
Anthracene	0	0	-	300.0	245.5	81.8	1000	861.2	86.1
Acridine	0	0	-	402.0	406.5	101	1508	1732	115
Carbazole	0	0	-	404.8	389.7	96.3	1518	1491	98.2
Fluoranthene	0	0	-	300.0	278.0	92.7	1000	1029	103
Phenanthrol	0	0	-	400.2	-	0.0	1501	47.6	3.2
Pyrene	0	0	-	300.0	301.1	100	1000	1062	106
Benzo(a)anthracene	0	0	-	300.0	290.0	96.7	1000	988.0	98.8
Chrysene	0	0	-	300.0	293.0	97.7	1000	1008	101
Benzo(b)fluoranthene	0	0	-	300.0	275.5	91.8	1000	1026	103
Benzo(k)fluoranthene	0	0	-	300.0	254.6	84.9	1000	945.3	94.5
Benzo(a)pyrene	0	0	-	300.0	234.2	78.1	1000	811.5	81.2
3-methylcholanthrene	0	0	-	200.8	85.2	42.4	2008	449.1	22.4
Benzo(g,h,i)perylene	0	0	-	300.0	287.0	95.7	1000	1095	110
Dibenzo(a,h)anthracene	0	0	-	300.0	310.2	103	1000	1131	113
Indeno(1,2,3-cd)pyrene	0	0	-	300.0	284.2	94.7	1000	1108	111

* All PAH's @ 300
\+ All PAH's @ 1000

concluded

APPENDIX C

RESEARCH TRIANGLE INSTITUTE
ANALYTICAL PROCEDURES FOR TCO, GRAVIMETRIC, AND PAH SPOT TEST

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Status: INTERIM
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RECOMMENDED OPERATING PROCEDURE FOR TOTAL CHROMATOGRAPHABLE ORGANICS (TCO) ANALYSIS

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RECOMMENDED OPERATING PROCEDURE FOR TOTAL CHROMATOGRAPHABLE ORGANICS (TCO) ANALYSIS

1.0 PROCEDURAL ELEMENTS

1.1 Scope and Application

This method provides semi-quantitative data for organic compounds with boiling points between 100°C and 300°C. Samples that might include organic compounds in this volatility range are organic liquids, solid sample extracts, aqueous extracts, extracts from Source Assessment Samplng System (SASS) and Modified Method 5 (MM5) train sorbent modules, and liquid chromatography (LC) fractions obtained from those samples. This method is based on separating the components of a gas or liquid mixture in a gas chromatography (GC) column and measuring the separated components with a suitable detector.

The upper end of applicability is limited by column overloading and detector saturation. Typical range is 1 to 20 mg/mL. The operating range can be extended by dilution of samples with solvent (e.g., dichloromethane). The sensitivity limit shall be determined by the minimum detectable concentration of standards.

1.2 Summary of Method

TCO analysis quantifies chromatographable material with boiling points in the range of 100° to 300°C. This analysis is applied to all samples that might contain compounds in this volatility and boiling point range.

For TCO analysis, a 0.9- to 3-uL portion of the extract is analyzed by gas chromatography using a flame ionization detector (F.I.D.). Column conditions are described in this document in tabular form in section 1.5.

The peak areas are converted to concentration values using quantitative calibration standards.

For more information, consult Lentzen et al., IERL Procedures Manual: Level 1 (reference 1).

1.3 Definitions

- QC Sample:
  This sample is prepared from a stock solution in an identical manner as the calibration standard. Its concentration is approximately midway in the linear working range of the GC. This quality control (QC) sample is run daily along with the sample set.
- Method Blank:
  Also called concentrated solvent blank, the method blank provides a check on contamination resulting from sample preparation activities. It is typically prepared in the laboratory alongside a sample set by "extracting" and concentrating the appropriate amount of clean solvent in the desired size extraction apparatus.

1.4 Interferences

The analytical system shall be demonstrated to be free from internal contaminants on a daily basis by running a bakeout or a QC sample. A reagent blank must be run for each new batch of reagents used to determine that reagents are contaminant-free. This is verified by an instrument response less than the detection limit.

If duplicate runs of a sample show increasing concentration greater than 15%, or if cross-contamination is suspected (e.g., high-level sample followed by a low-level sample), a reagent blank shall be run to verify no contamination in the system. If contamination is evident, the column shall be baked out at approximately 250°C for 20 minutes or until the detector is stable, and the blank check repeated.

1.5 Personnel Requirements

This ROP is written for individuals with a BS/BA degree in chemistry and at least two years experience in gas chromatography, or equivalent.

1.6 Facilities Requirements

This procedure requires a standard analytical chemistry laboratory with counter space, secured areas for compressed gas storage, and electricity to operate the equipment. Flasks, beakers, tubing, etc. customarily found in such a laboratory are also needed and assumed to be readily available. GC tools (e.g., wrenches, screwdrivers, spare parts, etc.) need to also be available in the laboratory.

1.7 Safety Requirements

Routine safety precautions required in any analytical chemistry laboratory are applicable here. These include such measures as no smoking while in the laboratory; wearing safety glasses, lab coats, and gloves when handling samples; handling organic solvents in a fume hood, etc. Compressed gases considered to be fuels (e.g., hydrogen) must be stored on a pad outside the confines of the laboratory. A safety shower, eye wash, first aid kit, and fire extinguisher must be readily available inside the laboratory.

1.8 Apparatus

1. Gas Chromatograph - GC with packed column and/or capillary column capabilities, oven temperature controller, and flame ionization detector (F.I.D.). (e.g., Perkin Elmer Sigma 115 or Hewlett Packard 5890.)

2. Autosampler - (optional) - Capable of handling methylene chloride extracts and appropriate wash vials.

3. Autosampler vials (optional) - Clear glass vials with teflon faced crimp caps, typically 100 microliter or 1 mL size.

4. Crimping Tool (optional) - Used to secure caps on autosampler vials.

INSTRUMENTAL OPERATING CONDTIONS FOR GAS CHROMATOGRAPHY

Column	Temperature Program (optional)	Injector	Detector	Carrier Gas	Split Injector (optional)	Injection Volume	Solvent
Fused Silica Capillary Column (15 meters typically DB-1, DB-5, or equivalent)	40°C for 3 minutes 8°C/min increase to 250° C and hold for total run time of 45 minutes	300°C	F.I.D. 300°C	Helium 1-3 mL/min	10/1 split ratio	Not to exceed 3 ul (Typically 1 ul)	Dichloromethane (pesticide grade, distilled in glass o equivalent
Packed Column (Methyl Silicone oil coated at 10% on Supelcort AW DMCS or equivalent 1/8 in. x 6 ft. steel)	50°C for 5 minutes 20°C/min increase to 250°C, then hold	300°C	F.I.D. 300°C	Helium at 30 mL/min	N/A	1-5 ul	Dichloromethane (pesticide grade, distilled in glass o equivalent

N/A = Not Applicable

1.9 Reagents and Materials

1. Methylene Chloride: Burdick and Jackson or equivalent grade.

2. Syringe - 5 or 10 microliter, gas tight, syringe for hand injections. Otherwise, 3 or 10 microliter syringes are used for autosampler injections.

3. Disposable Pasteur Pipets - Used for sample transfer.

4. Pipet bulbs - 1 mL, amber.

5. Teflon Squeeze Bottle - 250 mL, or equivalent, used for methylene chloride rinse of vials.

1.10 Samples/Sampling Procedures

NOTE: All glassware coming in contact with a sample shall be cleaned by Level 1 procedures (ref. 1). Briefly, this entails sequential cleaning with soapy water, deionized water, 50:50 (V/V) nitric acid/sulfuric acid, deionized water, methyl alcohol, and methylene chloride, followed by oven drying.

1.10.1 Sampling/Analysis Procedures

(1) Start up by the manufacturer's suggested method.

*(2) Replace septum on auto-sampler and column.

*(3) Insure injection needle is in line with injection port. The autosampler needle should be manually "injected" through the injection port to verify alignment.

(4) Bakeout GC at 200°C for 20 minutes until F.I.D. response is stable and all evidence of column contamination is gone (no peaks) or run an injection of clean solvent as the first injection of the day to verify column contamination is eliminated.

*(5) Load auto-sampler tray with samples.

*(5A) Check the autosampler flush by placing the autosampler in manual mode and flushing a vial of clean solvent through the needle assembly.

*(6) Set auto-sampler to inject approximately 1 uL of samples. Capillary column can be damaged if too great a volume is injected.

(7) Run a QC standard using the specified conditions to verify that the system is operating properly. Check the TCO window (C_7 - C_{17} to insure the range has not changed. (Retention times may change with column aging.) The TCO window for calculations should be adjusted as required.

(8) Flush needle with solvent (dichoromethane) between injections.

(9) Run samples and collect data.

(10) Analyze data according to prescribed method.

(11) After all analyses are complete, bakeout the column at 200°C for 20 minutes, or run clean solvent as a "sample."

(12) Shut down instrument by method suggested by manufacturer.

* These steps are only applicable to automatic injection.

1.10.2 Preparation

Samples for TCO analysis arrive or are prepared as methylene chloride (or occasionally as methanol) extracts of environmental samples, filters, resins, or ambient sampling components. An aliquot of the extract is transferred to a TCO vial and loaded into the autosampler as required.

1.11 Sample Stability

All samples will be stored in a refrigerator at or below 4°C to retard analyte degradation. Samples will be analyzed as soon as possible after sample receipt and preparation to avoid loss of sample due to volatilization and degradation.

1.12 Calibration

(1) Preparation/dilution of a stock solution: Weigh approximately 100 uL aliquots of each (heptane, decane, dodecane, tetradecane, and heptadecane, C7, C10, C12, C14, C17) (99% + pure) into a 10 mL volumetric flask or septum-sealed vial. Quantitative calibration of the TCO procedure is accomplished by the use of mixtures of known concentration of the normal hydrocarbons decane, dodecane, and tetradecane. Retention time limits correspond to the TCO range of boiling points and are defined by the peak maxima for n-heptane (C7, B.P. 98°C) and n-heptadecane (C17, B.P. 303°C). Therefore, integration of detector response should begin at the retention time of C7 and terminate at the retention time of C17. The C7 and C17 peaks are not included in this integration. By this procedure, the integrated area will cover material in the boiling range of approximately 100°C to 300°C. Weigh each hydrocarbon successively into the vial starting from least volatile to most volatile.

(2) Dilute the vial contents up to approximately 3 mL with dichloromethane.

(3) Transfer this quantitatively to a clean, 10-mL amber volumetric flask and add dichloromethane up to the 10-mL mark. This stock solution will have approximately 22 mg (C7 to C12)/mL and 15 mg (C14 to C17)/mL. Several (at least three) dilutions of the stock solution are made to cover the linear working range.

1.13 Sample Analysis

A portion of the extract is injected into the GC under the conditions specified. The peak area (F.I.D. response/uL) is summed over the TCO range window and corresponding TCO value (mg/mL) is determined from the calibration curve. In the event that the TCO value is outside the linear working range, the sample shall be concentrated or diluted, depending on the requirement, and re-analyzed. If there is not enough sample to concentrate, the values are reported as found, and an appropriate qualifying statement is included in the analytical report.

It is important that the observed values of the total integrated area for samples be corrected by subtracting an appropriate solvent blank, prepared in the same manner as the samples.

1.14 Calculations

The peak area (F.I.D. response/uL) is summed over the TCO window and a corresponding TCO value (mg/mL) is determined from the calibration curve.

(1) Construct the calibration line by fitting a linear regression equation to the results of the analysis of the calibration standard solution. The concentration of the standards must fall within the linear working range of the instrument and bracket the concentration of the sample. Use the C10 to C14 standards for calibration.

Standard Calibration Equation:

$$R_i = (M)\ C_i + (B)$$

R_i = F.I.D. Response (total C10 to C14 Peaks)
C_i = Concentration mg/L (total of C10 to C14 standards)
M = Slope of line
B = Intercept of line

(2) Calculate the TCO value for the sample (C_U, measured value) and blank (C_B,blank value) by summing the F.I.D. response over the TCO retention time span and calculating the concentration from the calibration equation.

It is important that the observed values of the total integrated area for samples be corrected by subtracting an appropriate solvent blank prepared in the same manner as the samples. The sample is corrected for the blank:

$$C_U \text{ corrected} = C_U \text{ measured} - C_B$$

1.15 Data Reporting

The results of each TCO analysis should be reported as one number (in milligrams), corresponding to the quantity of material in the 100°C to 300° boiling range in the original sample collected. If more information is available (e.g., cubic meters of gas sampled), the mg/sample value can then be easily converted to the required reporting units.

1.16 Corrective Action

Corrective action procedures in this ROP are covered in the QC check (2.1) and QC control (2.2) sections of the document.

1.17 Precision

Duplicate results by the same operator will be rejected if they differ by more than 15%.

1.18 Accuracy

The result of a quality control sample, run daily, will be considered deficient if it differs by more than 15% from the preparation value. If this value falls outside the accepted range, the system must be evaluated for the probable cause and a second standard run or a new calibration performed over the range of interest.

2.0 QUALITY ASSURANCE/QUALITY CONTROL

2.1 QC Checks

- All glassware used in the TCO analysis shall be cleaned by the method described in reference 1.
- Change the GC inlet septum daily; follow this with a column bakeout at 300°C for twenty minutes or until the F.I.D. response is stable and all evidence of contamination is gone (no peaks) or run an injection of clean solvent to verify column contamination is eliminated. Repeat this procedure during the run if evidence of septum failure appears (e.g., increasing peak elution time with each run or major loss of sensitivity).

2.2 QC Controls

- Run a reagent sample for each new batch of reagent or lot of solvent used. If the analysis fails to show organic contaminants to be below detection limits under identical instrument operating conditions as used for samples, then the reagent shall be distilled in glass and retested or the reagent batch will be unacceptable for TCO analyses.

- Calibrate the GC with standards that generate a response/concentration curve. The calibration curve must be 1 and must have a correlation coefficient greater than 0.97 to b acceptable.

- Prepare a QC standard that is approximatey mid-way in the linear working range. Run this QC standard daily to verify the performance of the GC. Determine the TCO value using the calibration curve and its value plotted compared to the theoretical value. If two runs of the QC standard differ by more than 15% of the actual value, prepare a new QC standard and repeat the test. If the new sample fails the test, determine if there is a loose column connection, septum, or altered split flow. After correction, run a new QC standard. If the new sample fails the test, recalibrate the instrument and/or perform a column change if needed.

3.0 REFERENCES

1. Lentzen, D. E., D. E. Wagoner, E. D. Estes, and W. F. Gutknecht. IERL-RTP Procedures Manual: Level 1 Environmental Assessment (Second Edition). EPA 600/7-78/201, NTIS No. PB293-795, pp. 140-142, October 1978.

Document No: AEERL/12
Status: INTERIM
Revision No: 0
Date: 9/2/86
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RECOMMENDED OPERATING PROCEDURE FOR GRAVIMETRIC ANALYSIS OF ORGANIC EXTRACTS

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RECOMMENDED OPERATING PROCEDURE FOR GRAVIMETRIC ANALYSIS OF ORGANIC EXTRACTS

1.0 PROCEDURAL ELEMENTS

1.1 Scope and Application

Organic compounds with boiling points of 300°C and higher, after extraction with methylene chloride, evaporation of the solvent, and drying to constant weight, can be determined quantitatively by the gravimetric analysis described in this procedure.[1] This method is applicable to organic liquids, solid sample extracts, aqueous extracts, and extracts from the Source Assessment Sampling System or Modified Method 5 train sorbent module. This analysis should be performed after enough of the sample extract has been concentrated to weigh accurately.[2] The suggested solvent is methylene chloride because of its good extraction properties and high volatility. Other solvents may give different results (e.g., methyl alcohol may extract polar compounds which would not be extracted with methylene chloride). All samples being dried to constant weight should be stored in a desiccator.

The range of applicability is limited by the sensitivity of the balance and the organic content of the sample. The balance must be accurate to ± 0.01 mg. If a sample of five milliliters is used for the analysis, then a sensitivity of 0.01 mg/5 mL or 0.002 mg/mL of sample can be achieved. This can be improved by further concentration of more sample.

1.2 Definitions

- o Method Blank: Provides a check on contamination resulting from sample preparation and measurement activities. Typically run in the laboratory after receipt of samples from the field by preparing a material known not to contain the target parameter. Addresses all chemicals and reagents used in a method.
- o Reagent Blank: Provides information on contamination due to specific chemical reagents used during sample preparation, plus any background from the measurement system.
- o Audit Sample: Has known "true values," but is flagged for the laboratory as a "performance evaluation (PE) sample." Provides information on performance, but this information must be tempered with the understanding that the sample may be given extra attention by the analyst. An internal PE sample is created by the in-house analytical laboratory, while an external PE sample is created outside of the analytical laboratory.

1.3 Interferences

Results may be biased due to contamination of the solvent, glassware, or both. A method blank (control) shall be run in duplicate for each run lot of solvent and/or set of samples to provide a control check on the purity of the solvent and the glassware cleaning procedure. The method blank, consisting of a solvent sample from the same lot as that used to prepare samples, shall be prepared and concentrated in an identical manner.

Two reagent blanks shall be analyzed each day samples are run to ensure results which are not biased due to solvent contamination. The reagent blank shall be a solvent sample from the same lot used to prepare the samples and shall not be concentrated prior to analysis. To minimize error in weight due to moisture condensation, the pans containing the sample must appear visually dry before being placed in a desiccator in preparation for drying to constant weight.

1.4 Apparatus

(1) Analytical Balance: Capable of weighing 0.01 mg with an accuracy of ± 0.005 mg.

(2) Desiccating Cabinet: Seal-tight door gasketed with gum rubber. (Desiccators which use silicone sealant shall not be used because of possible contamination of the sample. Silicone grease may interfere with subsequent analysis.)

(3) Oven: Capable of operation to 175°C.

(4) Fume Hood: Standard laboratory.

(5) Dust Cover, Plexiglas, or equivalent: To protect samples drying in hood.

1.5 Reagents and Materials

(1) Disposable Aluminum Weighing Pans: Approximately 2" in diameter, 1/2" deep; crimped sides; weighing approximately 1.0 grams.

(2) Tweezers.

(3) Aluminum Foil.

(4) Pipets: 1 to 5 mL (Class A Volumetric).

(5) Glass Beakers: 50 to 400 mL.

(6) Wash Bottles, Teflon or equivalent.

(7) Deionized Water.

(8) Nitric Acid/Sulfuric Acid, 50:50 (V/V): Prepared from reagent-grade acids.

(9) Methylene Chloride: Burdick and Jackson or equivalent grade.

(10) Methyl Alcohol: Burdick and Jackson or equivalent grade.

(11) Drierite and/or Silica Gel: New Drierite or silica gel may be used as received. Used Drierite or silica gel may be reactivated by drying it in an oven for at least two hours at 175°C.

1.6 Sample Handling

All apparatus that contacts either the concentrated or evaporated residue samples shall be glass, Teflon, aluminum, or stainless steel. Evaporation of samples shall be carried out in an area free of airborne dust and organic vapors that could contaminate the samples.

Ordinarily, all glassware coming in contact with a sample, in either dilute or concentrated form, must be cleaned by complete Level 1 procedures.[2] Briefly, this entails sequential cleaning with soapy water, deionized water, 50:50 (V/V) nitric acid/sulfuric acid, deionized water, methyl alcohol, and methylene chloride, followed by oven drying. The use of deionized water for cleaning glassware is critical when inorganic substances are being analyzed or heavy metal contaminants are present in high concentration in tap water.

This ROP, however, covers only the analysis of organic constituents. Tap water can be substituted for deionized water in glassware cleaning whenever the organic concentration exceeds one mg/sample as measured by this ROP. Experience has shown that tap water adds no measureable amount of organic contaminants to the method or reagent blanks under these conditions.

1.7 Sampling/Analysis Procedures

(1) Label aluminum sample pans on the underside using a ballpoint pen or other sharp object. Handle dishes only with clean tweezers.

(2) Clean the weighing pans by first rinsing them with deionized water, then dipping them successively into three beakers of methyl alcohol, methylene chloride, and, finally, methyl alcohol again.

(3) Dry the cleaned weighing pans to constant weight on a shelf lined with clean aluminum foil in an oven heated to at least 105°C. Cool the pans in a desiccator for a minimum of 4 to 8 hours or overnight.

(4) Weigh pans to constant weight to an accuracy of ± 0.01 mg, recording the pan tare weight.

(5) Transfer by pipet a 1.0 mL aliquot of the sample to the aluminum sample pan or use 1/10 of the concentrated sample. Aliquot size must never exceed 5 mL to avoid loss of sample through capillary action.

(6) Place the sample pan on a clean piece of aluminum foil in a clean fume hood. Shield the pan from dust with a Plexiglas or other cover positioned to allow for adequate air circulation. Evaporate sample to visual dryness at room temperature. This usually takes about 30 minutes.

(7) Place sample pan in desiccator over Drierite and/or silica gel for at least 8 hours.

(8) Weigh sample pan at approximately 4-hour intervals until three successive values differ by no more than ± 0.03 mg. If the residue weight is less than 0.1 mg, concentrate more sample in the same sample pan. If there is insufficient sample remaining for this purpose, report the initial value obtained, along with an explanation.

1.8 Calculations

The gravimetric range organics (GRAV) is calculated in units of mg/sample as follows:

$$\text{GRAV} = \frac{(\text{Sample Weight}_{\text{mg}} + \text{Pan Weight}_{\text{mg}}) - (\text{Pan Tare Weight}_{\text{mg}})}{\text{Aliquot Volume}_{\text{ml}}/\text{Total Concentration Sample Volume}_{\text{ml}}}$$

The calculated GRAV weight is corrected for the method blank:

GRAV CORRECTED = GRAV MEASURED - METHOD BLANK

1.9 Data Reporting

The results of the analysis are averaged and reported in units of mg organics/original sample.

1.10 Precision

Duplicate analyses shall be run by the same analyst and shall be rejected if results differ by more than 20% from the average. If insufficient material is present to rerun the sample, both values will be reported with a qualifying statement.

1.11 Accuracy

Dry sample weight should be at least 1 mg per analysis whenever possible. Accuracy of the analysis is ± 20% of actual value. A proficiency test should be performed by each analyst as described in Section 2.0

2.0 QUALITY CONTROL ELEMENTS

- All operators should demonstrate proficiency with Gravimetric Analysis of Organic Extracts (GRAV) prior to sample analysis. In the proficiency testing, include a GRAV analysis of a reagent blank, a method blank, and an audit sample. The method or reagent blank shall be less than 5 mg/mL of sample. Results of the audit sample shall be within the precision and accuracy specifications outlined in this ROP.

- Two types of audit samples are used. The first contains 100 mg of eicosane [$CH_3(CH_2)_{18}CH_3$] in 250 mL of methylene chloride. Concentrate this solution to 10 mL in a manner identical to that used for sample preparation prior to GRAV analysis. The second type of audit sample can be either prepared in-house or received from an independent laboratory. It must contain organic compounds with chain lengths of more than 18 carbons (and boiling points above 300°C) in sufficient concentration to be determined accurately. Perform the GRAV analysis in duplicate as described in Section 1.7 of this procedure.

- Determine the GRAV value of duplicate method blanks for each new lot of solvent and/or set of samples. Run a method blank any time contamination is suspected. Prepare the blank using the same lot of reagent and the same concentration procedure as that used to prepare the samples. The solvent sample shall be an equivalent volume to that used for sample preparation. If the blank GRAV value is unusually high (i.e., 5 mg/mL of sample), find the cause of the contamination and repeat the method blank GRAV analysis.

- Analyze two reagent blanks for GRAV each day samples are run to ensure the results are not biased due to solvent contamination. The reagent blank shall consist of an aliquot of the solvent used to prepare the samples. If both reagent blank GRAV values are high (i.e., 2 mg/mL of sample), find the cause of the contamination and reanalyze samples and reagent blanks.

- Analyze all samples in duplicate. Samples are analyzed by the same analyst and must agree to within 20% of the average. In the event this condition is not met, repeat the analyses.

  NOTE: If the conditions require the sample to be reanalyzed (e.g., high blank values or poor precision) and insufficent sample remains, then report the value obtained by the initial analysis and include a qualifying statement.

3.0 REFERENCES

1. Harris, J.C. et al. Laboratory Evaluation of Level 1 Organic Analysis Procedures. EPA-600/7-82-048, NTIS PB 82-239294, pp. 30-36, June 1982.

2. Lentzen, D.E., D.E. Wagoner, E.D. Estes, and W.F. Gutknecht. IERL-RTP Procedures Manual: Level 1 Environmental Assessment (Second Edition). EPA-600/7-78-201, NTIS PB 293-795, pp. 26-142, October 1978.

APPENDIX D

ELEMENTED ANALYSIS OF RTI WOODSTOVE SAMPLES PROCEDURES, DATA, QUALITY CONTROL

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ANALYTICAL REPORT

RESULTS OF ANALYSES ON SAMPLES

ELEMENTAL ANALYSIS BY ICAP FOR HAP

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Task No. 85-5
Report No. 8288.28-85-01

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INTRODUCTION

Nineteen samples, including blanks, of woodsmoke collected on glass fiber filters, four samples of wood, ten wood "ash" samples, and two samples of concentrated methylene chloride extracts of woodsmoke collected on glass fiber filters were received from Mr. Bob McCrillis for preparation and elemental analysis. Sample preparation procedures were developed for this project. All analyses were performed on an ARL 35000 Inductively Coupled Argon Plasma(ICAP) atomic emission spectrometer using procedures developed by the Technical Support Office of the Air and Energy Engineering Research Laboratory (AEERL) of EPA.

SAMPLE PREPARATION

The sample preparation procedures used were based upon destruction of organic material through the use of hydrogen peroxide or low temperature ashing, followed by extraction of metallic constituents with aqua regia. For comparison purposes, the wood ash samples were also subjected to a total digestion with hydrofluoric acid. Since the woodsmoke samples were collected on a glass fiber matrix a complete set of data,based upon "total" digestions of sample and filter, would not have been meaningful.

Concentrated Methylene Chloride Extracts

The original work plan specified the splitting of woodsmoke samples between organic and inorganic analysis; providing each with a virgin sample. This was not followed. This lab received filtered samples after extraction. As a check on potential loss of organometallic constituents due to this modification, portions of two concentrated extracts were digested and analyzed.

TSO #	volume(mL)	weight(g.)
442A	1.4	1.2778
442B	1.3	1.4045

The aliquot of extract was flushed from its container with reagent grade methylene chloride. The solvent was allowed to evaporate at room temperature. Ten mL. of 30% reagent grade hydrogen peroxide was added and the sample was heated at a reflux. Destruction of organic matter was completed by oxidation with two 1 mL. portions of reagent grade concentrated nitric acid, heated at reflux till dry. Metals were extracted from the residue by refluxing with 4 mL. of aqua regia. The sample was transferred to a 100 mL. volumetric flask and made up to volume with de-ionized water. The samples were stored in acid cleaned polypropylene vials prior to analysis.

Woodsmoke Collected on Glass Fiber Filters

The samples were received after methylene chloride extraction by the laboratory performing the analysis for organic constituents. The samples were received in poor shape; brittle flaking, broken in most cases. Many filters were discolored on the back side. It is not known whether this is a result of the extraction procedure or indicates possible breakthrough during collection. No duplicate filter samples were taken. Therefore. the filter in the best condition was halved prior to preparation to provide a duplicate sample.

Each filter was cut with a scalpel into pieces small enough to fit the neck of a 125 mL erlenmeyer flask. The pieces of filter and any recoverable loose particles were transferred to an acid cleaned erlenmeyer flask. A reflux cap was fitted to the flask. 20 mL of 30% reagent grade hydrogen peroxide was added, and the mixture was heated carefully for several hours until the filter appeared clean. The reflux caps were removed and the samples were partially evaporated: 1 mL of concentrated reagent grade nitric acid was added to destroy the remaining hydrogen peroxide. The flasks were cooled to room temperature. Eight mL of aqua regia were added and heated. Water was added and the mixture was boiled. After cooling, the sample was filtered into a 100 mL volumetric flask and made up to volume with de-ionized water. The digests were stored in polypropylene bottles prior to analysis

Preparation of Organometallic Recovery Sample

Two Gelman type A-E glass fiber filters were cleaned by leaching with 5%(1 part: 19 parts de-ionized water) nitric acid and de-ionized water. They were cut up and transferred to flasks. To one of the flasks was added 8.31 mg. of sodium cyclohexanebutyrate, 0.38 mg. cadmium cyclohexanebutyrate, and 1.28 mg. of mercury cyclohexanebutyrate as the solids. The contents of these flasks were then digested as woodsmoke samples.

Preparation of Wood Samples

Four wood samples were received as quartered logs. A representative homogeneous sample was prepared from each log by cutting it in two with a tungsten carbide hacksaw blade and collecting the sawdust. A tungsten carbide blade was used to avoid contaminating the samples with an element of interest. The samples were not analyzed for tungsten.

Five gram portions of the sawdust were weighed into 125 mL. erlenmeyer flasks and fitted with reflux caps. The samples were digested by heating with 25 mL. of 30 % hydrogen peroxide in a 120 degree Centigrade oven overnight. This was repeated three times (total hydrogen peroxide = 100 mL.). The flasks were transferred to a hot plate and the residue was further oxidized by refluxing with 3 mL. of concentrated reagent grade nitric acid till the residue was barely moist and the evolution of brown fumes had ceased. This was repeated once with 3 mL. and once with 2 mL. of nitric acid. No activity was noted during the final reflux. Four mL. of aqua regia was added and heated. Some water was added and the mixture was boiled. After cooling, the sample was transferred to a 100 mL. volumetric flask and made up to volume with de-ionized water. The digests were stored in polypropylene bottles prior to analysis.

Preparation of Wood Recovery Sample

A five gram portion of one of the wood samples was weighed into a 125 mL erlenmeyer flask. The sample was spiked with inorganic standards by volumetric dispensing of the commercially available stock solutions also used for calibration standard preparation. The spikes were allowed to soak into the sawdust. This spiked sample was then digested as above. 100 micrograms of chromium, lithium, titanium, cobalt, barium, antimony, nickel, cadmium, silver, vanadium, copper, and tin; 500 micrograms of phosphorus, mercury, lead, thallium, selenium, arsenic, zinc, manganese, and sulfur; 1 milligram of iron, aluminum, strontium, potassium, and sodium; and 10 milligrams of calcium and magnesium were added as spikes.

Preparation of Wood Ash Samples

The ash samples as received were not the finely divided, uniform residues of complete combustion runs anticipated when the work plan for the sample analysis was written. The samples were heterogeneous with large chunks and appeared to have a high carbon content. It was the EPA engineering project officer's decision to work with the samples as received. The samples were homogenized and carbon was removed by low temperature ashing prior to digestion. Each sample was then digested by two procedures, aqua regia and 'total' digestion, for comparison purposes.

Homogenization

The entire sample was ground with a porcelain mortar and pestle. The ground sample was sieved to 100 mesh. This was repeated until the entire sample passed through the sieve. The ground sample was returned to its original polypropylene zip lock bag and the sample was mixed by rotation.

Low Temperature Ashing

A 1 gram portion of the homogenized sample was split between three to five boats and ashed to a constant weight in a Trapelo model 505 low temperature asher. Every three hours the process was interrupted and the sample was stirred with a glass rod. After constant weight was reached (+ or - 1 mg.) the residue was transferred to a plastic vial for storage. A % recovery was calculated for each sample.

Aqua Regia Digest

A 50 mg. portion of the ashed sample was weighed into an acid cleaned fleaker. The sample was refluxed with 4 mL of aqua regia for 20 minutes. Some de-ionized water was added and the mixture was boiled. After it had cooled the digest was transferred to a 100 mL volumetric flask and made up to volume with more de-ionized water. The digest was transferred to a polypropylene bottle for storage prior to analysis.

Total Digest

A 50 mg. portion of the ashed sample was weighed into the teflon liner from a Parr bomb. It was refluxed gently with 4 mL.

of aqua regia. The teflon lid was in place to prevent physical losses. The mixture was vacuum filtered through teflon and the filtrate was transferred to a 100 mL. volumetric flask. The residue and the teflon filter were placed in a Parr acid bomb liner, 1 mL. of reagent grade concentrated nitric acid and 2 mL. of reagent grade concentrated hydrofluoric acid were added, and the bomb was assembled. The Parr bomb was heated overnight in a 120 degree Centigrade oven. In the morning, the bombs were removed from the oven and chilled in an ice bath. The bombs were opened and 20 mL. of a boric acid solution (20 g/liter) were added to complex any excess hydrofluoric acid. This mixture was added to the filtrate in the volumetric flask and the digest was made up to volume with de-ionized water. The digest was transferred to a polypropylene bottle for storage prior to analysis.

SAMPLE ANALYSIS

All samples were analyzed for presence of certain elements using the standard ICAP file for multi-element analyses. First, the instrument was calibrated, using a range of standards which covered the working range of the technique. The solutions were aspirated into the plasma at a constant rate while the light that was emitted was scanned by the monochromator over the wavelength range for the various elemental emission lines. The intensities of these lines were recorded and stored for generation of a calibration curve for each element. These calibration curves were used by the computer to calculate the concentration of each element found in each of the samples.

After the calibration curves were determined, each sample digest was aspirated into the plasma of the ICAP using the same conditions as for the standards. The response for each element was obtained and compared to that value for a reagent blank. If the response was greater than the blank, the blank correction was made, and a value for the element in the original sample, before it was dissolved was calculated. This value was compared to the available limits of detection, to determine if it was within the working range of the technique. Each digest was analyzed in duplicate.

PRESENTATION OF RESULTS

The results are labeled in the tables on the basis of our internal sample code. Use Table 2 to correlate that number with the sample descriptors. The results presented here have been corrected for blank contribution. In all cases this includes the contribution due to reagents used in sample preparation. In the specific case of the woodsmoke samples the contribution due to the glass fiber filters used to collect the samples was also included in this correction. Table 1 presents the detection and quantifiable limits used for the woodsmoke and the methylene chloride extracts of woodsmoke samples. The quantifiable limits are calculated as 5 times the detection limits. The detection limits are calculated as 3 times the standard deviation of replicate analyses. The standard deviation values used for this calculation are the means of the standard deviations of all replicate analyses, from samples prepared in a similar manner in this test series.

The results for the methylene chloride extracts of glass fiber collected woodsmoke are in Table 3; the results for woodsmoke collected on glass fiber filters are in Tables 4-6. The results for these two classes of samples are presented in units of total micrograms found. The results for woodsmoke sample 432 H are not available since a flask broke near the end of the digestion of this sample. No recovery was possible.

Tables 7 - 18 present the results for the wood ash samples. Each table has the results for both digestions on a single sample. Table 18 repeats data already available on Tables 11 and 17 so that the analyses of duplicate digests by both procedures may be compared more easily. The results for wood ash samples are blank corrected and in units of weight %. They are calculated on the basis of "as received". Table 19 presents the recoveries of the wood ash samples after treatment by low temperature ashing (the ash content of the wood ash samples). These are the correction values used in calculating the wood ash results presented in Tables 7 - 18.

Table 20 presents the results for the wood samples in units of micrograms per gram, Table 21 presents the results of the recovery of organometallics, Table 22 presents the elemental recovery results, and Table 23 presents the results of the duplicate woodsmoke sample analysis. Table 24 presents the results for the analysis of duplicate wood digestions. Finally, Table 25 presents a comparison of the wood ash data based on the ratio of major elements.

DISCUSSION

There are several points to be noted from a review of the data. This part of the project took much longer than anticipated because of the extra sample preparation steps which were found to be necessary. A specific example is the homogenization and low temperature ashing which were added to the original work plan and were required to digest the wood ash samples. The actual analysis of the digested samples proceeded without any unusual problems.

METHYLENE CHLORIDE EXTRACTS-The results in Table 3 would indicate that any elemental losses are probably minimal and no special corrections need to be made to the woodsmoke data to compensate for this extraction. One of the digests was scanned to provide a graphical output. On the basis of these graphics calcium, sodium, and zinc were found. Another study of this type with optimized procedures could find these elements quantifiable and require correction factors.

Despite the fact that these samples do not indicate the need for a correction factor, the woodsmoke results are probably still in question due to the physical handling through the extraction step. Assuming that a Soxhlet procedure was used- typical procedure for environmental work- there is nothing in the design or the standard operation of a Soxhlet apparatus which guarantees the complete recovery of the residue. The draining stage of a Soxhlet is physically vigorous. Particulates may be knocked off a filter and never recovered from the bottom of the sample chamber. The filters as received after extraction were brittle. Some were broken; others had chipped edges. It is not known what percentage of the original woodsmoke samples were actually present and analyzed because of the handling and extraction.

WOODSMOKE-The results are in Tables 4,5,6. Potassium is the element found in significant quantities in most of the samples with sulfur also found in a majority of the samples. The actual values are somewhat in question due to the poor condition of the filters and the organic extractions they were subjected to between sample generation and digestion for reasons described above.

Table 23 has the results on the precision of duplicate digesations. These samples were generated by splitting a sample into two halves. The split was made on a line where the centerlines of the woodsmoke and the filter coincided but this was a qualitative effort. More data is necessary but the sparse results here are within reasonable limits for a first effort.

WOOD-The results for these samples are in Table 20; duplicate digestions are in Table 24. Several elements show unacceptable precision. The digestion procedure may be the source of the imprecision.

The procedure used was simply a scaled up version of one which has been used in the past for the preparation of biological samples. Several observations may be made. The reaction involved is quite vigorous which restricts the volume of reagent which may be used while the large sample size used required large amounts of reagents. These conflicting requirements forced a stepwise procedure which may explain part of the imprecision. Additionally, a visible residue was observed at the end of the digestion procedure. This residue had the appearance of silica. It is possible that silicon is taken up by the plants as soluble silicates which are converted by this procedure to silica. If true, other elements would be occluded in this silica as it formed. This also would explain variable recovery. Finding ways to reduce the sample size requirement to allow a single hydrogen peroxide oxidation step, leaching soluble silicates from the sample prior to the start of the digestion would be suggested steps to investigate in improving this procedure.

WOOD ASH-Once these samples were cleaned up by low temperature ashing each sample was subjected to two separate digestion procedures for comparison purposes. Tables 7 through 18 present the results. Table 18 presents the results for duplicate digestions on a single sample by both procedures. Table 19 presents the per cent ash found after low temperature ashing for these samples. Because of these factors, the detection and quantification limits differ greatly from one sample to the next when calculated on an "as received" basis. For this reason, detection and quantification limits were calculated for each sample and are included in the respective tables.

The standard deviations were found to be significantly higher for the "Total" digestion procedure. This is probably due to the higher solids level in these digests raising the noise level.

As can be seen from Table 18 both procedures exhibit good reproducibility for those elements which may be detected. For most elements, there is excellent agreement between the results obtained from both sample preparation techniques. These results would indicate that there is very little silica in the ash samples.

Table 25 presents a comparison of wood ash results based upon the ratio of the major elements calcium, magnesium, and potasium versus the type of wood from which the ash originated. This table clearly shows that the results from this study are good enough to differentiate ash samples on the basis of wood type. These results are encouraging and would indicate that there is merit in further studies of this type.

RECOVERY SAMPLES-Results for the recovery of known spikes may be found in Tables 21 and 22. Table 21 presents the recovery of cadmium, mercury, and sodium as their cyclohexanebutyrate salts after digestion with hydrogen peroxide. This was done to investigate the recovery of organometallics. These results are acceptable for a first attempt with the exception of mercury. This is an expected exception. The importance of organometallic recovery in samples of this type is not known.

The results in Table 22 are based upon the addition of inorganic spikes added to a wood sample prior to its digestion with hydrogen peroxide. The results are poor but their interpretation is complicated by the poor precision of replicate digestions. In addition to the possible explanations above, another applies to a spiked sample. The hydrogen peroxide oxidation of organic matter is a metal ion catalyzed reaction. As such, the kinetics of the spiked digest could be different.

QA/QC

All digests were analyzed in duplicate. Duplicate digests wer prepared and analyzed. Spike recovery samples were prepared and analyzed. Standard Reference Materials for samples of these types were not available. The discussion of these samples has been presented above. The results for the wood samples must be considered questionable and out of control. The results for the wood smoke and wood ash and methylene chloride samples are satisfactory with the exception of the mercury results.

RECOMMENDATIONS

Wood Ash-Since both HF and Aqua Regia procedures provide comparable results, and the Aqua Regia reflux procedure is quicker, future samples of this type should be prepared in that manner. As a side benefit, this procedure tends to provide more quantifiable results.

Woodsmoke-Serious consideration should be given to separate samples collected simultaneously for elemental analysis. This would avoid the questions referred to above. More importantly, this would allow the use of a different filter media for the elemental samples. Glass fiber filters are not a good media for these samples. Even after the acid cleaning, the filters used in this study had a significant and somewhat variable background for certain elements.

If this study is continued a small expenditure for modifying the sample introduction system and validation of the modification would allow samples of this type to be prepared with less dilution which should improve the number of elements quantified and detected.

Table 1. Detection & Quantifiable limits for Digests of Wood, Woodsmoke and Their Extracts

	MICROGRAMS		WEIGHT %	
	detection limit	quantifiable limit	detection limit	quantifiable limit
Ag	1.7	8.4	0.000034	0.00017
Al	15	73	0.00029	0.0015
As	24	120	0.00049	0.0024
Ba	1.3	6.6	0.000026	0.00013
Ca	32	160	0.00064	0.0032
Cd	1.2	5.9	0.000024	0.00012
Co	1.6	7.8	0.000031	0.00016
Cr	1.3	6.4	0.000026	0.00013
Cu	1.2	6.2	0.000025	0.00012
Fe	2.1	10	0.000042	0.00021
Hg	15	75	0.00030	0.0015
K	90	450	0.0018	0.0090
Li	4.5	23	0.000090	0.00045
Mg	25	120	0.00049	0.0025
Mn	0.76	3.8	0.000015	0.000076
Na	140	700	0.0028	0.014
Ni	2.5	12	0.000050	0.00025
P	8.9	45	0.00018	0.00089
Pb	32	160	0.00064	0.0032
S	84	420	0.0017	0.0084
Sb	60	300	0.0012	0.0060
Se	370	1800	0.0073	0.037
Si	23	110	0.00046	0.0023
Sn	8.9	44	0.00018	0.00089
Sr	0.25	1.2	0.0000049	0.000025
Ti	0.80	4.0	0.000016	0.000080
Tl	36	180	0.00072	0.0036
V	7.5	38	0.00015	0.00075
Zn	3.8	19	0.000076	0.00038

Table 2. Sample Codes

TSO #				
432-A		IACP85RZOZ01811	FILTER #1	Blank filter- contaminated
432-B	50403	IACP85RSOH01801	FILTER #2	Glass fiber filtered woodsmoke
432-C	50411	IACP85RSOH01802	FILTER #3	Glass fiber filtered woodsmoke
432-D	50417	IACP85RSOH01803	FILTER #4	Glass fiber filtered woodsmoke
432-E	50424	IACP85RSOH01804	FILTER #5	Glass fiber filtered woodsmoke
432-F	50424	IACP85RSOH01804	FILTER #6	Glass fiber filtered woodsmoke
432-G	50501	IACP85RSOH01805	FILTER #7	Glass fiber filtered woodsmoke
432-H	50501	IACP85RSOH01805	FILTER #8	Glass fiber filtered woodsmoke
432-I	50501	IACP85RSOH01805	FILTER #9	Glass fiber filtered woodsmoke
433-A	50508	IACP85RSOH01806	FILTER #10	Glass fiber filtered woodsmoke
433-B	50515	IACP85RSOH01807	FILTER #11	Glass fiber filtered woodsmoke
433-C	50515	IACP85RSOH01807	FILTER #12	Glass fiber filtered woodsmoke
433-D	50515	IACP85RSOH01807	FILTER #13	Glass fiber filtered woodsmoke
433-E	50522	IACP85RSOH01808	FILTER #14	Glass fiber filtered woodsmoke
435-A	50605	IACP85RSOH01809	FILTER #15	Glass fiber filtered woodsmoke
435-B	50605	IACP85RSOH01809	FILTER #16	Glass fiber filtered woodsmoke
435-C	50612	IACP85RSOH01810	FILTER #17	Glass fiber filtered woodsmoke
435-D	50612	IACP85RSOH01810	FILTER #18	Glass fiber filtered woodsmoke
439-A	50501	IACP85RZOZ01815	TEST 5	woodstove ash
439-B	50424	IACP85RZOZ01815	TEST 4	woodstove ash
439-C	50411	IACP85RZOZ01815	TEST 2	woodstove ash
439-D	50403	IACP85RZOZ01815	TEST 1	woodstove ash
439-E	50417	IACP85RZOZ01815	TEST 3	woodstove ash
439-F	50612	IACP85RZOZ01815	TEST 10	woodstove ash
439-G	50605	IACP85RZOZ01815	TEST 9	woodstove ash
439-H	50522	IACP85RZOZ01815	TEST 8	woodstove ash
439-I	50515	IACP85RZOZ01815	TEST 7	woodstove ash
440-A	50508	IACP85RZOZ01815	TEST 6	woodstove ash
440-B	50625	IACP85RZOZ01815	FILTER #19	replacement blank filter
440-C		IACP85RZOZ01815		uncured pine wood- debarked
440-D		IACP85RZOZ01815		cured pine wood- debarked
440-E		IACP85RZOZ01815		cured oak wood- w/bark
440-F		IACP85RZOZ01815		uncured oak wood- w/bark
442-A	50605	IACP85RSOG01816		methylene chloride extract
442-B	50522	IACP85RSOG01818		methylene chloride extract

Table 3. Analytical Results for Methylene Chloride Extracts

	442A TOTAL MICROGRAMS	442B TOTAL MICROGRAMS
Ag	N. D.	N. D.
Al	BQL	BQL
As	N. D.	N. D.,
Ba	N. D.	N. D.
Ca	N. D.	BQL
Cd	N. D.	N. D.
Co	N. D.	N. D.
Cr	N. D.	N. D.
Cu	N. D.	BQL
Fe	N. D.	N. D.
Hg	N. D.	N. D.
K	N. D.	N. D.
Li	N. D.	N. D.
Mg	N. D.	N. D.
Mn	N. D.	N. D.
Na	N. D.	BQL
Ni	N. D.	N. D.
P	BQL	BQL
Pb	N. D.	N. D.
S	N. D.	N. D.
Sb	N. D.	N. D.
Se	N. D.	N. D.
Sn	N. D.	N. D.
Sr	N. D.	N. D.
Ti	BQL	BQL
Tl	N. D.	N. D.
V	N. D.	N. D.
Zn	N. D.	N. D.

N. D.= not detected

BQL = below the quantifiable limit

Table 4. Analytical Results for Woodsmoke
Collected on Glass Fiber Filters

	432A TOTAL micrograms	432B TOTAL micrograms	432C TOTAL micrograms	432D TOTAL micrograms	432E TOTAL micrograms
Ag	BQL	8.6	BQL	BQL	N. D.
Al	N. D.	N. D.	N. D.	N. D.	N. D.
As	BQL	N. D.	N. D.	N. D.	N. D.
Ba	N. D.	N. D.	BQL	10.3	N. D.
Ca	N. D.	N. D.	N. D.	N. D.	N. D.
Cd	N. D.	N. D.	BQL	BQL	BQL
Co	N. D.	N. D.	N. D.	N. D.	N. D.
Cr	N. D.	N. D.	N. D.	N. D.	N. D.
Cu	N. D.	BQL	N. D.	N. D.	N. D.
Fe	N. D.	23.9	14.2	13.1	N. D.
Hg	N. D.	N. D.	N. D.	N. D.	N. D.
K	N. D.	2610	2460	1180	684
Li	N. D.	N. D.	N. D.	N. D.	N. D.
Mg	N. D.	N. D.	N. D.	N. D.	N. D.
Mn	N. D.	6.1	5.1	N. D.	3.9
Na	BQL	N. D.	BQL	1060	N. D.
Ni	N. D.	15.6	N. D.	N. D.	N. D.
P	N. D.	N. D.	N. D.	N. D.	N. D.
Pb	N. D.	N. D.	N. D.	N. D.	N. D.
S	N. D.	885	849	BQL	544
Sb	N. D.	N. D.	N. D.	N. D.	N. D.
Se	N. D.	N. D.	N. D.	N. D.	N. D.
Sn	N. D.	N. D.	N. D.	BQL	BQL
Sr	N. D.	N. D.	N. D.	N. D.	N. D.
Ti	BQL	BQL	4.4	4.2	N. D.
Tl	N. D.	N. D.	N. D.	N. D.	N. D.
V	N. D.	N. D.	N. D.	N. D.	N. D.
Zn	N. D.	BQL	N. D.	BQL	BQL

N. D.= not detected
BQL = below the quantifiable limit

Table 5. Analytical Results for Woodsmoke Collected on Glass Fiber Filters

	432F	432G	432I	433A	433B	433C
	TOTAL micrograms	TOTAL micrograms	TOTAL micrograms	TOTAL micrograms	TOTAL micrograms	TOTAL micrograms
Ag	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Al	N. D.	BQL	N. D.	N. D.	N. D.	N. D.
As	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Ba	13	7.7	N. D.	N. D.	N. D.	N. D.
Ca	BQL	371	N. D.	N. D.	N. D.	N. D.
Cd	31.8	BQL	N. D.	7.5	6.4	BQL
Co	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Cr	N. D.	N. D.	N. D.	7.1	N. D.	N. D.
Cu	BQL	N. D.	N. D.	N. D.	N. D.	N. D.
Fe	BQL	N. D.	N. D.	63.1	26.4	N. D.
Hg	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
K	13200	BQL	BQL	1910	1670	576
Li	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Mg	N. D.	BQL	N. D.	N. D.	N. D.	N. D.
Mn	32.7	11.6	15.9	108	28.4	4.1
Na	BQL	1940	BQL	BQL	915	2590
Ni	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
P	BQL	N. D.	N. D.	N. D.	N. D.	N. D.
Pb	286	N. D.	N. D.	N. D.	N. D.	N. D.
S	5110	BQL	N. D.	881	736	1050
Sb	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Se	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Sn	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Sr	2.4	2.6	N. D.	BQL	N. D.	N. D.
Ti	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Tl	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
V	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Zn	387	102	N. D.	834	334	154

N. D.= not detected
BQL = below the quantifiable limit

Table 6. Analytical Results for Woodsmoke
Collected on Glass Fiber Filters

	433D	433E	435A	435B	435C	435D
	TOTAL micrograms	TOTAL micrograms	TOTAL micrograms	TOTAL micrograms	TOTAL micrograms	TOTAL micrograms
Ag	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Al	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
As	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Ba	BQL	15.3	7.3	BQL	N. D.	BQL
Ca	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Cd	N. D.	8.8	8.7	N. D.	N. D.	N. D.
Co	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Cr	N. D.	BQL	N. D.	N. D.	N. D.	N. D.
Cu	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Fe	N. D.	27.7	296	55.2	N. D.	N. D.
Hg	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
K	BQL	1320	2110	532	550	1640
Li	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Mg	BQL	N. D.	N. D.	N. D.	N. D.	N. D.
Mn	4.2	53.4	7.3	N. D.	3.9	BQL
Na	BQL	N. D.	N. D.	N. D.	BQL	BQL
Ni	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
P	N. D.	BQL	N. D.	N. D.	N. D.	N. D.
Pb	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
S	N. D.	BQL	494	N. D.	BQL	695
Sb	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Se	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Sn	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Sr	BQL	1.5	N. D.	N. D.	N. D.	N. D.
Ti	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Tl	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
V	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Zn	50.8	78.2	BQL	N. D.	N. D.	N. D.

N. D.= not detected N. D.
BQL = below the quantifiable limit

Table 7. Comparison of results for Wood Ash sample 439 A

	Aqua Regia Digestion			'Total' digest		
	detection limit	quantifiable limit	Wt. %	detection limit	quantifiable limit	Wt. %
Ag	0.00040	0.0020	N. D.	0.00070	0.0035	N. D.
Al	0.0034	0.017	0.0537	0.042	0.21	BQL
As	0.0057	0.029	N. D.	0.0045	0.022	N. D.
Ba	0.00031	0.0015	0.0223	0.0024	0.012	0.0186
Ca	0.0075	0.038	1.43	0.059	0.30	1.27
Cd	0.00028	0.0014	N. D.	0.00013	0.00064	N. D.
Co	0.00037	0.0018	N. D.	0.0014	0.0070	N. D.
Cr	0.00030	0.0015	N. D.	0.00033	0.0017	N. D.
Cu	0.00029	0.0015	0.00237	0.00029	0.0015	BQL
Fe	0.00049	0.0025	0.0257	0.033	0.16	N. D.
Hg	0.0035	0.018	N. D.	0.0035	0.018	N. D.
K	0.021	0.11	0.864	0.013	0.065	0.707
Li	0.0011	0.0053	N. D.	0.0011	0.0053	N. D.
Mg	0.0058	0.029	0.468	0.049	0.25	0.385
Mn	0.00018	0.00089	0.287	0.00021	0.0011	0.241
Na	0.033	0.17	N. D.	0.0047	0.024	BQL
Ni	0.00059	0.0029	N. D.	0.00080	0.0040	N. D.
P	0.0021	0.010	0.0541	0.0047	0.023	0.0374
Pb	0.0076	0.038	N. D.	0.011	0.056	N. D.
S	0.020	0.099	0.102	0.022	0.11	BQL
Sb	0.014	0.071	N. D.	0.014	0.070	N. D.
Se	0.086	0.43	N. D.	0.17	0.85	N. D.
Si	0.0054	0.027	BQL	0.15	0.76	BQL
Sn	0.0021	0.010	N. D.	0.0068	0.034	N. D.
Sr	0.000058	0.00029	0.0121	0.0016	0.0080	0.0103
Ti	0.00019	0.00095	N. D.	0.00074	0.0037	0.00440
Tl	0.0085	0.042	N. D.	0.0038	0.019	BQL
V	0.0018	0.0088	N. D.	0.0018	0.0088	N. D.
Zn	0.00090	0.0045	0.0170	0.00022	0.0011	0.0113

units = Wt. %
N. D. = not detected
BQL = below the quantifiable limit

Table 8. Comparison of results for Wood Ash sample 439 B

	Aqua Regia Digestion			'Total' digest		
	detection limit	quantifiable limit	Wt. %	detection limit	quantifiable limit	Wt. %
Ag	0.0030	0.015	N. D.	0.0053	0.027	N. D.
Al	0.026	0.13	0.162	0.32	1.6	N. D.
As	0.043	0.22	N. D.	0.034	0.17	N. D.
Ba	0.0023	0.012	0.154	0.018	0.091	0.156
Ca	0.057	0.28	24.5	0.45	2.2	25.6
Cd	0.0021	0.011	N. D.	0.00098	0.0049	N. D.
Co	0.0028	0.014	N. D.	0.011	0.053	N. D.
Cr	0.0023	0.011	N. D.	0.0025	0.013	N. D.
Cu	0.0022	0.011	BQL	0.0022	0.011	N. D.
Fe	0.0037	0.019	0.0741	0.25	1.2	N. D.
Hg	0.027	0.13	N. D.	0.027	0.13	N. D.
K	0.16	0.80	6.84	0.099	0.50	6.37
Li	0.0080	0.040	N. D.	0.0080	0.040	N. D.
Mg	0.044	0.22	1.28	0.37	1.9	BQL
Mn	0.0013	0.0067	0.858	0.0016	0.0080	1.06
Na	0.25	1.2	N. D.	0.036	0.18	BQL
Ni	0.0044	0.022	N. D.	0.0061	0.030	N. D.
P	0.016	0.079	0.301	0.036	0.18	0.324
Pb	0.057	0.28	N. D.	0.085	0.42	N. D.
S	0.15	0.74	BQL	0.17	0.84	BQL
Sb	0.11	0.53	N. D.	0.11	0.53	N. D.
Se	0.65	3.3	N. D.	1.3	6.4	N. D.
Si	0.041	0.20	BQL	1.1	5.7	N. D.
Sn	0.016	0.079	N. D.	0.052	0.26	N. D.
Sr	0.00044	0.0022	0.147	0.012	0.061	0.151
Ti	0.0014	0.0071	N. D.	0.0056	0.028	BQL
Tl	0.064	0.32	BQL	0.029	0.14	N. D.
V	0.013	0.067	N. D.	0.013	0.067	N. D.
Zn	0.0068	0.034	BQL	0.0017	0.0083	0.0303

units = Wt. %

N. D. = not detected

BQL = below the quantifiable limit

Table 9. Comparison of results for Wood Ash sample 439 C

	Aqua Regia Digestion			'Total' digest		
	detection limit	quantifiable limit	Wt. %	detection limit	quantifiable limit	Wt. %
Ag	0.0028	0.014	N. D.	0.0050	0.025	N. D.
Al	0.024	0.12	N. D.	0.30	1.5	N. D.
As	0.041	0.20	N. D.	0.032	0.16	N. D.
Ba	0.0022	0.011	0.217	0.017	0.087	0.179
Ca	0.053	0.27	25.2	0.42	2.1	21.5
Cd	0.0020	0.0099	N. D.	0.00092	0.0046	N. D.
Co	0.0026	0.013	N. D.	0.010	0.050	N. D.
Cr	0.0022	0.011	N. D.	0.0024	0.012	N. D.
Cu	0.0021	0.010	BQL	0.0021	0.010	N. D.
Fe	0.0035	0.017	0.0448	0.24	1.2	N. D.
Hg	0.025	0.13	N. D.	0.025	0.13	N. D.
K	0.15	0.75	6.49	0.094	0.47	5.07
Li	0.0075	0.038	N. D.	0.0076	0.038	N. D.
Mg	0.041	0.21	1.51	0.35	1.8	BQL
Mn	0.0013	0.0063	0.665	0.0015	0.0076	0.594
Na	0.23	1.2	N. D.	0.034	0.17	BQL
Ni	0.0042	0.021	N. D.	0.0057	0.029	BQL
P	0.015	0.074	0.797	0.034	0.17	0.655
Pb	0.054	0.27	N. D.	0.080	0.40	N. D.
S	0.14	0.70	BQL	0.16	0.80	BQL
Sb	0.10	0.50	N. D.	0.10	0.50	N. D.
Se	0.61	3.1	N. D.	1.2	6.1	N. D.
Si	0.038	0.19	BQL	1.1	5.4	N. D.
Sn	0.015	0.074	N. D.	0.049	0.24	N. D.
Sr	0.00041	0.0021	0.290	0.011	0.057	0.236
Ti	0.0013	0.0067	N. D.	0.0053	0.026	N. D.
Tl	0.060	0.30	N. D.	0.027	0.14	N. D.
V	0.013	0.063	N. D.	0.013	0.063	N. D.
Zn	0.0064	0.032	BQL	0.0016	0.0079	BQL

units = Wt. %

N. D. = not detected

BQL = below the quantifiable limit

Table 10. Comparison of results for Wood Ash sample 439 D

	Aqua Regia Digestion			'Total' digest		
	detection limit	quantifiable limit	Wt. %	detection limit	quantifiable limit	Wt. %
Ag	0.0021	0.010	N. D.	0.0036	0.018	N. D.
Al	0.018	0.089	0.135	0.22	1.1	N. D.
As	0.030	0.15	N. D.	0.023	0.11	N. D.
Ba	0.0016	0.0080	0.166	0.012	0.062	0.140
Ca	0.039	0.20	18.5	0.30	1.5	15.6
Cd	0.0014	0.0072	N. D.	0.00066	0.0033	N. D.
Co	0.0019	0.0095	N. D.	0.0072	0.036	N. D.
Cr	0.0016	0.0079	N. D.	0.0017	0.0086	N. D.
Cu	0.0015	0.0076	BQL	0.0015	0.0075	BQL
Fe	0.0026	0.013	0.0460	0.17	0.85	N. D.
Hg	0.018	0.092	N. D.	0.018	0.090	N. D.
K	0.11	0.55	4.50	0.067	0.34	3.70
Li	0.0055	0.028	N. D.	0.0054	0.027	N. D.
Mg	0.030	0.15	1.19	0.25	1.3	1.13
Mn	0.00093	0.0046	0.518	0.0011	0.0054	0.488
Na	0.17	0.86	N. D.	0.024	0.12	BQL
Ni	0.0031	0.015	N. D.	0.0041	0.021	N. D.
P	0.011	0.055	0.583	0.024	0.12	0.473
Pb	0.039	0.20	N. D.	0.057	0.29	N. D.
S	0.10	0.51	BQL	0.11	0.57	BQL
Sb	0.074	0.37	N. D.	0.072	0.36	N. D.
Se	0.45	2.2	N. D.	0.87	4.4	N. D.
Si	0.028	0.14	BQL	0.78	3.9	N. D.
Sn	0.011	0.054	N. D.	0.035	0.18	N. D.
Sr	0.00030	0.0015	0.201	0.0082	0.041	0.169
Ti	0.00098	0.0049	N. D.	0.0038	0.019	N. D.
Tl	0.044	0.22	N. D.	0.019	0.097	N. D.
V	0.0092	0.046	N. D.	0.0090	0.045	N. D.
Zn	0.0047	0.023	0.0241	0.0011	0.0056	BQL

units = Wt. %
N. D. = not detected
BQL = below the quantifiable limit

Table 11. Comparison of results for Wood Ash sample 439 E

	Aqua Regia Digestion			'Total' digest		
	detection limit	quantifiable limit	Wt. %	detection limit	quantifiable limit	Wt. %
Ag	0.0029	0.015	N. D.	0.0053	0.027	N. D.
Al	0.025	0.13	0.141	0.32	1.6	N. D.
As	0.043	0.21	N. D.	0.034	0.17	N. D.
Ba	0.0023	0.011	0.172	0.018	0.092	0.166
Ca	0.056	0.28	27.4	0.45	2.2	27.5
Cd	0.0021	0.010	N. D.	0.00098	0.0049	N. D.
Co	0.0027	0.014	N. D.	0.011	0.053	N. D.
Cr	0.0022	0.011	N. D.	0.0025	0.013	N. D.
Cu	0.0022	0.011	BQL	0.0022	0.011	N. D.
Fe	0.0036	0.018	0.0695	0.25	1.2	N. D.
Hg	0.026	0.13	N. D.	0.027	0.13	N. D.
K	0.16	0.79	7.98	0.099	0.50	7.31
Li	0.0079	0.039	N. D.	0.0080	0.040	N. D.
Mg	0.043	0.22	1.13	0.37	1.9	BQL
Mn	0.0013	0.0066	0.798	0.0016	0.0080	0.908
Na	0.25	1.2	N. D.	0.036	0.18	BQL
Ni	0.0044	0.022	N. D.	0.0061	0.030	N. D.
P	0.016	0.078	0.432	0.036	0.18	0.393
Pb	0.056	0.28	N. D.	0.085	0.42	N. D.
S	0.15	0.73	BQL	0.17	0.85	BQL
Sb	0.10	0.52	N. D.	0.11	0.53	N. D.
Se	0.64	3.2	N. D.	1.3	6.4	N. D.
Si	0.040	0.20	BQL	1.1	5.7	N. D.
Sn	0.016	0.078	N. D.	0.052	0.26	N. D.
Sr	0.00043	0.0022	0.135	0.012	0.061	0.136
Ti	0.0014	0.0070	N. D.	0.0056	0.028	BQL
Tl	0.063	0.31	N. D.	0.029	0.14	N. D.
V	0.013	0.066	N. D.	0.013	0.067	N. D.
Zn	0.0067	0.033	BQL	0.0017	0.0083	0.0200

units = Wt. %
N. D. = not detected
BQL = below the quantifiable limit

Table 12. Comparison of results for Wood Ash sample 439 F

	Aqua Regia Digestion			'Total' digest		
	detection limit	quantifiable limit	Wt. %	detection limit	quantifiable limit	Wt. %
Ag	0.0030	0.015	N. D.	0.0053	0.026	N. D.
Al	0.026	0.13	0.163	0.32	1.6	N. D.
As	0.043	0.22	N. D.	0.034	0.17	N. D.
Ba	0.0023	0.012	0.234	0.018	0.091	0.194
Ca	0.056	0.28	26.4	0.44	2.2	22.8
Cd	0.0021	0.010	N. D.	0.00097	0.0048	N. D.
Co	0.0027	0.014	N. D.	0.010	0.052	N. D.
Cr	0.0023	0.011	N. D.	0.0025	0.013	N. D.
Cu	0.0022	0.011	BQL	0.0022	0.011	BQL
Fe	0.0037	0.018	0.0983	0.25	1.2	0.0794
Hg	0.027	0.13	N. D.	0.026	0.13	N. D.
K	0.16	0.80	6.03	0.098	0.49	5.10
Li	0.0080	0.040	N. D.	0.0079	0.040	N. D.
Mg	0.044	0.22	1.79	0.37	1.9	BQL
Mn	0.0013	0.0067	0.731	0.0016	0.0079	0.716
Na	0.25	1.2	N. D.	0.035	0.18	BQL
Ni	0.0044	0.022	N. D.	0.0060	0.030	BQL
P	0.016	0.079	0.931	0.035	0.18	0.803
Pb	0.057	0.28	N. D.	0.084	0.42	N. D.
S	0.15	0.74	BQL	0.17	0.84	N. D.
Sb	0.11	0.53	N. D.	0.11	0.53	N. D.
Se	0.65	3.2	N. D.	1.3	6.4	N. D.
Si	0.041	0.20	BQL	1.1	5.7	N. D.
Sn	0.016	0.079	N. D.	0.051	0.26	N. D.
Sr	0.00044	0.0022	0.294	0.012	0.060	0.246
Ti	0.0014	0.0071	N. D.	0.0055	0.028	BQL
Tl	0.064	0.32	N. D.	0.029	0.14	N. D.
V	0.013	0.066	N. D.	0.013	0.066	N. D.
Zn	0.0067	0.034	BQL	0.0016	0.0082	BQL

units = Wt. %
N. D. = not detected
BQL = below the quantifiable limit

Table 13. Comparison of results for Wood Ash sample 439 G

	Aqua Regia Digestion			'Total' digest		
	detection limit	quantifiable limit	Wt. %	detection limit	quantifiable limit	Wt. %
Ag	0.0024	0.012	N. D.	0.0043	0.021	N. D.
Al	0.021	0.10	BQL	0.26	1.3	BQL
As	0.035	0.17	N. D.	0.027	0.14	N. D.
Ba	0.0019	0.0094	0.136	0.015	0.073	0.121
Ca	0.046	0.23	22.0	0.36	1.8	19.7
Cd	0.0017	0.0085	N. D.	0.00078	0.0039	N. D.
Co	0.0022	0.011	N. D.	0.0085	0.042	N. D.
Cr	0.0018	0.0092	N. D.	0.0020	0.010	N. D.
Cu	0.0018	0.0089	N. D.	0.0018	0.0089	BQL
Fe	0.0030	0.015	0.0536	0.20	1.0	N. D.
Hg	0.022	0.11	N. D.	0.021	0.11	N. D.
K	0.13	0.65	8.04	0.080	0.40	6.78
Li	0.0065	0.032	N. D.	0.0064	0.032	N. D.
Mg	0.035	0.18	1.15	0.30	1.5	BQL
Mn	0.0011	0.0054	0.857	0.0013	0.0064	0.841
Na	0.20	1.0	N. D.	0.029	0.14	BQL
Ni	0.0036	0.018	N. D.	0.0049	0.024	BQL
P	0.013	0.064	0.316	0.029	0.14	0.280
Pb	0.046	0.23	N. D.	0.068	0.34	N. D.
S	0.12	0.60	BQL	0.14	0.68	BQL
Sb	0.086	0.43	N. D.	0.086	0.43	N. D.
Se	0.53	2.6	N. D.	1.0	5.2	N. D.
Si	0.033	0.16	BQL	0.92	4.6	N. D.
Sn	0.013	0.064	N. D.	0.042	0.21	N. D.
Sr	0.00035	0.0018	0.119	0.0097	0.049	0.110
Ti	0.0012	0.0058	N. D.	0.0045	0.022	N. D.
Tl	0.052	0.26	N. D.	0.023	0.12	N. D.
V	0.011	0.054	N. D.	0.011	0.053	N. D.
Zn	0.0055	0.027	0.0338	0.0013	0.0067	0.0157

units = Wt. %

N. D. = not detected

BQL = below the quantifiable limit

Table 14. Comparison of results for Wood Ash sample 439 H

	Aqua Regia Digestion			'Total' digest		
	detection limit	quantifiable limit	Wt. %	detection limit	quantifiable limit	Wt. %
Ag	0.00032	0.0016	N. D.	0.00081	0.0041	N. D.
Al	0.0028	0.014	0.0175	0.049	0.24	N. D.
As	0.0047	0.023	N. D.	0.0051	0.026	N. D.
Ba	0.00025	0.0013	0.0114	0.0028	0.014	BQL
Ca	0.0061	0.031	1.06	0.068	0.34	1.15
Cd	0.00023	0.0011	N. D.	0.00015	0.00074	N. D.
Co	0.00030	0.0015	N. D.	0.0016	0.0080	N. D.
Cr	0.00025	0.0012	N. D.	0.00038	0.0019	N. D.
Cu	0.00024	0.0012	N. D.	0.00034	0.0017	N. D.
Fe	0.00040	0.0020	0.00554	0.038	0.19	N. D.
Hg	0.0029	0.014	N. D.	0.0041	0.020	N. D.
K	0.017	0.086	0.614	0.015	0.075	0.586
Li	0.00086	0.0043	N. D.	0.0012	0.0061	N. D.
Mg	0.0047	0.024	0.326	0.057	0.28	0.321
Mn	0.00015	0.00073	0.173	0.00024	0.0012	0.175
Na	0.027	0.13	N. D.	0.0054	0.027	BQL
Ni	0.00048	0.0024	N. D.	0.00092	0.0046	N. D.
P	0.0017	0.0085	0.0463	0.0054	0.027	0.0463
Pb	0.0061	0.031	N. D.	0.013	0.065	N. D.
S	0.016	0.080	BQL	0.026	0.13	N. D.
Sb	0.011	0.057	N. D.	0.016	0.081	N. D.
Se	0.070	0.35	N. D.	0.20	0.98	N. D.
Si	0.0044	0.022	N. D.	0.17	0.87	N. D.
Sn	0.0017	0.0085	N. D.	0.0079	0.039	N. D.
Sr	0.000047	0.00024	0.00607	0.0018	0.0092	BQL
Ti	0.00015	0.00077	N. D.	0.00085	0.0043	N. D.
Tl	0.0069	0.034	N. D.	0.0044	0.022	BQL
V	0.0014	0.0072	N. D.	0.0020	0.010	N. D.
Zn	0.00073	0.0037	0.0104	0.00025	0.0013	0.00924

units = Wt. %

N. D. = not detected

BQL = below the quantifiable limit

Table 15. Comparison of results for Wood Ash sample 439 I

	Aqua Regia Digestion			'Total' digest		
	detection limit	quanti-fiable limit	Wt. %	detection limit	quanti-fiable limit	Wt. %
Ag	0.0011	0.0054	N. D.	0.0019	0.0096	N. D.
Al	0.0094	0.047	0.0627	0.12	0.58	N. D.
As	0.016	0.078	N. D.	0.012	0.061	N. D.
Ba	0.00085	0.0042	0.0233	0.0066	0.033	BQL
Ca	0.021	0.10	3.43	0.16	0.81	2.94
Cd	0.00076	0.0038	N. D.	0.00035	0.0018	N. D.
Co	0.0010	0.0050	N. D.	0.0038	0.019	N. D.
Cr	0.00083	0.0042	N. D.	0.00091	0.0046	N. D.
Cu	0.00080	0.0040	N. D.	0.00080	0.0040	N. D.
Fe	0.0013	0.0067	0.0143	0.090	0.45	N. D.
Hg	0.0097	0.048	N. D.	0.0096	0.048	N. D.
K	0.058	0.29	1.91	0.036	0.18	1.58
Li	0.0029	0.015	N. D.	0.0029	0.014	N. D.
Mg	0.016	0.080	0.836	0.13	0.67	0.753
Mn	0.00049	0.0024	0.538	0.00058	0.0029	0.474
Na	0.091	0.45	N. D.	0.013	0.065	BQL
Ni	0.0016	0.0080	N. D.	0.0022	0.011	N. D.
P	0.0057	0.029	0.173	0.013	0.064	0.124
Pb	0.021	0.10	N. D.	0.031	0.15	N. D.
S	0.054	0.27	BQL	0.061	0.31	BQL
Sb	0.039	0.19	N. D.	0.039	0.19	N. D.
Se	0.24	1.2	N. D.	0.46	2.3	N. D.
Si	0.015	0.074	N. D.	0.41	2.1	N. D.
Sn	0.0057	0.029	N. D.	0.019	0.094	N. D.
Sr	0.00016	0.00080	0.0145	0.0044	0.022	BQL
Ti	0.00052	0.0026	N. D.	0.0020	0.010	N. D.
Tl	0.023	0.12	0.0204	0.010	0.052	BQL
V	0.0048	0.024	N. D.	0.0048	0.024	N. D.
Zn	0.0025	0.012	0.0306	0.00060	0.0030	0.0227

units = Wt. %
N. D. = not detected
BQL = below the quantifiable limit

Table 16. Comparison of results for Wood Ash sample 440 A

	Aqua Regia Digestion			'Total' digest		
	detection limit	quantifiable limit	Wt. %	detection limit	quantifiable limit	Wt. %
Ag	0.00061	0.0030	N. D.	0.0011	0.0054	N. D.
Al	0.0053	0.026	0.0536	0.065	0.33	BQL
As	0.0088	0.044	N. D.	0.0069	0.034	N. D.
Ba	0.00048	0.0024	0.0453	0.0037	0.019	0.0445
Ca	0.012	0.058	2.07	0.091	0.46	2.16
Cd	0.00043	0.0021	N. D.	0.00020	0.00099	N. D.
Co	0.00056	0.0028	N. D.	0.0021	0.011	N. D.
Cr	0.00047	0.0023	N. D.	0.00051	0.0026	N. D.
Cu	0.00045	0.0023	BQL	0.00045	0.0023	BQL
Fe	0.00076	0.0038	0.0203	0.051	0.25	N. D.
Hg	0.0054	0.027	N. D.	0.0054	0.027	N. D.
K	0.033	0.16	1.22	0.020	0.10	1.18
Li	0.0016	0.0082	N. D.	0.0016	0.0081	N. D.
Mg	0.0090	0.045	0.689	0.076	0.38	0.716
Mn	0.00027	0.0014	0.512	0.00032	0.0016	0.526
Na	0.051	0.25	N. D.	0.0073	0.036	BQL
Ni	0.00090	0.0045	N. D.	0.0012	0.0062	BQL
P	0.0032	0.016	0.0780	0.0072	0.036	0.0731
Pb	0.012	0.058	N. D.	0.017	0.086	N. D.
S	0.030	0.15	BQL	0.034	0.17	BQL
Sb	0.022	0.11	N. D.	0.022	0.11	N. D.
Se	0.13	0.67	N. D.	0.26	1.3	N. D.
Si	0.0083	0.042	BQL	0.23	1.2	BQL
Sn	0.0032	0.016	N. D.	0.011	0.053	N. D.
Sr	0.000090	0.00045	0.0197	0.0025	0.012	0.0203
Ti	0.00029	0.0015	N. D.	0.0011	0.0057	BQL
Tl	0.013	0.065	N. D.	0.0058	0.029	N. D.
V	0.0027	0.014	N. D.	0.0027	0.014	N. D.
Zn	0.0014	0.0069	0.0190	0.00034	0.0017	0.0180

units = Wt. %
N. D. = not detected
BQL = below the quantifiable limit

Table 17. Comparison of results for Wood Ash sample 439 E (duplicate digests)

	Aqua Regia Digestion			'Total' digest		
	detection limit	quantifiable limit	Wt. %	detection limit	quantifiable limit	Wt. %
Ag	0.0030	0.015	N. D.	0.0053	0.026	N. D.
Al	0.026	0.13	0.161	0.32	1.6	N. D.
As	0.043	0.21	N. D.	0.033	0.17	N. D.
Ba	0.0023	0.012	0.175	0.018	0.090	0.164
Ca	0.056	0.28	27.5	0.44	2.2	27.1
Cd	0.0021	0.010	N. D.	0.00096	0.0048	N. D.
Co	0.0027	0.014	N. D.	0.010	0.052	N. D.
Cr	0.0023	0.011	N. D.	0.0025	0.012	N. D.
Cu	0.0022	0.011	BQL	0.0022	0.011	N. D.
Fe	0.0037	0.018	0.0799	0.25	1.2	N. D.
Hg	0.026	0.13	N. D.	0.026	0.13	N. D.
K	0.16	0.79	8.19	0.098	0.49	7.04
Li	0.0079	0.040	N. D.	0.0079	0.039	N. D.
Mg	0.043	0.22	1.18	0.37	1.8	BQL
Mn	0.0013	0.0067	0.827	0.0016	0.0079	0.874
Na	0.25	1.2	N. D.	0.035	0.18	BQL
Ni	0.0044	0.022	N. D.	0.0060	0.030	N. D.
P	0.016	0.078	0.438	0.035	0.18	0.410
Pb	0.056	0.28	N. D.	0.084	0.42	N. D.
S	0.15	0.74	BQL	0.17	0.83	BQL
Sb	0.11	0.53	N. D.	0.11	0.53	N. D.
Se	0.64	3.2	N. D.	1.3	6.3	N. D.
Si	0.040	0.20	BQL	1.1	5.7	N. D.
Sn	0.016	0.078	N. D.	0.051	0.26	N. D.
Sr	0.00043	0.0022	0.138	0.012	0.060	0.131
Ti	0.0014	0.0070	N. D.	0.0055	0.028	BQL
Tl	0.063	0.32	N. D.	0.028	0.14	N. D.
V	0.013	0.066	N. D.	0.013	0.066	N. D.
Zn	0.0067	0.033	BQL	0.0016	0.0082	0.0175

units = Wt. %
N. D. = not detected
BQL = below the quantifiable limit

Table 18. Comparison of results for Wood Ash sample 439 E

	DUPLICATE Aqua Regia Digests		DUPLICATE 'Total' (HF) Diges	
Ag	N. D.	N. D.	N. D.	N. D.
Al	0.141	0.161	N. D.	N. D.
As	N. D.	N. D.	N. D.	N. D.
Ba	0.172	0.175	0.166	0.164
Ca	27.4	27.5	27.5	27.1
Cd	N. D.	N. D.	N. D.	N. D.
Co	N. D.	N. D.	N. D.	N. D.
Cr	N. D.	N. D.	N. D.	N. D.
Cu	BQL	BQL	N. D.	N. D.
Fe	0.0695	0.0799	N. D.	N. D.
Hg	N. D.	N. D.	N. D.	N. D.
K	7.98	8.19	7.31	7.04
Li	N. D.	N. D.	N. D.	N. D.
Mg	1.13	1.18	BQL	BQL
Mn	0.798	0.827	0.908	0.874
Na	N. D.	N. D.	BQL	BQL
Ni	N. D.	N. D.	N. D.	N. D.
P	0.432	0.438	0.393	0.410
Pb	N. D.	N. D.	N. D.	N. D.
S	BQL	BQL	BQL	BQL
Sb	N. D.	N. D.	N. D.	N. D.
Se	N. D.	N. D.	N. D.	N. D.
Si	BQL	BQL	N. D.	N. D.
Sn	N. D.	N. D.	N. D.	N. D.
Sr	0.135	0.138	0.136	0.131
Ti	N. D.	N. D.	BQL	BQL
Tl	N. D.	N. D.	N. D.	N. D.
V	N. D.	N. D.	N. D.	N. D.
Zn	BQL	BQL	0.0200	0.0175

units = Wt. %
N. D. = not detected
BQL = below the quantifiable limit

Table 19. Residue Remaining After Low Temperature Ashing of the Wood Ash Samples

TSD #	Wt %
439 A	11.82
439 B	89.25
439 C	86.14
439 D	61.66
439 E	89.57
439 F	89.58
439 G	72.00
439 H	9.56
439 I	33.00
440 A	18.22

Table 20. Elemental Analysis of Wood Samples

	440 C	440 D	440 E	440 F
Ag	N. D.	BQL	N. D.	N. D.
Al	BQL	0.00627	0.00191	0.0138
As	N. D.	N. D.	N. D.	N. D.
Ba	0.000337	0.00106	0.00609	0.00198
Ca	0.0638	0.0571	1.14	0.301
Cd	N. D.	BQL	N. D.	BQL
Co	0.00720	0.00924	0.00309	0.00214
Cr	0.000328	0.000353	0.000159	0.000234
Cu	BQL	0.000114	0.000129	0.000185
Fe	0.0112	0.0191	0.00491	0.0170
Hg	N. D.	N. D.	N. D.	N. D.
K	0.0335	0.0389	0.0612	0.0819
Li	N. D.	N. D.	N. D.	N. D.
Mg	0.0163	0.0195	0.0214	0.0162
Mn	0.00829	0.0140	0.0169	0.0101
Na	BQL	BQL	BQL	BQL
Ni	0.00168	0.00196	0.00101	0.00130
P	0.00295	0.00316	0.0152	0.00595
Pb	0.00482	0.0193	BQL	0.00440
S	BQL	0.00927	0.0123	0.0114
Sb	N. D.	N. D.	N. D.	N. D.
Se	N. D.	N. D.	N. D.	N. D.
Si	N. D.	BQL	N. D.	N. D.
Sn	N. D.	N. D.	N. D.	N. D.
Sr	0.000249	0.000476	0.0106	0.00115
Ti	BQL	0.000202	0.000308	0.000646
Tl	BQL	BQL	BQL	N. D.
V	N. D.	N. D.	N. D.	N. D.
Zn	0.00128	0.00129	BQL	0.000872

units = Wt. %
N. D. = not detected
BQL = below the quantifiable limit

Table 21. Recovery of organometallics after a Hydrogen Peroxide Digestion

ELEMENT	SPIKE MICRO- GRAMS	FOUND MICRO- GRAMS	RECOVERY %
CADMIUM	92.5	106.5	115
MERCURY	476	0	0
SODIUM	1006	1282.2	127

Table 22. Elemental Recoveries from Hydrogen Peroxide Digest of Spiked Wood

ELEMENT	SPIKE MICRO-GRAMS	RECOVERY %
Ag	100	65
Al	1000	55
As	500	85
Ba	100	160
Ca	10000	203
Cd	100	87
Co	100	199
Cr	100	90
Cu	100	83
Fe	1000	74
Hg	500	0
K	1000	315
Li	100	77
Mg	10000	84
Mn	500	133
Na	1000	84
Ni	100	103
P	500	105
Pb	500	174
S	500	2016
Sb	100	50
Se	500	13
Si		
Sn	100	48
Sr	1000	93
Ti	100	79
Tl	500	76
V	100	77
Zn	500	87

Table 23. Reproducibility of Digested Duplicate Woodsmoke

DUPLICATE DIGESTS SAMPLE 432 D Total micrograms			Average	Standard Deviation	% Relative Standard Deviation
Ag	BQL	N. D.			
Al	N. D.	N. D.			
As	N. D.	N. D.			
Ba	10.3	N. D.			
Ca	N. D.	N. D.			
Cd	BQL	BQL			
Co	N. D.	N. D.			
Cr	N. D.	BQL			
Cu	N. D.	N. D.			
Fe	13.1	13.9	13.5	0.566	4.19
Hg	N. D.	N. D.			
K	1180	987	1080	137	12.6
Li	N. D.	N. D.			
Mg	N. D.	N. D.			
Mn	N. D.	N. D.			
Na	1060	724	890	234	26.3
Ni	N. D.	N. D.			
P	N. D.	N. D.			
Pb	N. D.	N. D.			
S	BQL	487			
Sb	N. D.	N. D.			
Se	N. D.	N. D.			
Sn	BQL	BQL			
Sr	N. D.	N. D.			
Ti	4.20	N. D.			
Tl	N. D.	N. D.			
V	N. D.	N. D.			
Zn	BQL	N. D.			

N. D. = not detected
BQL = below the quantifiable limit

Table 24. Elemental Analysis of Duplicate Wood Digests

DUPLICATE DIGESTIONS
SAMPLE 440 E

	WT. %	WT. %	AVERAGE	STANDARD DEVIATION	% RELATIVE STANDARD DEVIATION
Ag	N. D.	BQL			
Al	0.00191	BQL			
As	N. D.	N. D.			
Ba	0.00609	0.00720	0.00665	0.000787	11.8
Ca	1.14	1.31	1.23	0.121	9.85
Cd	N. D.	N. D.			
Co	0.00309	0.00847	0.00578	0.00380	65.9
Cr	0.000159	0.000333	0.000246	0.000123	49.9
Cu	0.000129	0.000197	0.000163	0.0000482	29.6
Fe	0.00491	0.00725	0.00608	0.00165	27.2
Hg	N. D.	N. D.			
K	0.0612	0.102	0.0817	0.0289	35.4
Li	N. D.	N. D.			
Mg	0.0214	0.0328	0.0271	0.00802	29.6
Mn	0.0169	0.0192	0.0181	0.00157	8.72
Na	BQL	BQL			
Ni	0.00101	0.00227	0.00164	0.000891	54.3
P	0.0152	0.0143	0.0147	0.000627	4.25
Pb	BQL	0.0202			
S	0.0123	0.0221	0.0172	0.00691	40.2
Sb	N. D.	N. D.			
Se	N. D.	N. D.			
Si	N. D.	N. D.			
Sn	N. D.	N. D.			
Sr	0.0106	0.0136	0.0121	0.00214	17.7
Ti	0.000308	0.000365	0.000336	0.0000400	11.9
Tl	BQL	BQL			
V	N. D.	N. D.			
Zn	BQL	0.000404			

Table 25. Wood Ash Major Element Ratios

TYPE	TSO #	K Wt %	Ca Wt %	Mg Wt %	K/Ca	Mg/Ca
OAK CURED	439 D	3.70	15.6	1.19	0.237	0.0763
	439 C	5.07	21.5	1.51	0.236	0.0702
	439 F	5.10	22.8	1.79	0.224	0.0785
	average	4.62	20.0	1.50	0.232	0.0750
	std dev	0.800	3.84	0.300	0.00740	0.00430
UNCURED	439 E	7.18	27.3	1.16	0.263	0.0425
	439 B	6.37	25.6	1.28	0.249	0.0500
	439 G	6.78	19.7	1.15	0.344	0.0584
	average	6.78	24.2	1.20	0.285	0.0503
	std dev	0.405	3.99	0.0700	0.0515	0.00810
ALL	average	5.70	22.1	1.35	0.259	0.0626
	std dev	1.31	4.20	0.260	0.0439	0.0147
PINE CURED	439 A	0.707	1.27	0.468	0.557	0.369
	440 A	1.18	2.16	0.689	0.546	0.319
	average	0.944	1.72	0.579	0.551	0.344
	std dev	0.334	0.629	0.156	0.00735	0.0350
UNCURED	439 I	1.58	2.94	0.836	0.537	0.284
	439 H	0.586	1.15	0.326	0.510	0.283
	average	1.08	2.05	0.581	0.523	0.284
	std dev	0.703	1.27	0.361	0.0197	0.000619
ALL	average	1.01	1.88	0.580	0.537	0.314
	std dev	0.460	0.840	0.230	0.0202	0.0400

APPENDIX E

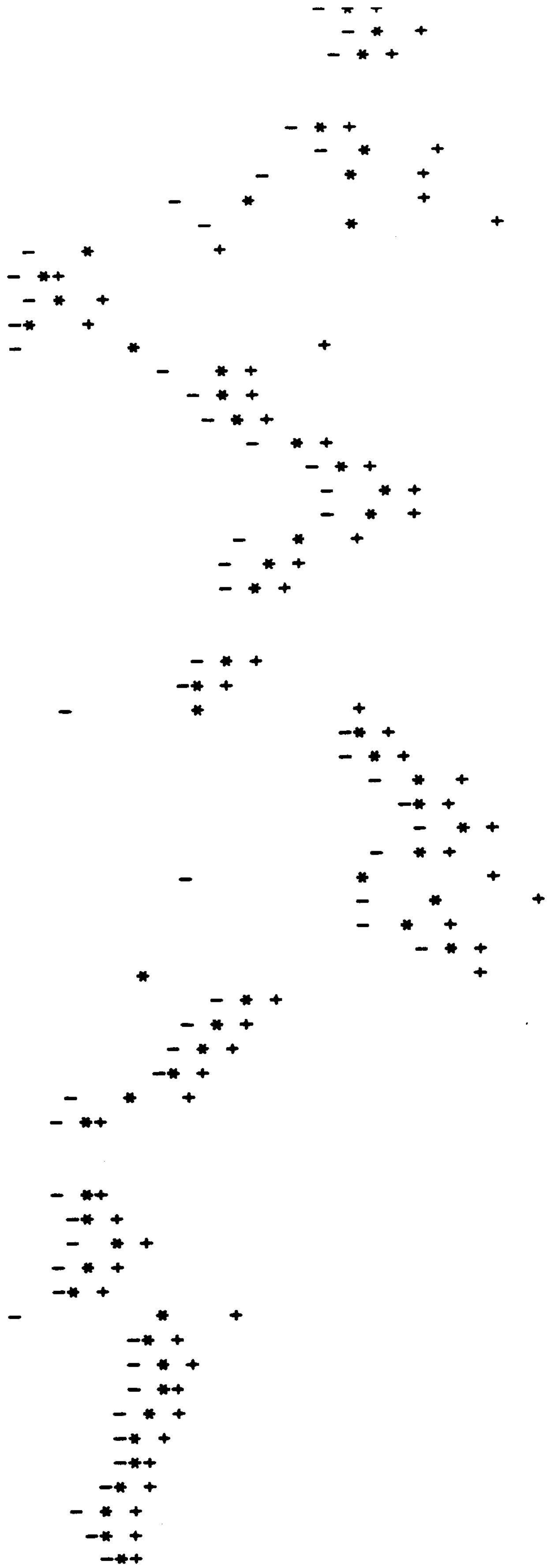
TEST NUMBER 7: DATA LOGGER OUTPUT

```
  METROSONICS  d1721
VERSION 1.5  1/85

 SERIAL NUMBER: 1112


IACP RUN 7
RTI RUN 50515
KEL SMH
P/UC/LOADH/BRH


CURRENT  DATE:      05/15/85
CURRENT  TIME:      16:48:22

TEST STARTING  DATE:      05/15/85
TEST STARTING  TIME:      10:00:10

    ELAPSED TIME:
000 DAYS    06:16:22

 SAMPLE  RATE= 2 SEC
 AVG.PERIOD=  1 MIN

 SCHD RUN:    MANUAL

 CHNL 1 INPUT RNG=
  - 5.0V TO   5.0V


   SLOPE= 23.182
CHNL 1 B=-  0.17

P1: 0.0075     V=-  0.00     %CO2
P2: 0.6675     V=  15.30     %CO2

UPPER ALARM CH1:OFF  115.74     %CO2
LOWER ALARM CH1:OFF -116.09     %CO2

 OVERALL MINIMUM FOR CHANNEL 1= -  0.02    %CO2
 @ 10:00:10 05/15/85

 OVERALL AVERAGE FOR CHANNEL 1=    4.43    %CO2

 OVERALL MAXIMUM FOR CHANNEL 1=   10.49    %CO2
 @ 12:00:58 05/15/85



TIME HISTORY FOR CHANNEL 1
AVERAGING PERIOD=  1 MIN
 COMBINED  BY: 005
UNITS= %CO2

     MIN.          AVG.          MAX.
---------------------------------------- ----------------------------------------
```

```
-  0.02         1.27          3.16     -   *      +
   1.91         3.15          4.40           -    *   +
   1.88         2.86          4.14           -   *   +
   3.73         4.31          4.86                  - *+
   1.36         2.49          3.91         -   *    +
   1.30         2.28          2.86         -   * +
   0.46         0.72          1.21      -* +
   0.46         0.75          1.33      -* +
   0.81         1.24          1.85       - * +
   0.78         1.15          1.68       - *+
   0.98         1.41          1.79        - *+
   0.84         1.24          1.62        -*+
   0.81         1.13          1.53       - *+
   0.95         1.41          1.76        - *+
   1.21         3.33          4.52         -      *   +
   3.88         4.17          4.54                  -*+
   4.11         4.40          4.78                   -*+
   4.11         4.28          4.49                   *+
   4.31         4.69          5.18                    -* +
   4.86         5.15          5.62                     -* +

DATE:     05/15/85  TIME:      11:40:10  MM5 1
   5.10         5.70          6.43                      - *  +
   5.96         6.72          7.82                         -  *   +
   7.73         8.31          9.04                               - *  +
   8.14         8.98          9.99 —                               -  *  +
   9.12         9.99         10.49 — CUT DAMPERS                      -  * +
   8.31         8.54          9.21                                 -* +
   7.65         8.08          8.46                               - *+
   6.75         7.12          7.91                            -*  +
   6.78         7.12          7.41 — 12:27                    -*+
   1.59         5.73          7.41 ADD WOOD -             *     +
   3.36         4.46          5.01                -   * +
   3.82         4.02          4.25                  -*
   3.94         4.52          4.89                  - * +
   4.57         5.18          5.67                    -  *+
   5.50         5.73          5.99                        *+
   5.85         6.46          6.92                         - * +
   6.60         6.95          7.27 — 13:00                 - *+
   5.96         6.40          7.01                         - * +
   5.91         6.17          6.57                         -*+
   5.99         6.25          6.54                         -*+

DATE:     05/15/85  TIME:      13:20:10
   6.08         6.23          6.52                          *+
   6.14         6.37          6.78                          -*+
   1.99         5.50          6.88            -           *   +
   5.36         6.54          7.09                       -   * +
   6.02         6.37          6.98                         - * +
   5.65         6.17          6.52                        - *+
   5.38         5.59          5.82                       -*+
   5.67         6.83          7.73                        -   *   +
   7.47         8.43          9.33                              -   *  +
   3.79         7.62          9.07 — MM5 2 -             *   +
   4.72         5.10          6.23                     -*   +
   4.86         5.07          5.36                     -*+
   4.89         5.82          6.49                      -  * +
-  0.00         2.37          7.04     -       *               +
   3.30         3.79          4.31                - * +
   3.07         3.33          3.56               -*+
   3.24         3.50          3.79                -*+
   3.33         3.47          3.65                -*
   3.24         3.36          3.56                *+
   3.33         3.56          3.73                -*+
```

```
   3.50          3.62          3.76                   *+
   3.44          3.62          3.82                   *+
   3.39          3.65          3.91                  -*+
   3.10          3.27          3.50                 -*+
   1.01          1.99          3.36          -   *   +
   1.91          2.05          2.31             -*+
   1.88          2.20          2.57             -* +
   2.17          2.37          2.55        ③     -*
   2.28          2.57          3.10 ─┐           -*+
   2.43          2.66          3.01  │ m5        -*+
   2.43          2.55          2.75  │           *+
   2.37          2.52          2.78 ─┘           *+
   2.63          2.75          2.95               *+
   2.60          2.75          2.98               *+
   2.55          2.69          2.83              -*
 PERIOD STOPPED    ELAPSED TIME:000:00:01:22
 CHNL 2 INPUT RNG=
  - 5.0V TO   5.0V


   SLOPE= .89457
CHNL 2 B=-0.0178

P1: 0.0200      V= 0.0000      %CO
P2: 1.1938      V= 1.0500      %CO

UPPER ALARM CH2:OFF  4.4550      %CO
LOWER ALARM CH2:OFF -4.4907      %CO

 OVERALL MINIMUM FOR CHANNEL 2= -0.0078    %CO
 @ 10:01:36 05/15/85

 OVERALL AVERAGE FOR CHANNEL 2=  0.5803    %CO

 OVERALL MAXIMUM FOR CHANNEL 2=  1.4481    %CO
 @ 14:10:22 05/15/85


TIME HISTORY FOR CHANNEL 2
AVERAGING PERIOD=  1 MIN
 COMBINED  BY: 005
UNITS= %CO

     MIN.          AVG.         MAX.
------------------------------- --------------------------------

 DATE:      05/15/85  TIME:      10:00:10
-0.0078        0.0178        0.1912      *    +
 0.0022        0.0234        0.0905      * +
 0.0044        0.0279        0.0626      *+
 0.0067        0.0223        0.0402      *+
 0.0134        0.0637        0.1576      -*   +
 0.0178        0.0436        0.0939      -*+
 0.0525        0.0950        0.1833       -*   +
 0.0458        0.1118        0.2493       - *   +
 0.1040        0.2068        0.3399        -   *    +
 0.0972        0.1912        0.3198        -   *   +
 0.1230        0.2191        0.3455         - *    +
 0.1476        0.2661        0.3701          -   * +
 0.1174        0.1934        0.3265         - *   +
 0.1464        0.1934        0.2471          -*+
 0.2001        0.6060        0.9068           -            *        +
 0.6888        0.8028        0.9024                           -   * +
 0.8174        0.9035        0.9829                              - *   +
```

```
0.9124        0.9963        1.0914
0.9974        1.0914        1.2054
0.9650        1.0455        1.1294

DATE:      05/15/85  TIME:     11:40:10
0.8341        0.9180        1.0008
0.9214        1.0511        1.2312
0.7682        1.0098        1.1943
0.5401        0.7425        1.1741
0.6049        0.9806        1.3844
0.1509        0.3175        0.6485
0.1431        0.1878        0.2348
0.1543        0.2516        0.3667
0.1174        0.1733        0.3310
0.1308        0.4182        0.9281
0.4953        0.6563        0.7458
0.5747        0.6530        0.7257
0.6217        0.7100        0.7883
0.7257        0.8464        0.9415
0.8744        0.9493        1.0366
0.9337        1.0757        1.1630
0.9102        1.0489        1.1663
0.7022        0.8375        0.9806
0.6754        0.7536        0.8442
0.6541        0.7279        0.8230

DATE:      05/15/85  TIME:     13:20:10
0.5658        0.6552        0.7212
0.5356        0.5915        0.6452
0.2292        0.5825        0.9851
0.9437        1.0109        1.0768
0.9717        1.0366        1.1126
1.0366        1.1540        1.2546
1.1048        1.1697        1.2457
1.1630        1.2670        1.3363
1.0400        1.1440        1.2222
0.5389        1.0053        1.3553
1.0165        1.1786        1.4481
1.0176        1.1026        1.2267
1.1663        1.2390        1.3094
0.0067        0.4316        1.3106
0.6183        0.7067        0.7861
0.5591        0.6295        0.7078
0.5032        0.5725        0.6474
0.4562        0.5199        0.5792
0.2527        0.3891        0.5289
0.2180        0.2627        0.3164

DATE:      05/15/85  TIME:     15:00:10
0.2169        0.2605        0.2963
0.2303        0.2929        0.3544
0.2571        0.3388        0.4282
0.2091        0.2806        0.3477
0.1867        0.2560        0.3254
0.0693        0.4562        0.6552
0.3723        0.4305        0.5177
0.3779        0.4562        0.5244
0.4092        0.4674        0.5199
0.3645        0.4472        0.5121
0.3343        0.3902        0.4484
0.3388        0.3869        0.4361
0.3153        0.3712        0.4171
0.2549        0.3220        0.3802
0.2762        0.3276        0.3768
0.3052        0.3455        0.3835
```



APPENDIX F

QUALITY ASSURANCE AUDIT REPORT ON WOODSTOVE TESTING

RESEARCH TRIANGLE INSTITUTE

Center for Environmental Quality Assurance

May 21, 1985

MEMORANDUM

TO: Wayne Westbrook
Contract Manager
RTI Project 2500

FROM: Michael J. Messner

SUBJECT: Systems Audit of EPA Contract 68-02-3992-07, RTI project no. 3065-07 Integrated Air Cancer Project: Source Measurement

The purpose of this memorandum is to report the results of a systems audit of this task. The audit was performed on 5/15/85 at RTI's Bacon Street Laboratory. In addition to myself, Keith Leese and Scott Harkins were present.

The purpose of the project is to investigate the effects of different variables on toxic emissions from woodstoves. The original Plackett-Burnham test design was dropped in favor of a semi-factorial design at the request of EPA. Details of the new test design were not reviewed in the course of the audit. The four variables controlled were wood specie, moisture content, burn rate, and wood load. The run observed on the day of the audit consisted of burning uncured pine at high loading and high burn rates.

Scott Harkins performed all instrument calibration and recorded run information (leak check, filter weight, ambient conditions, etc.) at the start of and during the run. Keith Leese loaded the stove and maintained the MM5 system during the run. Communications between Leese and Harkins were excellent and the balance of responsibilities contributed to smooth performance throughout the run. Mr. Harkins kept the log book current with log weights and MM5 filter changes while monitoring the instruments. The only minor "glitch" observed was failure to perform a leak test before removing a fouled filter from the MM5 train.

Analytical activities were not observed; however, Mr. Leese explained the extraction and sample preparation procedures. Sample storage procedures were discussed and shown.

The Tedlar bag sample was taken off the FID exhaust over a short period. This is a change vs. the four-hour sampling described in the plan. Since sample times are carefully recorded, the gas captured is directly traceable to a portion of the FID output, and therefore, the quality of the bag sample data is not compromized.

Analysis of samples by IEA were discussed, and it was recommended that blind split samples be used as additional indicators of IEA's analytical precision.

The final run of this project will be a duplicate of an earlier run. The results from these runs will indicate the overall experimental method precision. It is recommended that while performing this final burn the specific conditions of the earlier test be ignored. For example, if a high loading is one parameter, then high loading should be sought rather than to seek to match the specific weight of wood loaded in the earlier run.

In conclusion, the test burn went quite smoothly considering the number of activities performed. Sampling and monitoring were performed according to plan. The laboratory notebook provided an excellent record of events and information on the day's burn and previous activities.

No further audit of this project is planned.

MM:sjd

cc: Keith Leese
Scott Harkins
Michael Messner
Wayne Westbrook

File: 3065-07

APPENDIX G

ANOVA TABLES OF VARIABLES

ANALYSIS OF VARIANCE (ANOVA) FOR CO2 (g/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	110.943	1	1	1	1	1	1	1
2	69.866	1	1	-1	-1	1	-1	-1
9	75.442	1	-1	1	-1	-1	1	-1
4	109.599	1	-1	-1	1	-1	-1	1
5	71.334	-1	1	1	-1	-1	-1	1
6	105.028	-1	1	-1	1	-1	1	-1
7	83.615	-1	-1	1	1	1	-1	-1
8	75.336	-1	-1	-1	-1	1	1	1
CONTRAST		30.536	13.180	-18.495	117.207	-21.6	32.3	33.3
SUM OF SQUARES		116.557	21.713	42.760	1717.198	58.6	130.7	138.3
SSTOTAL		2225.764						
MAIN EFFECT		7.634	3.295	-4.624	29.302			

SOURCE	SS	DF	MS	F
FUEL	116.557	1	116.56	1.07
MOISTURE	21.713	1	21.71	0.20
LOAD	42.760	1	42.76	0.39
RATE	1717.198	1	1717.20	15.73
ERROR	327.535	3	109.18	
TOTAL	2225.764	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR CO (g/M^3 STP WET)

RUN NO	VALUE	FUEL	MOIS	LOAD	RATE	AB	AC	AD
		A	B	C	D	CD	BD	BC
1	8.515	1	1	1	1	1	1	1
2	9.833	1	1	-1	-1	1	-1	-1
9	9.891	1	-1	1	-1	-1	1	-1
4	8.514	1	-1	-1	1	-1	-1	1
5	10.485	-1	1	1	-1	-1	-1	1
6	2.122	-1	1	-1	1	-1	1	-1
7	6.701	-1	-1	1	1	1	-1	-1
8	12.038	-1	-1	-1	-1	1	1	1
CONTRAST		5.406	-6.190	3.086	-16.395	6.1	-3.0	11.0
SUM OF SQUARES		3.653	4.789	1.190	33.598	4.6	1.1	15.1
SSTOTAL		64.082						
MAIN EFFECT		1.351	-1.547	0.771	-4.099			

SOURCE	SS	DF	MS	F
FUEL	3.653	1	3.65	0.53
MOISTURE	4.789	1	4.79	0.69
LOAD	1.190	1	1.19	0.17
RATE	33.598	1	33.60	4.83
ERROR	20.851	3	6.95	
TOTAL	64.082	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR O2 (g/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	172.008	1	1	1	1	1	1	1
2	210.704	1	1	-1	-1	1	-1	-1
9	185.404	1	-1	1	-1	-1	1	-1
4	172.268	1	-1	-1	1	-1	-1	1
5	201.292	-1	1	1	-1	-1	-1	1
6	193.944	-1	1	-1	1	-1	1	-1
7	185.765	-1	-1	1	1	1	-1	-1
8	215.608	-1	-1	-1	-1	1	1	1
CONTRAST		-56.225	18.903	-48.056	-89.023	31.2	-3.1	-14.6
SUM OF SQUARES		395.152	44.665	288.678	990.639	121.5	1.2	26.8
SSTOTAL		1868.611						
MAIN EFFECT		-14.056	4.726	-12.014	-22.256			

SOURCE	SS	DF	MS	F
FUEL	395.152	1	395.15	7.93
MOISTURE	44.665	1	44.66	0.90
LOAD	288.678	1	288.68	5.79
RATE	990.639	1	990.64	19.88
ERROR	149.479	3	49.83	
TOTAL	1868.611	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR H20 (g/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	80.926	1	1	1	1	1	1	1
2	72.083	1	1	-1	-1	1	-1	-1
9	131.145	1	-1	1	-1	-1	1	-1
4	89.016	1	-1	-1	1	-1	-1	1
5	53.532	-1	1	1	-1	-1	-1	1
6	66.351	-1	1	-1	1	-1	1	-1
7	114.939	-1	-1	1	1	1	-1	-1
8	92.643	-1	-1	-1	-1	1	1	1

CONTRAST		45.706	-154.851	60.449	1.828	20.5	41.5	-68.4
SUM OF SQUARES		261.131	2997.352	456.756	0.418	52.8	215.2	584.8
SSTOTAL		4568.498						
MAIN EFFECT		11.427	-38.713	15.112	0.457			

SOURCE	SS	DF	MS	F
FUEL	261.131	1	261.13	0.92
MOISTURE	2997.352	1	2997.35	10.54
LOAD	456.756	1	456.76	1.61
RATE	0.418	1	0.42	.00
ERROR	852.840	3	284.28	
TOTAL	4568.498	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE (g/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.321	1	1	1	1	1	1	1
2	0.498	1	1	-1	-1	1	-1	-1
9	0.626	1	-1	1	-1	-1	1	-1
4	0.165	1	-1	-1	1	-1	-1	1
5	0.375	-1	1	1	-1	-1	-1	1
6	0.115	-1	1	-1	1	-1	1	-1
7	0.242	-1	-1	1	1	1	-1	-1
8	0.416	-1	-1	-1	-1	1	1	1

CONTRAST	0.461	-0.140	0.371	-1.073	0.2	0.2	-0.2
SUM OF SQUARES	0.027	0.002	0.017	0.144	.0	.0	.0
SSTOTAL	0.205						
MAIN EFFECT	0.115	-0.035	0.093	-0.268			

SOURCE	SS	DF	MS	F
FUEL	0.027	1	0.03	5.33
MOISTURE	0.002	1	.00	0.49
LOAD	0.017	1	0.02	3.45
RATE	0.144	1	0.14	28.85
ERROR	0.015	3	.00	
TOTAL	0.205	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

-6

ANALYSIS OF VARIANCE (ANOVA) FOR GRAV (g/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.521	1	1	1	1	1	1	1
2	2.080	1	1	-1	-1	1	-1	-1
9	2.237	1	-1	1	-1	-1	1	-1
4	0.484	1	-1	-1	1	-1	-1	1
5	2.834	-1	1	1	-1	-1	-1	1
6	0.060	-1	1	-1	1	-1	1	-1
7	1.033	-1	-1	1	1	1	-1	-1
8	2.790	-1	-1	-1	-1	1	1	1

CONTRAST	-1.395	-1.050	1.211	-7.845	0.8	-0.8	1.2
SUM OF SQUARES	0.243	0.138	0.183	7.692	0.1	0.1	0.2
SSTOTAL	8.609						
MAIN EFFECT	-0.349	-0.263	0.303	-1.961			

SOURCE	SS	DF	MS	F
FUEL	0.243	1	0.24	2.07
MOISTURE	0.138	1	0.14	1.17
LOAD	0.183	1	0.18	1.56
RATE	7.692	1	7.69	65.50
ERROR	0.352	3	0.12	
TOTAL	8.609	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR TCO (g/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.124	1	1	1	1	1	1	1
2	0.537	1	1	-1	-1	1	-1	-1
9	0.617	1	-1	1	-1	-1	1	-1
4	0.164	1	-1	-1	1	-1	-1	1
5	0.688	-1	1	1	-1	-1	-1	1
6	0.031	-1	1	-1	1	-1	1	-1
7	0.394	-1	-1	1	1	1	-1	-1
8	0.934	-1	-1	-1	-1	1	1	1
CONTRAST		-0.604	-0.730	0.157	-2.063	0.5	-0.1	0.3
SUM OF SQUARES		0.046	0.067	0.003	0.532	.0	.0	.0
SSTOTAL		0.692						
MAIN EFFECT		-0.151	-0.182	0.039	-0.516			

SOURCE	SS	DF	MS	F
FUEL	0.046	1	0.05	3.07
MOISTURE	0.067	1	0.07	4.49
LOAD	0.003	1	.00	0.21
RATE	0.532	1	0.53	35.88
ERROR	0.044	3	0.01	
TOTAL	0.692	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR TOTAL HC (g/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.645	1	1	1	1	1	1	1
2	2.617	1	1	-1	-1	1	-1	-1
9	2.854	1	-1	1	-1	-1	1	-1
4	0.648	1	-1	-1	1	-1	-1	1
5	3.521	-1	1	1	-1	-1	-1	1
6	0.090	-1	1	-1	1	-1	1	-1
7	1.427	-1	-1	1	1	1	-1	-1
8	3.724	-1	-1	-1	-1	1	1	1
CONTRAST		-1.999	-1.780	1.368	-9.907	1.3	-0.9	1.6
SUM OF SQUARES		0.500	0.396	0.234	12.270	0.2	0.1	0.3
SSTOTAL		14.012						
MAIN EFFECT		-0.500	-0.445	0.342	-2.477			

SOURCE	SS	DF	MS	F
FUEL	0.500	1	0.50	2.45
MOISTURE	0.396	1	0.40	1.94
LOAD	0.234	1	0.23	1.14
RATE	12.270	1	12.27	60.07
ERROR	0.613	3	0.20	
TOTAL	14.012	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR C1-C7 (g/m^3 STP)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1*	2.373	1	1	1	1	1	1	1
2	5.060	1	1	-1	-1	1	-1	-1
9	4.314	1	-1	1	-1	-1	1	-1
4	1.004	1	-1	-1	1	-1	-1	1
5	2.618	-1	1	1	-1	-1	-1	1
6	0.201	-1	1	-1	1	-1	1	-1
7	2.328	-1	-1	1	1	1	-1	-1
8	4.504	-1	-1	-1	-1	1	1	1

* - MISSING DATA

CONTRAST	3.100	-1.899	0.864	-10.591	6.1	0.4	-1.4
SUM OF SQUARES	1.201	0.451	0.093	14.021	4.7	.0	0.2
SSTOTAL	20.723						
MAIN EFFECT	0.775	-0.475	0.216	-2.648			

SOURCE	SS	DF	MS	F
FUEL	1.201	1	1.20	0.48
MOISTURE	0.451	1	0.45	0.18
LOAD	0.093	1	0.09	0.04
RATE	14.021	1	14.02	5.66
ERROR	4.957	2	2.48	
TOTAL	20.723	[illegible]		

F(0.01,1,2)=98.50
F(0.05,1,2)=18.50
F(0.10,1,2)= 8.53

ANALYSIS OF VARIANCE (ANOVA) FOR CO2 (g/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	10109.266	1	1	1	1	1	1	1
2	1640.299	1	1	-1	-1	1	-1	-1
9	2070.199	1	-1	1	-1	-1	1	-1
4	5828.872	1	-1	-1	1	-1	-1	1
5	3429.788	-1	1	1	-1	-1	-1	1
6	8393.566	-1	1	-1	1	-1	1	-1
7	5678.121	-1	-1	1	1	1	-1	-1
8	1918.688	-1	-1	-1	-1	1	1	1
CONTRAST		228.473	8077.039	3505.948	20950.851	-376.1	5914.6	3504.4
SUM OF SQUARES		6524.988	8154819.475	1536459.022	54867268.648	17676.8	4372869.2	1535129.0
SSTOTAL		70490747.185						
MAIN EFFECT		57.118	2019.260	876.487	5237.713			

SOURCE	SS	DF	MS	F
FUEL	6524.988	1	6524.99	.00
MOISTURE	8154819.475	1	8154819.48	4.13
LOAD	1536459.022	1	1536459.02	0.78
RATE	54867268.648	1	54867268.65	27.78
ERROR	5925675.052	3	1975225.02	
TOTAL	70490747.185	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR CO (g/hr)

RUN	VALUE	FUEL	MOIS	LOAD	RATE	AB	AC	AD
		A	B	C	D	CD	BD	BC
1	775.874	1	1	1	1	1	1	1
2	230.468	1	1	-1	-1	1	-1	-1
9	271.422	1	-1	1	-1	-1	1	-1
4	452.814	1	-1	-1	1	-1	-1	1
5	504.146	-1	1	1	-1	-1	-1	1
6	169.591	-1	1	-1	1	-1	1	-1
7	455.078	-1	-1	1	1	1	-1	-1
8	306.588	-1	-1	-1	-1	1	1	1

CONTRAST	295.175	194.175	847.060	540.733	370.0	-119.0	912.9
SUM OF SQUARES	10891.032	4712.982	89688.738	36549.089	17115.7	1771.1	104164.7
SSTOTAL	264893.274						
MAIN EFFECT	73.794	48.544	211.765	135.183			

SOURCE	SS	DF	MS	F
FUEL	10891.032	1	10891.03	0.27
MOISTURE	4712.982	1	4712.98	0.11
LOAD	89688.738	1	89688.74	2.19
RATE	36549.089	1	36549.09	0.89
ERROR	123051.433	3	41017.14	
TOTAL	264893.274	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR O2 (g/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	15673.614	1	1	1	1	1	1	1
2	5094.958	1	1	-1	-1	1	-1	-1
9	5087.673	1	-1	1	-1	-1	1	-1
4	9161.855	1	-1	-1	1	-1	-1	1
5	9678.232	-1	1	1	-1	-1	-1	1
6	15499.453	-1	1	-1	1	-1	1	-1
7	12614.942	-1	-1	1	1	1	-1	-1
8	5491.219	-1	-1	-1	-1	1	1	1

CONTRAST	-8265.746	13590.570	7806.977	27597.783	-552.5	5202.0	1707.9
SUM OF SQUARES	8540319.647	23087948.611	7618610.406	95204701.580	38154.3	3382564.9	364612.9
SSTOTAL	138236912.327						
MAIN EFFECT	-2066.437	3397.642	1951.744	6899.446			

SOURCE	SS	DF	MS	F
FUEL	8540319.647	1	8540319.65	6.77
MOISTURE	23087948.611	1	23087948.61	18.30
LOAD	7618610.406	1	7618610.41	6.04
RATE	95204701.580	1	95204701.58	75.45
ERROR	3785332.084	3	1261777.36	
TOTAL	138236912.327	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR H20 (g/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	7374.095	1	1	1	1	1	1	1
2	1599.205	1	1	-1	-1	1	-1	-1
9	3598.753	1	-1	1	-1	-1	1	-1
4	4734.193	1	-1	-1	1	-1	-1	1
5	2573.840	-1	1	1	-1	-1	-1	1
6	5302.545	-1	1	-1	1	-1	1	-1
7	7805.273	-1	-1	1	1	1	-1	-1
8	2359.477	-1	-1	-1	-1	1	1	1

CONTRAST	-734.889	-1648.010	7356.542	15084.830	2928.7	1922.4	-1264.2
SUM OF SQUARES	67507.647	339492.006	6764838.675	28444012.135	1072174.6	461932.8	199765.9
SSTOTAL	37349723.865						
MAIN EFFECT	-183.722	-412.002	1839.135	3771.208			

SOURCE	SS	DF	MS	F
FUEL	67507.647	1	67507.65	0.12
MOISTURE	339492.006	1	339492.01	0.59
LOAD	6764838.675	1	6764838.68	11.70
RATE	28444012.135	1	28444012.14	49.21
ERROR	1733873.401	3	577957.80	
TOTAL	37349723.865	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE (g/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	29.270	1	1	1	1	1	1	1
2	12.134	1	1	-1	-1	1	-1	-1
9	17.183	1	-1	1	-1	-1	1	-1
4	8.757	1	-1	-1	1	-1	-1	1
5	18.041	-1	1	1	-1	-1	-1	1
6	9.189	-1	1	-1	1	-1	1	-1
7	16.444	-1	-1	1	1	1	-1	-1
8	10.604	-1	-1	-1	-1	1	1	1
CONTRAST		13.066	15.645	40.254	5.697	15.3	10.9	11.7
SUM OF SQUARES		21.340	30.597	202.550	4.056	29.2	14.8	17.2
SSTOTAL		319.685						
MAIN EFFECT		3.266	3.911	10.064	1.424			

SOURCE	SS	DF	MS	F
FUEL	21.340	1	21.34	1.05
MOISTURE	30.597	1	30.60	1.50
LOAD	202.550	1	202.55	9.94
RATE	4.056	1	4.06	0.20
ERROR	61.142	3	20.38	
TOTAL	319.685	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR GRAV (g/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	47.434	1	1	1	1	1	1	1
2	48.122	1	1	-1	-1	1	-1	-1
9	61.387	1	-1	1	-1	-1	1	-1
4	25.722	1	-1	-1	1	-1	-1	1
5	136.252	-1	1	1	-1	-1	-1	1
6	4.755	-1	1	-1	1	-1	1	-1
7	70.153	-1	-1	1	1	1	-1	-1
8	71.064	-1	-1	-1	-1	1	1	1
CONTRAST		-99.560	8.236	165.564	-168.762	8.7	-95.6	96.1
SUM OF SQUARES		1239.027	8.479	3426.412	3560.056	9.4	1142.6	1153.3
SSTOTAL		10539.257						
MAIN EFFECT		-24.890	2.059	41.391	-42.190			

SOURCE	SS	DF	MS	F
FUEL	1239.027	1	1239.03	1.61
MOISTURE	8.479	1	8.48	0.01
LOAD	3426.412	1	3426.41	4.46
RATE	3560.056	1	3560.06	4.63
ERROR	2305.283	3	768.43	
TOTAL	10539.257	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR TCO (g/hr)

RUN	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	11.327	1	1	1	1	1	1	1
2	12.042	1	1	-1	-1	1	-1	-1
9	16.931	1	-1	1	-1	-1	1	-1
4	8.729	1	-1	-1	1	-1	-1	1
5	33.059	-1	1	1	-1	-1	-1	1
6	2.452	-1	1	-1	1	-1	1	-1
7	26.740	-1	-1	1	1	1	-1	-1
8	23.792	-1	-1	-1	-1	1	1	1

CONTRAST	-37.015	-17.313	41.044	-36.576	12.7	-26.1	18.7
SUM OF SQUARES	171.265	37.466	210.577	167.229	20.3	84.9	43.9
SSTOTAL	735.644						
MAIN EFFECT	-9.254	-4.328	10.261	-9.144			

SOURCE	SS	DF	MS	F
FUEL	171.265	1	171.26	3.45
MOISTURE	37.466	1	37.47	0.75
LOAD	210.577	1	210.58	4.24
RATE	167.229	1	167.23	3.36
ERROR	149.107	3	49.70	
TOTAL	735.644	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR TOTAL HC (g/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	58.761	1	1	1	1	1	1	1
2	60.163	1	1	-1	-1	1	-1	-1
9	78.319	1	-1	1	-1	-1	1	-1
4	34.450	1	-1	-1	1	-1	-1	1
5	169.311	-1	1	1	-1	-1	-1	1
6	7.207	-1	1	-1	1	-1	1	-1
7	96.894	-1	-1	1	1	1	-1	-1
8	94.857	-1	-1	-1	-1	1	1	1
CONTRAST		-136.575	-9.077	206.608	-205.338	21.4	-121.7	114.8
SUM OF SQUARES		2331.599	10.298	5335.840	5270.456	57.2	1850.6	1647.3
SSTOTAL		16503.273						
MAIN EFFECT		-34.144	-2.269	51.652	-51.334			

SOURCE	SS	DF	MS	F
FUEL	2331.599	1	2331.60	1.97
MOISTURE	10.298	1	10.30	0.01
LOAD	5335.840	1	5335.84	4.50
RATE	5270.456	1	5270.46	4.45
ERROR	3555.079	3	1185.03	
TOTAL	16503.273	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

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             ANALYSIS OF VARIANCE (ANOVA) FOR C1-C7 (g/hr)


 RUN NO       VALUE        FUEL        MOIS         LOAD        RATE     AB     AC     AD
                              A           B            C           D     CD     BD     BC
   1*       216.188           1           1            1           1      1      1      1
   2        119.555           1           1           -1          -1      1     -1     -1
   9        118.381           1          -1            1          -1     -1      1     -1
   4         53.422           1          -1           -1           1     -1     -1      1
   5        125.894          -1           1            1          -1     -1     -1      1
   6         16.024          -1           1           -1           1     -1      1     -1
   7        158.082          -1          -1            1           1      1     -1     -1
   8        114.712          -1          -1           -1          -1      1      1      1
    * - MISSING DATA

CONTRAST                 92.834      33.064      314.832     -34.827  294.8    8.4   98.2
SUM OF SQUARES         1077.268     136.655    12389.925     151.614 10864.5   8.7 1204.8
SSTOTAL               25833.474
MAIN EFFECT              23.208       8.266       78.708      -8.707


SOURCE           SS          DF          MS            F

FUEL        1077.268          1     1077.27         0.18
MOISTURE     136.655          1      136.65         0.02
LOAD       12389.925          1    12389.93         2.05
RATE         151.614          1      151.61         0.03

ERROR      12078.011          2     6039.01

TOTAL      25833.474          6


        F(0.01,1,2)=98.50
        F(0.05,1,2)=18.50
        F(0.10,1,2)= 8.53
```

ANALYSIS OF VARIANCE (ANOVA) FOR CO2 (g/kg WET WOOD)

RUN NO	VALUE	FUEL	MOIS	LOAD	RATE	AB	AC	AD
		A	B	C	D	CD	BD	BC
1	1404.065	1	1	1	1	1	1	1
2	1316.239	1	1	-1	-1	1	-1	-1
9	930.938	1	-1	1	-1	-1	1	-1
4	852.958	1	-1	-1	1	-1	-1	1
5	1831.007	-1	1	1	-1	-1	-1	1
6	1581.965	-1	1	-1	1	-1	1	-1
7	821.009	-1	-1	1	1	1	-1	-1
8	885.831	-1	-1	-1	-1	1	1	1

CONTRAST	-615.611	2642.539	350.025	-304.019	-769.7	-18.4	323.7
SUM OF SQUARES	47372.089	872876.395	15314.683	11553.421	74059.5	42.4	13098.5
SSTOTAL	1034316.988						
MAIN EFFECT	-153.903	660.635	87.506	-76.005			

SOURCE	SS	DF	MS	F
FUEL	47372.089	1	47372.09	1.63
MOISTURE	872876.395	1	872876.39	30.03
LOAD	15314.683	1	15314.68	0.53
RATE	11553.421	1	11553.42	0.40
ERROR	87200.401	3	29066.80	
TOTAL	1034316.988	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR CO (g/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	107.760	1	1	1	1	1	1	1
2	184.942	1	1	-1	-1	1	-1	-1
9	122.055	1	-1	1	-1	-1	1	-1
4	66.262	1	-1	-1	1	-1	-1	1
5	269.140	-1	1	1	-1	-1	-1	1
6	31.963	-1	1	-1	1	-1	1	-1
7	65.801	-1	-1	1	1	1	-1	-1
8	141.547	-1	-1	-1	-1	1	1	1

	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
CONTRAST	-27.433	198.141	140.041	-445.898	10.6	-182.8	179.9
SUM OF SQUARES	94.070	4907.503	2451.451	24853.151	14.1	4177.8	4047.7
SSTOTAL	40545.857						
MAIN EFFECT	-6.858	49.535	35.010	-111.475			

SOURCE	SS	DF	MS	F
FUEL	94.070	1	94.07	0.03
MOISTURE	4907.503	1	4907.50	1.79
LOAD	2451.451	1	2451.45	0.89
RATE	24853.151	1	24853.15	9.05
ERROR	8239.681	3	2746.56	
TOTAL	40545.857	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR O2 (g/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	2176.891	1	1	1	1	1	1	1
2	4086.120	1	1	-1	-1	1	-1	-1
9	2287.853	1	-1	1	-1	-1	1	-1
4	1340.685	1	-1	-1	1	-1	-1	1
5	5166.765	-1	1	1	-1	-1	-1	1
6	2921.237	-1	1	-1	1	-1	1	-1
7	1824.015	-1	-1	1	1	1	-1	-1
8	2535.218	-1	-1	-1	-1	1	1	1
CONTRAST		-2555.685	6363.242	572.264	-5813.128	-1094.3	-2496.4	100.3
SUM OF SQUARES		816440.812	5061355.896	40935.762	4224057.689	149685.3	778992.9	1258.4
SSTOTAL		11072726.698						
MAIN EFFECT		-638.921	1590.810	143.066	-1453.282			

SOURCE	SS	DF	MS	F
FUEL	816440.812	1	816440.81	2.63
MOISTURE	5061355.896	1	5061355.90	16.33
LOAD	40935.762	1	40935.76	0.13
RATE	4224057.689	1	4224057.69	13.63
ERROR	929936.539	3	309978.85	
TOTAL	11072726.698	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR H20 (g/kg WET WOOD)

RUN NO	VALUE	FUEL	MOIS	LOAD	RATE	AB	AC	AD
		A	B	C	D	CD	BD	BC
1	1024.180	1	1	1	1	1	1	1
2	1284.692	1	1	-1	-1	1	-1	-1
9	1618.307	1	-1	1	-1	-1	1	-1
4	692.770	1	-1	-1	1	-1	-1	1
5	1374.055	-1	1	1	-1	-1	-1	1
6	999.389	-1	1	-1	1	-1	1	-1
7	1128.577	-1	-1	1	1	1	-1	-1
8	1089.337	-1	-1	-1	-1	1	1	1
CONTRAST		28.591	153.326	1078.931	-1521.476	-157.7	251.1	-850.6
SUM OF SQUARES		102.181	2938.594	145511.398	289360.996	3110.1	7882.6	90445.0
SSTOTAL		539350.798						
MAIN EFFECT		7.148	38.331	269.733	-380.369			

SOURCE	SS	DF	MS	F
FUEL	102.181	1	102.18	.00
MOISTURE	2938.594	1	2938.59	0.09
LOAD	145511.398	1	145511.40	4.30
RATE	289360.996	1	289361.00	8.56
ERROR	101437.630	3	33812.54	
TOTAL	539350.798	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE (g/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	4.065	1	1	1	1	1	1	1
2	9.730	1	1	-1	-1	1	-1	-1
9	7.727	1	-1	1	-1	-1	1	-1
4	1.281	1	-1	-1	1	-1	-1	1
5	9.631	-1	1	1	-1	-1	-1	1
6	1.732	-1	1	-1	1	-1	1	-1
7	2.378	-1	-1	1	1	1	-1	-1
8	4.896	-1	-1	-1	-1	1	1	1
CONTRAST		4.167	8.876	6.162	-22.528	0.7	-4.6	-1.7
SUM OF SQUARES		2.170	9.848	4.747	63.439	0.1	2.6	0.4
SSTOTAL		83.268						
MAIN EFFECT		1.042	2.219	1.541	-5.632			

SOURCE	SS	DF	MS	F
FUEL	2.170	1	2.17	2.13
MOISTURE	9.848	1	9.85	9.64
LOAD	4.747	1	4.75	4.65
RATE	63.439	1	63.44	62.12
ERROR	3.064	3	1.02	
TOTAL	83.268	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR GRAV (g/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	6.588	1	1	1	1	1	1	1
2	38.626	1	1	-1	-1	1	-1	-1
9	27.605	1	-1	1	-1	-1	1	-1
4	3.764	1	-1	-1	1	-1	-1	1
5	72.739	-1	1	1	-1	-1	-1	1
6	0.896	-1	1	-1	1	-1	1	-1
7	10.144	-1	-1	1	1	1	-1	-1
8	32.809	-1	-1	-1	-1	1	1	1
CONTRAST		-40.005	44.527	40.980	-150.387	-16.8	-57.4	38.6
SUM OF SQUARES		200.053	247.828	209.922	2827.028	35.4	411.5	186.5
SSTOTAL		4118.259						
MAIN EFFECT		-10.001	11.132	10.245	-37.597			

SOURCE	SS	DF	MS	F
FUEL	200.053	1	200.05	0.95
MOISTURE	247.828	1	247.83	1.17
LOAD	209.922	1	209.92	0.99
RATE	2827.028	1	2827.03	13.39
ERROR	633.428	3	211.14	
TOTAL	4118.259	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR C1-C7 (g/kg WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1*	30.026	1	1	1	1	1	1	1
2	95.924	1	1	-1	-1	1	-1	-1
9	53.234	1	-1	1	-1	-1	1	-1
4	7.817	1	-1	-1	1	-1	-1	1
5	67.209	-1	1	1	-1	-1	-1	1
6	3.020	-1	1	-1	1	-1	1	-1
7	22.857	-1	-1	1	1	1	-1	-1
8	52.961	-1	-1	-1	-1	1	1	1

* - MISSING DATA

	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
CONTRAST	40.954	59.309	13.604	-205.607	70.5	-54.6	-17.0
SUM OF SQUARES	209.658	439.702	23.135	5284.304	621.1	372.2	36.2
SSTOTAL	6986.266						
MAIN EFFECT	10.239	14.827	3.401	-51.402			

SOURCE	SS	DF	MS	F
FUEL	209.658	1	209.66	0.41
MOISTURE	439.702	1	439.70	0.85
LOAD	23.135	1	23.14	0.04
RATE	5284.304	1	5284.30	10.27
ERROR	1029.468	2	514.73	
TOTAL	6986.266	~~7~~6		

F(0.01,1,2)=98.50
F(0.05,1,2)=18.50
F(0.10,1,2)= 8.53

ANALYSIS OF VARIANCE (ANOVA) FOR TCO (g/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	1.573	1	1	1	1	1	1	1
2	9.671	1	1	-1	-1	1	-1	-1
9	7.614	1	-1	1	-1	-1	1	-1
4	1.277	1	-1	-1	1	-1	-1	1
5	17.649	-1	1	1	-1	-1	-1	1
6	0.462	-1	1	-1	1	-1	1	-1
7	3.866	-1	-1	1	1	1	-1	-1
8	10.985	-1	-1	-1	-1	1	1	1
CONTRAST		-12.826	5.613	8.307	-38.740	-0.9	-11.8	9.9
SUM OF SQUARES		20.565	3.939	8.626	187.594	0.1	17.5	12.2
SSTOTAL		250.499						
MAIN EFFECT		-3.207	1.403	2.077	-9.685			

SOURCE	SS	DF	MS	F
FUEL	20.565	1	20.56	2.07
MOISTURE	3.939	1	3.94	0.40
LOAD	8.626	1	8.63	0.87
RATE	187.594	1	187.59	18.90
ERROR	29.775	3	9.93	
TOTAL	250.499	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR TOTAL HC (g/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	8.161	1	1	1	1	1	1	1
2	48.297	1	1	-1	-1	1	-1	-1
9	35.219	1	-1	1	-1	-1	1	-1
4	5.041	1	-1	-1	1	-1	-1	1
5	90.388	-1	1	1	-1	-1	-1	1
6	1.358	-1	1	-1	1	-1	1	-1
7	14.010	-1	-1	1	1	1	-1	-1
8	43.794	-1	-1	-1	-1	1	1	1

CONTRAST	-52.832	50.140	49.287	-189.127	-17.7	-69.2	48.5
SUM OF SQUARES	348.900	314.253	303.654	4471.104	39.4	598.6	294.0
SSTOTAL	6369.937						
MAIN EFFECT	-13.208	12.535	12.322	-47.282			

SOURCE	SS	DF	MS	F
FUEL	348.900	1	348.90	1.12
MOISTURE	314.253	1	314.25	1.01
LOAD	303.654	1	303.65	0.98
RATE	4471.104	1	4471.10	14.39
ERROR	932.026	3	310.68	
TOTAL	6369.937	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR CO2 (g/kg DRY WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	1727.017	1	1	1	1	1	1	1
2	1618.990	1	1	-1	-1	1	-1	-1
9	1430.013	1	-1	1	-1	-1	1	-1
4	1310.228	1	-1	-1	1	-1	-1	1
5	2156.663	-1	1	1	-1	-1	-1	1
6	1863.327	-1	1	-1	1	-1	1	-1
7	1200.305	-1	-1	1	1	1	-1	-1
8	1295.075	-1	-1	-1	-1	1	1	1
CONTRAST		-429.122	2130.377	426.377	-399.864	-918.8	29.2	376.3
SUM OF SQUARES		23018.214	567313.036	22724.701	19986.363	105534.3	106.9	17704.6
SSTOTAL		756388.090						
MAIN EFFECT		-107.281	532.594	106.594	-99.966			

SOURCE	SS	DF	MS	F
FUEL	23018.214	1	23018.21	0.56
MOISTURE	567313.036	1	567313.04	13.80
LOAD	22724.701	1	22724.70	0.55
RATE	19986.363	1	19986.36	0.49
ERROR	123345.777	3	41115.26	
TOTAL	756388.090	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR CO (g/kg DRY WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	132.546	1	1	1	1	1	1	1
2	227.481	1	1	-1	-1	1	-1	-1
9	187.488	1	-1	1	-1	-1	1	-1
4	101.785	1	-1	-1	1	-1	-1	1
5	317.009	-1	1	1	-1	-1	-1	1
6	37.648	-1	1	-1	1	-1	1	-1
7	96.200	-1	-1	1	1	1	-1	-1
8	206.940	-1	-1	-1	-1	1	1	1

CONTRAST	-8.497	122.271	159.389	-570.739	19.2	-177.9	209.5
SUM OF SQUARES	9.025	1868.783	3175.587	40717.867	46.3	3953.8	5484.4
SSTOTAL	55255.740						
MAIN EFFECT	-2.124	30.568	39.847	-142.685			

SOURCE	SS	DF	MS	F
FUEL	9.025	1	9.03	.00
MOISTURE	1868.783	1	1868.78	0.59
LOAD	3175.587	1	3175.59	1.00
RATE	40717.867	1	40717.87	12.88
ERROR	9484.479	3	3161.49	
TOTAL	55255.740	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR O2 (g/kg DRY WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	2677.603	1	1	1	1	1	1	1
2	5025.978	1	1	-1	-1	1	-1	-1
9	3514.367	1	-1	1	-1	-1	1	-1
4	2059.424	1	-1	-1	1	-1	-1	1
5	6085.706	-1	1	1	-1	-1	-1	1
6	3440.797	-1	1	-1	1	-1	1	-1
7	2666.688	-1	-1	1	1	1	-1	-1
8	3706.459	-1	-1	-1	-1	1	1	1
CONTRAST		-2622.279	5283.146	711.707	-7487.999	-1023.6	-2498.6	-118.6
SUM OF SQUARES		859543.469	3488954.018	63315.836	7008765.376	130961.0	780357.0	1759.4
SSTOTAL		12333656.069						
MAIN EFFECT		-655.570	1320.787	177.927	-1872.000			

SOURCE	SS	DF	MS	F
FUEL	859543.469	1	859543.47	2.82
MOISTURE	3488954.018	1	3488954.02	11.46
LOAD	63315.836	1	63315.84	0.21
RATE	7008765.376	1	7008765.38	23.03
ERROR	913077.371	3	304359.12	
TOTAL	12333656.069	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR H20 (g/kg DRY WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	1259.754	1	1	1	1	1	1	1
2	1580.187	1	1	-1	-1	1	-1	-1
9	2485.879	1	-1	1	-1	-1	1	-1
4	1064.163	1	-1	-1	1	-1	-1	1
5	1618.440	-1	1	1	-1	-1	-1	1
6	1177.137	-1	1	-1	1	-1	1	-1
7	1649.966	-1	-1	1	1	1	-1	-1
8	1592.598	-1	-1	-1	-1	1	1	1

CONTRAST	351.842	-1157.088	1599.953	-2126.084	-263.1	602.6	-1358.2
SUM OF SQUARES	15474.127	167356.639	319981.377	565029.030	8653.6	45392.5	230593.5
SSTOTAL	1352480.691						
MAIN EFFECT	87.961	-289.272	399.988	-531.521			

SOURCE	SS	DF	MS	F
FUEL	15474.127	1	15474.13	0.16
MOISTURE	167356.639	1	167356.64	1.76
LOAD	319981.377	1	319981.38	3.37
RATE	565029.030	1	565029.03	5.96
ERROR	284639.519	3	94879.84	
TOTAL	1352480.691	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE (g/kg DRY WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	5.000	1	1	1	1	1	1	1
2	11.968	1	1	-1	-1	1	-1	-1
9	11.870	1	-1	1	-1	-1	1	-1
4	1.968	1	-1	-1	1	-1	-1	1
5	11.344	-1	1	1	-1	-1	-1	1
6	2.040	-1	1	-1	1	-1	1	-1
7	3.476	-1	-1	1	1	1	-1	-1
8	7.158	-1	-1	-1	-1	1	1	1
CONTRAST		6.788	5.881	8.556	-29.855	0.4	-2.7	-3.9
SUM OF SQUARES		5.760	4.323	9.152	111.413	.0	0.9	1.9
SSTOTAL		133.453						
MAIN EFFECT		1.697	1.470	2.139	-7.464			

SOURCE	SS	DF	MS	F
FUEL	5.760	1	5.76	6.16
MOISTURE	4.323	1	4.32	4.62
LOAD	9.152	1	9.15	9.78
RATE	111.413	1	111.41	119.12
ERROR	2.806	3	0.94	
TOTAL	133.453	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR GRAV (g/kg DRY WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	8.103	1	1	1	1	1	1	1
2	47.510	1	1	-1	-1	1	-1	-1
9	42.404	1	-1	1	-1	-1	1	-1
4	5.782	1	-1	-1	1	-1	-1	1
5	85.676	-1	1	1	-1	-1	-1	1
6	1.056	-1	1	-1	1	-1	1	-1
7	14.830	-1	-1	1	1	1	-1	-1
8	47.967	-1	-1	-1	-1	1	1	1

CONTRAST		-45.729	31.362	48.699	-193.786	-16.5	-54.3	41.7
SUM OF SQUARES		261.393	122.948	296.444	4694.132	34.1	368.1	217.7
SSTOTAL		5994.753						
MAIN EFFECT		-11.432	7.841	12.175	-48.447			

SOURCE	SS	DF	MS	F
FUEL	261.393	1	261.39	1.27
MOISTURE	122.948	1	122.95	0.60
LOAD	296.444	1	296.44	1.43
RATE	4694.132	1	4694.13	22.72
ERROR	619.836	3	206.61	
TOTAL	5994.753	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR TCO (g/kg DRY WOOD)

RUN NO	VALUE	FUEL	MOIS	LOAD	RATE	AB	AC	AD
		A	B	C	D	CD	BD	BC
1	1.935	1	1	1	1	1	1	1
2	11.896	1	1	-1	-1	1	-1	-1
9	11.696	1	-1	1	-1	-1	1	-1
4	1.962	1	-1	-1	1	-1	-1	1
5	20.788	-1	1	1	-1	-1	-1	1
6	0.544	-1	1	-1	1	-1	1	-1
7	5.653	-1	-1	1	1	1	-1	-1
8	16.059	-1	-1	-1	-1	1	1	1
CONTRAST		-15.556	-0.207	9.610	-50.345	0.6	-10.1	11.0
SUM OF SQUARES		30.248	0.005	11.543	316.821	.0	12.7	15.0
SSTOTAL		386.322						
MAIN EFFECT		-3.889	-0.052	2.402	-12.586			

SOURCE	SS	DF	MS	F
FUEL	30.248	1	30.25	3.28
MOISTURE	0.005	1	0.01	.00
LOAD	11.543	1	11.54	1.25
RATE	316.821	1	316.82	34.31
ERROR	27.704	3	9.23	
TOTAL	386.322	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR TOTAL HC (g/kg DRY WOOD)

RUN NO	VALUE	FUEL	MOIS	LOAD	RATE	AB	AC	AD
		A	B	C	D	CD	BD	BC
1	10.038	1	1	1	1	1	1	1
2	59.406	1	1	-1	-1	1	-1	-1
9	54.100	1	-1	1	-1	-1	1	-1
4	7.744	1	-1	-1	1	-1	-1	1
5	106.464	-1	1	1	-1	-1	-1	1
6	1.600	-1	1	-1	1	-1	1	-1
7	20.482	-1	-1	1	1	1	-1	-1
8	64.026	-1	-1	-1	-1	1	1	1

CONTRAST	-61.285	31.156	58.308	-244.131	-16.0	-64.3	52.7
SUM OF SQUARES	469.478	121.334	424.981	7449.970	31.8	517.3	347.0
SSTOTAL	9361.855						
MAIN EFFECT	-15.321	7.789	14.577	-61.033			

SOURCE	SS	DF	MS	F
FUEL	469.478	1	469.48	1.57
MOISTURE	121.334	1	121.33	0.41
LOAD	424.981	1	424.98	1.42
RATE	7449.970	1	7449.97	24.94
ERROR	896.091	3	298.70	
TOTAL	9361.855	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PAH PWF SPOT TEST (mg/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.001	1	1	1	1	1	1	1
2	0.107	1	1	-1	-1	1	-1	-1
9	0.108	1	-1	1	-1	-1	1	-1
4	0.005	1	-1	-1	1	-1	-1	1
5	0.262	-1	1	1	-1	-1	-1	1
6	0.002	-1	1	-1	1	-1	1	-1
7	0.043	-1	-1	1	1	1	-1	-1
8	0.007	-1	-1	-1	-1	1	1	1

CONTRAST	-0.093	0.209	0.293	-0.434	-0.2	-0.3	.0
SUM OF SQUARES	0.001	0.005	0.011	0.024	.0	.0	.0
SSTOTAL	0.058						
MAIN EFFECT	-0.023	0.052	0.073	-0.108			

SOURCE	SS	DF	MS	F
FUEL	0.001	1	.00	0.19
MOISTURE	0.005	1	0.01	0.96
LOAD	0.011	1	0.01	1.88
RATE	0.024	1	0.02	4.13
ERROR	0.017	3	0.01	
TOTAL	0.058	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR GCMS TOTAL PAH (g/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.005	1	1	1	1	1	1	1
2	0.003	1	1	-1	-1	1	-1	-1
9	0.012	1	-1	1	-1	-1	1	-1
4	0.041	1	-1	-1	1	-1	-1	1
5	0.016	-1	1	1	-1	-1	-1	1
6	0.011	-1	1	-1	1	-1	1	-1
7	0.049	-1	-1	1	1	1	-1	-1
8	0.017	-1	-1	-1	-1	1	1	1
CONTRAST		-0.033	-0.084	0.010	0.058	.0	-0.1	.0
SUM OF SQUARES		.000	0.001	.000	.000	.0	.0	.0
SSTOTAL		0.002						
MAIN EFFECT		-0.008	-0.021	0.003	0.015			

SOURCE	SS	DF	MS	F
FUEL	.000	1	.00	0.80
MOISTURE	0.001	1	.00	5.06
LOAD	.000	1	.00	0.08
RATE	.000	1	.00	2.48
ERROR	0.001	3	.00	
TOTAL	0.002	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PAH TCO (g/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.000	1	1	1	1	1	1	1
2	0.035	1	1	-1	-1	1	-1	-1
9	0.660	1	-1	1	-1	-1	1	-1
4	0.074	1	-1	-1	1	-1	-1	1
5	0.103	-1	1	1	-1	-1	-1	1
6	0.006	-1	1	-1	1	-1	1	-1
7	0.308	-1	-1	1	1	1	-1	-1
8	0.701	-1	-1	-1	-1	1	1	1

CONTRAST		-0.349	-1.599	0.255	-1.112	0.2	0.8	-0.1
SUM OF SQUARES		0.015	0.320	0.008	0.155	.0	0.1	.0
SSTOTAL		0.595						
MAIN EFFECT		-0.087	-0.400	0.064	-0.278			

SOURCE	SS	DF	MS	F
FUEL	0.015	1	0.02	0.47
MOISTURE	0.320	1	0.32	9.89
LOAD	0.008	1	0.01	0.25
RATE	0.155	1	0.15	4.78
ERROR	0.097	3	0.03	
TOTAL	0.595	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PAH GRAV+TCO (g/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.316	1	1	1	1	1	1	1
2	0.237	1	1	-1	-1	1	-1	-1
9	2.017	1	-1	1	-1	-1	1	-1
4	0.141	1	-1	-1	1	-1	-1	1
5	0.241	-1	1	1	-1	-1	-1	1
6	0.022	-1	1	-1	1	-1	1	-1
7	0.509	-1	-1	1	1	1	-1	-1
8	1.067	-1	-1	-1	-1	1	1	1

	FUEL	MOIS	LOAD	RATE	AB	AC	AD
CONTRAST	0.870	-2.918	1.616	-2.574	-0.3	2.3	-1.0
SUM OF SQUARES	0.095	1.064	0.326	0.828	.0	0.7	0.1
SSTOTAL	3.112						
MAIN EFFECT	0.218	-0.729	0.404	-0.644			

SOURCE	SS	DF	MS	F
FUEL	0.095	1	0.09	0.36
MOISTURE	1.064	1	1.06	4.00
LOAD	0.326	1	0.33	1.23
RATE	0.828	1	0.83	3.11
ERROR	0.798	3	0.27	
TOTAL	3.112	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PAH (GCMS TOTAL)/(GRAV+TCO) (g/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.016	1	1	1	1	1	1	1
2	0.023	1	1	-1	-1	1	-1	-1
9	0.006	1	-1	1	-1	-1	1	-1
4	0.290	1	-1	-1	1	-1	-1	1
5	0.067	-1	1	1	-1	-1	-1	1
6	0.504	-1	1	-1	1	-1	1	-1
7	0.096	-1	-1	1	1	1	-1	-1
8	0.016	-1	-1	-1	-1	1	1	1
CONTRAST		-0.348	0.202	-0.648	0.794	-0.7	0.1	-0.2
SUM OF SQUARES		0.015	0.005	0.052	0.079	0.1	.0	.0
SSTOTAL		0.223						
MAIN EFFECT		-0.087	0.051	-0.162	0.198			

SOURCE	SS	DF	MS	F
FUEL	0.015	1	0.02	0.63
MOISTURE	0.005	1	0.01	0.21
LOAD	0.052	1	0.05	2.19
RATE	0.079	1	0.08	3.30
ERROR	0.072	3	0.02	
TOTAL	0.223	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR GCMS TOTA[illegible])

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.459	1	1	1	1	1	1	1
2	0.077	1	1	-1	-1	1	-1	-1
9	0.321	1	-1	1	-1	-1	1	-1
4	2.171	1	-1	-1	1	-1	-1	1
5	0.780	-1	1	1	-1	-1	-1	1
6	0.888	-1	1	-1	1	-1	1	-1
7	3.331	-1	-1	1	1	1	-1	-1
8	0.432	-1	-1	-1	-1	1	1	1

	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
CONTRAST	-2.403	-4.051	1.323	5.239	0.1	-4.3	-0.8
SUM OF SQUARES	0.722	2.051	0.219	3.431	.0	2.3	0.1
SSTOTAL	8.766						
MAIN EFFECT	-0.601	-1.013	0.331	1.310			

SOURCE	SS	DF	MS	F
FUEL	0.722	1	0.72	0.92
MOISTURE	2.051	1	2.05	2.63
LOAD	0.219	1	0.22	0.28
RATE	3.431	1	3.43	4.39
ERROR	2.344	3	0.78	
TOTAL	8.766	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PAH GRAV (g/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	28.775	1	1	1	1	1	1	1
2	3.935	1	1	-1	-1	1	-1	-1
9	37.221	1	-1	1	-1	-1	1	-1
4	3.560	1	-1	-1	1	-1	-1	1
5	6.648	-1	1	1	-1	-1	-1	1
6	1.302	-1	1	-1	1	-1	1	-1
7	13.669	-1	-1	1	1	1	-1	-1
8	9.325	-1	-1	-1	-1	1	1	1

CONTRAST	42.546	-23.115	68.191	-9.823	7.0	48.8	-7.8
SUM OF SQUARES	226.273	66.786	581.249	12.061	6.1	297.8	7.6
SSTOTAL	1197.920						
MAIN EFFECT	10.637	-5.779	17.048	-2.456			

SOURCE	SS	DF	MS	F
FUEL	226.273	1	226.27	2.18
MOISTURE	66.786	1	66.79	0.64
LOAD	581.249	1	581.25	5.60
RATE	12.061	1	12.06	0.12
ERROR	311.551	3	103.85	
TOTAL	1197.920	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PAH TCO (g/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.000	1	1	1	1	1	1	1
2	1.047	1	1	-1	-1	1	-1	-1
9	18.116	1	-1	1	-1	-1	1	-1
4	3.923	1	-1	-1	1	-1	-1	1
5	4.949	-1	1	1	-1	-1	-1	1
6	0.461	-1	1	-1	1	-1	1	-1
7	20.905	-1	-1	1	1	1	-1	-1
8	17.858	-1	-1	-1	-1	1	1	1
CONTRAST		-21.087	-54.345	20.682	-16.681	12.4	5.6	-13.8
SUM OF SQUARES		55.580	369.169	53.467	34.780	19.1	3.9	23.8
SSTOTAL		559.825						
MAIN EFFECT		-5.272	-13.586	5.170	-4.170			

SOURCE	SS	DF	MS	F
FUEL	55.580	1	55.58	3.56
MOISTURE	369.169	1	369.17	23.65
LOAD	53.467	1	53.47	3.43
RATE	34.780	1	34.78	2.23
ERROR	46.829	3	15.61	
TOTAL	559.825	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PAH GRAV+TCO (g/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	28.775	1	1	1	1	1	1	1
2	4.981	1	1	-1	-1	1	-1	-1
9	55.337	1	-1	1	-1	-1	1	-1
4	7.483	1	-1	-1	1	-1	-1	1
5	11.597	-1	1	1	-1	-1	-1	1
6	1.763	-1	1	-1	1	-1	1	-1
7	34.574	-1	-1	1	1	1	-1	-1
8	27.183	-1	-1	-1	-1	1	1	1

	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
CONTRAST	21.460	-77.459	88.873	-26.503	19.3	54.4	-21.6
SUM OF SQUARES	57.565	749.995	987.292	87.803	46.7	370.2	58.4
SSTOTAL	2358.013						
MAIN EFFECT	5.365	-19.365	22.218	-6.626			

SOURCE	SS	DF	MS	F
FUEL	57.565	1	57.57	0.36
MOISTURE	749.995	1	749.99	4.73
LOAD	987.292	1	987.29	6.23
RATE	87.803	1	87.80	0.55
ERROR	475.358	3	158.45	
TOTAL	2358.013	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PAH (GCMS TOTAL)/(GRAV+TCO) (g/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.016	1	1	1	1	1	1	1
2	0.023	1	1	-1	-1	1	-1	-1
9	0.006	1	-1	1	-1	-1	1	-1
4	0.290	1	-1	-1	1	-1	-1	1
5	0.067	-1	1	1	-1	-1	-1	1
6	0.504	-1	1	-1	1	-1	1	-1
7	0.096	-1	-1	1	1	1	-1	-1
8	0.016	-1	-1	-1	-1	1	1	1

CONTRAST	-0.348	0.202	-0.648	0.794	-0.7	0.1	-0.2
SUM OF SQUARES	0.015	0.005	0.052	0.079	0.1	.0	.0
SSTOTAL	0.223						
MAIN EFFECT	-0.087	0.051	-0.162	198			

SOURCE	SS	DF	MS	F
FUEL	0.015	1	0.02	0.63
MOISTURE	0.005	1	0.01	0.21
LOAD	0.052	1	0.05	2.19
RATE	0.079	1	0.08	3.30
ERROR	0.072	3	0.02	
TOTAL	0.223	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR GCMS TOTAL PAH (g/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.064	1	1	1	1	1	1	1
2	0.062	1	1	-1	-1	1	-1	-1
9	0.144	1	-1	1	-1	-1	1	-1
4	0.318	1	-1	-1	1	-1	-1	1
5	0.416	-1	1	1	-1	-1	-1	1
6	0.167	-1	1	-1	1	-1	1	-1
7	0.482	-1	-1	1	1	1	-1	-1
8	0.200	-1	-1	-1	-1	1	1	1

CONTRAST	-0.677	-0.434	0.360	0.208	-0.2	-0.7	0.1
SUM OF SQUARES	0.057	0.024	0.016	0.005	.0	0.1	.0
SSTOTAL	0.174						
MAIN EFFECT	-0.169	-0.109	0.090	0.052			

SOURCE	SS	DF	MS	F
FUEL	0.057	1	0.06	2.41
MOISTURE	0.024	1	0.02	0.99
LOAD	0.016	1	0.02	0.68
RATE	0.005	1	0.01	0.23
ERROR	0.071	3	0.02	
TOTAL	0.174	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PAH GRAV (g/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	3.997	1	1	1	1	1	1	1
2	3.170	1	1	-1	-1	1	-1	-1
9	16.738	1	-1	1	-1	-1	1	-1
4	0.521	1	-1	-1	1	-1	-1	1
5	3.549	-1	1	1	-1	-1	-1	1
6	0.245	-1	1	-1	1	-1	1	-1
7	1.976	-1	-1	1	1	1	-1	-1
8	4.305	-1	-1	-1	-1	1	1	1

CONTRAST	14.349	-12.580	18.018	-21.022	-7.6	16.1	-9.8
SUM OF SQUARES	25.735	19.781	40.583	55.242	7.2	32.3	11.9
SSTOTAL	192.749						
MAIN EFFECT	3.587	-3.145	4.505	-5.256			

SOURCE	SS	DF	MS	F
FUEL	25.735	1	25.74	1.50
MOISTURE	19.781	1	19.78	1.15
LOAD	40.583	1	40.58	2.37
RATE	55.242	1	55.24	3.22
ERROR	51.408	3	17.14	
TOTAL	192.749	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PAH TCO (g/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.000	1	1	1	1	1	1	1
2	0.837	1	1	-1	-1	1	-1	-1
9	8.147	1	-1	1	-1	-1	1	-1
4	0.574	1	-1	-1	1	-1	-1	1
5	2.642	-1	1	1	-1	-1	-1	1
6	0.087	-1	1	-1	1	-1	1	-1
7	3.023	-1	-1	1	1	1	-1	-1
8	8.245	-1	-1	-1	-1	1	1	1

CONTRAST	-4.439	-16.422	4.069	-16.186	0.7	9.4	-0.6
SUM OF SQUARES	2.463	33.711	2.070	32.750	0.1	11.1	.0
SSTOTAL	82.148						
MAIN EFFECT	-1.110	-4.106	1.017	-4.047			

SOURCE	SS	DF	MS	F
FUEL	2.463	1	2.46	0.66
MOISTURE	33.711	1	33.71	9.07
LOAD	2.070	1	2.07	0.56
RATE	32.750	1	32.75	8.81
ERROR	11.154	3	3.72	
TOTAL	82.148	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PAH GRAV+TCO (g/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	3.997	1	1	1	1	1	1	1
2	4.006	1	1	-1	-1	1	-1	-1
9	24.884	1	-1	1	-1	-1	1	-1
4	1.095	1	-1	-1	1	-1	-1	1
5	6.191	-1	1	1	-1	-1	-1	1
6	0.332	-1	1	-1	1	-1	1	-1
7	4.999	-1	-1	1	1	1	-1	-1
8	12.550	-1	-1	-1	-1	1	1	1
CONTRAST		9.910	-29.002	22.088	-37.209	-7.0	25.5	-10.4
SUM OF SQUARES		12.275	105.139	60.984	173.060	6.0	81.1	13.5
SSTOTAL		452.090						
MAIN EFFECT		2.477	-7.250	5.522	-9.302			

SOURCE	SS	DF	MS	F
FUEL	12.275	1	12.27	0.37
MOISTURE	105.139	1	105.14	3.13
LOAD	60.984	1	60.98	1.82
RATE	173.060	1	173.06	5.16
ERROR	100.632	3	33.54	
TOTAL	452.090	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR (GCMS TOTAL)/(PAH GRAV+TCO) (g/kg WET WOOD)

RUN NO	VALUE	FUEL	MOIS	LOAD	RATE	AB	AC	AD
		A	B	C	D	CD	BD	BC
1	0.016	1	1	1	1	1	1	1
2	0.023	1	1	-1	-1	1	-1	-1
9	0.006	1	-1	1	-1	-1	1	-1
4	0.290	1	-1	-1	1	-1	-1	1
5	0.067	-1	1	1	-1	-1	-1	1
6	0.504	-1	1	-1	1	-1	1	-1
7	0.096	-1	-1	1	1	1	-1	-1
8	0.016	-1	-1	-1	-1	1	1	1

CONTRAST	-0.348	0.202	-0.648	0.794	-0.7	0.1	-0.2
SUM OF SQUARES	0.015	0.005	0.052	0.079	0.1	.0	.0
SSTOTAL	0.223						
MAIN EFFECT	-0.087	0.051	-0.162	0.198			

SOURCE	SS	DF	MS	F
FUEL	0.015	1	0.02	0.63
MOISTURE	0.005	1	0.01	0.21
LOAD	0.052	1	0.05	2.19
RATE	0.079	1	0.08	3.30
ERROR	0.072	3	0.02	
TOTAL	0.223	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR GCMS TOTAL PAH (g/kg DRY WOOD)

RUN NO	VALUE	FUEL	MOIS	LOAD	RATE	AB	AC	AD
		A	B	C	D	CD	BD	BC
1	0.078	1	1	1	1	1	1	1
2	0.076	1	1	-1	-1	1	-1	-1
9	0.222	1	-1	1	-1	-1	1	-1
4	0.488	1	-1	-1	1	-1	-1	1
5	0.490	-1	1	1	-1	-1	-1	1
6	0.197	-1	1	-1	1	-1	1	-1
7	0.704	-1	-1	1	1	1	-1	-1
8	0.292	-1	-1	-1	-1	1	1	1

CONTRAST	-0.819	-0.864	0.442	0.388	-0.2	-1.0	0.1
SUM OF SQUARES	0.084	0.093	0.024	0.019	.0	0.1	.0
SSTOTAL	0.348						
MAIN EFFECT	-0.205	-0.216	0.111	0.097			

SOURCE	SS	DF	MS	F
FUEL	0.084	1	0.08	1.97
MOISTURE	0.093	1	0.09	2.19
LOAD	0.024	1	0.02	0.57
RATE	0.019	1	0.02	0.44
ERROR	0.128	3	0.04	
TOTAL	0.348	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PAH GRAV (g/kg DRY WOOD)

RUN NO	VALUE	FUEL	MOIS	LOAD	RATE	AB	AC	AD
		A	B	C	D	CD	BD	BC
1	4.916	1	1	1	1	1	1	1
2	3.899	1	1	-1	-1	1	-1	-1
9	25.711	1	-1	1	-1	-1	1	-1
4	0.800	1	-1	-1	1	-1	-1	1
5	4.180	-1	1	1	-1	-1	-1	1
6	0.289	-1	1	-1	1	-1	1	-1
7	2.889	-1	-1	1	1	1	-1	-1
8	6.294	-1	-1	-1	-1	1	1	1

CONTRAST	21.672	-22.411	26.414	-31.189	-13.0	25.4	-16.6
SUM OF SQUARES	58.711	62.781	87.213	121.596	21.1	80.9	34.4
SSTOTAL	466.711						
MAIN EFFECT	5.418	-5.603	6.604	-7.797			

SOURCE	SS	DF	MS	F
FUEL	58.711	1	58.71	1.29
MOISTURE	62.781	1	62.78	1.38
LOAD	87.213	1	87.21	1.92
RATE	121.596	1	121.60	2.67
ERROR	136.410	3	45.47	
TOTAL	466.711	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PAH TCO (g/kg DRY WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.000	1	1	1	1	1	1	1
2	1.029	1	1	-1	-1	1	-1	-1
9	12.514	1	-1	1	-1	-1	1	-1
4	0.882	1	-1	-1	1	-1	-1	1
5	3.112	-1	1	1	-1	-1	-1	1
6	0.102	-1	1	-1	1	-1	1	-1
7	4.419	-1	-1	1	1	1	-1	-1
8	12.053	-1	-1	-1	-1	1	1	1

CONTRAST		-5.262	-25.625	5.979	-23.305	0.9	15.2	-2.0
SUM OF SQUARES		3.461	82.080	4.468	67.893	0.1	29.0	0.5
SSTOTAL		187.494						
MAIN EFFECT		-1.316	-6.406	1.495	-5.826			

SOURCE	SS	DF	MS	F
FUEL	3.461	1	3.46	0.35
MOISTURE	82.080	1	82.08	8.32
LOAD	4.468	1	4.47	0.45
RATE	67.893	1	67.89	6.88
ERROR	29.593	3	9.86	
TOTAL	187.494	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PAH GRAV+TCO (g/kg DRY WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	4.916	1	1	1	1	1	1	1
2	4.928	1	1	-1	-1	1	-1	-1
9	38.225	1	-1	1	-1	-1	1	-1
4	1.682	1	-1	-1	1	-1	-1	1
5	7.292	-1	1	1	-1	-1	-1	1
6	0.391	-1	1	-1	1	-1	1	-1
7	7.309	-1	-1	1	1	1	-1	-1
8	18.348	-1	-1	-1	-1	1	1	1
CONTRAST		16.410	-48.036	32.393	-54.495	-12.1	40.7	-18.6
SUM OF SQUARES		33.661	288.430	131.161	371.208	18.3	206.7	43.3
SSTOTAL		1092.794						
MAIN EFFECT		4.103	-12.009	8.098	-13.624			

SOURCE	SS	DF	MS	F
FUEL	33.661	1	33.66	0.38
MOISTURE	288.430	1	288.43	3.22
LOAD	131.161	1	131.16	1.47
RATE	371.208	1	371.21	4.15
ERROR	268.333	3	89.44	
TOTAL	1092.794	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PAH (GCMS TOTAL)/(GRAV+TCO) (g/kg DRY WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.016	1	1	1	1	1	1	1
2	0.023	1	1	-1	-1	1	-1	-1
9	0.006	1	-1	1	-1	-1	1	-1
4	0.290	1	-1	-1	1	-1	-1	1
5	0.067	-1	1	1	-1	-1	-1	1
6	0.504	-1	1	-1	1	-1	1	-1
7	0.096	-1	-1	1	1	1	-1	-1
8	0.016	-1	-1	-1	-1	1	1	1
CONTRAST		-0.348	0.202	-0.648	0.794	-0.7	0.1	-0.2
SUM OF SQUARES		0.015	0.005	0.052	0.079	0.1	.0	.0
SSTOTAL		0.223						
MAIN EFFECT		-0.087	0.051	-0.162	0.198			

SOURCE	SS	DF	MS	F
FUEL	0.015	1	0.02	0.63
MOISTURE	0.005	1	0.01	0.21
LOAD	0.052	1	0.05	2.19
RATE	0.079	1	0.08	3.30
ERROR	0.072	3	0.02	
TOTAL	0.223	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PYRENE (mg/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.087	1	1	1	1	1	1	1
2	0.053	1	1	-1	-1	1	-1	-1
9	0.102	1	-1	1	-1	-1	1	-1
4	1.232	1	-1	-1	1	-1	-1	1
5	0.332	-1	1	1	-1	-1	-1	1
6	0.405	-1	1	-1	1	-1	1	-1
7	1.359	-1	-1	1	1	1	-1	-1
8	0.275	-1	-1	-1	-1	1	1	1
CONTRAST		-0.897	-2.091	-0.084	2.322	-0.3	-2.1	.0
SUM OF SQUARES		0.101	0.547	0.001	0.674	.0	0.6	.0
SSTOTAL		1.888						
MAIN EFFECT		-0.224	-0.523	-0.021	0.580			

SOURCE	SS	DF	MS	F
FUEL	0.101	1	0.10	0.53
MOISTURE	0.547	1	0.55	2.90
LOAD	0.001	1	.00	.00
RATE	0.674	1	0.67	3.57
ERROR	0.566	3	0.19	
TOTAL	1.888	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR BENZO(b)FLUORANTHENE (mg/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.000	1	1	1	1	1	1	1
2	0.097	1	1	-1	-1	1	-1	-1
9	0.000	1	-1	1	-1	-1	1	-1
4	2.811	1	-1	-1	1	-1	-1	1
5	0.000	-1	1	1	-1	-1	-1	1
6	2.005	-1	1	-1	1	-1	1	-1
7	4.371	-1	-1	1	1	1	-1	-1
8	0.000	-1	-1	-1	-1	1	1	1
CONTRAST		-3.469	-5.080	-0.541	9.090	-0.3	-5.3	-3.7
SUM OF SQUARES		1.504	3.226	0.037	10.328	.0	3.5	1.7
SSTOTAL		20.263						
MAIN EFFECT		-0.867	-1.270	-0.135	2.272			

SOURCE	SS	DF	MS	F
FUEL	1.504	1	1.50	0.87
MOISTURE	3.226	1	3.23	1.87
LOAD	0.037	1	0.04	0.02
RATE	10.328	1	10.33	5.99
ERROR	5.168	3	1.72	
TOTAL	20.263	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR NAPHTHALENE (mg/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	3.707	1	1	1	1	1	1	1
2	1.933	1	1	-1	-1	1	-1	-1
9	9.501	1	-1	1	-1	-1	1	-1
4	28.301	1	-1	-1	1	-1	-1	1
5	9.850	-1	1	1	-1	-1	-1	1
6	7.407	-1	1	-1	1	-1	1	-1
7	30.846	-1	-1	1	1	1	-1	-1
8	11.030	-1	-1	-1	-1	1	1	1

CONTRAST	-15.692	-56.781	5.232	37.947	-7.5	-39.3	3.2
SUM OF SQUARES	30.778	403.011	3.422	179.993	7.1	192.9	1.3
SSTOTAL	818.517						
MAIN EFFECT	-3.923	-14.195	1.308	9.487			

SOURCE	SS	DF	MS	F
FUEL	30.778	1	30.78	0.46
MOISTURE	403.011	1	403.01	6.01
LOAD	3.422	1	3.42	0.05
RATE	179.993	1	179.99	2.68
ERROR	201.313	3	67.10	
TOTAL	818.517	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR ACENAPHTHYLENE (mg/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.292	1	1	1	1	1	1	1
2	0.090	1	1	-1	-1	1	-1	-1
3	0.414	1	-1	1	-1	-1	1	-1
4	2.937	1	-1	-1	1	-1	-1	1
5	1.820	-1	1	1	-1	-1	-1	1
6	0.640	-1	1	-1	1	-1	1	-1
7	5.319	-1	-1	1	1	1	-1	-1
8	1.977	-1	-1	-1	-1	1	1	1

	FUEL	MOIS	LOAD	RATE	AB	AC	AD
CONTRAST	-6.022	-7.806	2.201	4.886	1.9	-6.8	0.6
SUM OF SQUARES	4.534	7.616	0.606	2.985	0.4	5.9	.0
SSTOTAL	22.066						
MAIN EFFECT	-1.506	-1.951	0.550	1.222			

SOURCE	SS	DF	MS	F
FUEL	4.534	1	4.53	2.15
MOISTURE	7.616	1	7.62	3.61
LOAD	0.606	1	0.61	0.29
RATE	2.985	1	2.98	1.42
ERROR	6.326	3	2.11	
TOTAL	22.066	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR FLUORENE (mg/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.091	1	1	1	1	1	1	1
2	0.140	1	1	-1	-1	1	-1	-1
9	0.498	1	-1	1	-1	-1	1	-1
4	0.853	1	-1	-1	1	-1	-1	1
5	0.973	-1	1	1	-1	-1	-1	1
6	0.197	-1	1	-1	1	-1	1	-1
7	1.729	-1	-1	1	1	1	-1	-1
8	0.870	-1	-1	-1	-1	1	1	1

CONTRAST	-2.186	-2.548	1.231	0.388	0.3	-2.0	0.2
SUM OF SQUARES	0.597	0.812	0.190	0.019	.0	0.5	.0
SSTOTAL	2.155						
MAIN EFFECT	-0.546	-0.637	0.308	0.097			

SOURCE	SS	DF	MS	F
FUEL	0.597	1	0.60	3.33
MOISTURE	0.812	1	0.81	4.53
LOAD	0.190	1	0.19	1.06
RATE	0.019	1	0.02	0.10
ERROR	0.538	3	0.18	
TOTAL	2.155	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PHENANTHRENE (mg/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.616	1	1	1	1	1	1	1
2	0.255	1	1	-1	-1	1	-1	-1
9	0.816	1	-1	1	-1	-1	1	-1
4	3.877	1	-1	-1	1	-1	-1	1
5	1.935	-1	1	1	-1	-1	-1	1
6	1.376	-1	1	-1	1	-1	1	-1
7	5.139	-1	-1	1	1	1	-1	-1
8	2.124	-1	-1	-1	-1	1	1	1
CONTRAST		-5.009	-7.773	0.874	5.878	0.1	-6.3	1.0
SUM OF SQUARES		3.137	7.553	0.095	4.318	.0	4.9	0.1
SSTOTAL		20.141						
MAIN EFFECT		-1.252	-1.943	0.218	1.469			

SOURCE	SS	DF	MS	F
FUEL	3.137	1	3.14	1.87
MOISTURE	7.553	1	7.55	4.50
LOAD	0.095	1	0.10	0.06
RATE	4.318	1	4.32	2.57
ERROR	5.037	3	1.68	
TOTAL	20.141	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR ANTHRACENE (mg/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.067	1	1	1	1	1	1	1
2	0.056	1	1	-1	-1	1	-1	-1
9	0.168	1	-1	1	-1	-1	1	-1
4	0.632	1	-1	-1	1	-1	-1	1
5	0.412	-1	1	1	-1	-1	-1	1
6	0.154	-1	1	-1	1	-1	1	-1
7	0.999	-1	-1	1	1	1	-1	-1
8	0.384	-1	-1	-1	-1	1	1	1
CONTRAST		-1.027	-1.494	0.420	0.831	0.1	-1.3	0.1
SUM OF SQUARES		0.132	0.279	0.022	0.086	.0	0.2	.0
SSTOTAL		0.743						
MAIN EFFECT		-0.257	-0.373	0.105	0.208			

SOURCE	SS	DF	MS	F
FUEL	0.132	1	0.13	1.76
MOISTURE	0.279	1	0.28	3.73
LOAD	0.022	1	0.02	0.30
RATE	0.086	1	0.09	1.16
ERROR	0.224	3	0.07	
TOTAL	0.743	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR FLUORANTHENE (mg/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS 8	LOAD C	RATE D	AB CD	AC 8D	AD BC
1	0.118	1	1	1	1	1	1	1
2	0.050	1	1	-1	-1	1	-1	-1
9	0.096	1	-1	1	-1	-1	1	-1
4	1.323	1	-1	-1	1	-1	-1	1
5	0.391	-1	1	1	-1	-1	-1	1
6	0.520	-1	1	-1	1	-1	1	-1
7	1.719	-1	-1	1	1	1	-1	-1
8	0.311	-1	-1	-1	-1	1	1	1

CONTRAST	-1.354	-2.370	0.120	2.832	-0.1	-2.4	-0.2
SUM OF SQUARES	0.229	0.702	0.002	1.003	.0	0.7	.0
SSTOTAL	2.687						
MAIN EFFECT	-0.338	-0.592	0.030	0.708			

SOURCE	SS	DF	MS	F
FUEL	0.229	1	0.23	0.91
MOISTURE	0.702	1	0.70	2.80
LOAD	0.002	1	.00	0.01
RATE	1.003	1	1.00	4.00
ERROR	0.752	3	0.25	
TOTAL	2.687	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR CHRYSENE (mg/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.063	1	1	1	1	1	1	1
2	0.018	1	1	-1	-1	1	-1	-1
9	0.000	1	-1	1	-1	-1	1	-1
4	0.330	1	-1	-1	1	-1	-1	1
5	0.102	-1	1	1	-1	-1	-1	1
6	0.101	-1	1	-1	1	-1	1	-1
7	0.459	-1	-1	1	1	1	-1	-1
8	0.000	-1	-1	-1	-1	1	1	1

CONTRAST		-0.252	-0.504	0.176	0.833	.0	-0.7	-0.1
SUM OF SQUARES		0.008	0.032	0.004	0.087	.0	0.1	.0
SSTOTAL		0.201						
MAIN EFFECT		-0.063	-0.126	0.044	0.208			

SOURCE	SS	DF	MS	F
FUEL	0.008	1	0.01	0.34
MOISTURE	0.032	1	0.03	1.36
LOAD	0.004	1	.00	0.17
RATE	0.087	1	0.09	3.70
ERROR	0.070	3	0.02	
TOTAL	0.201	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR BENZO(b)FLUORANTHENE (mg/M^3 STP WET)

RUN NO	VALUE	FUEL	MOIS	LOAD	RATE	AB	AC	AD
		A	B	C	D	CD	BD	BC
1	0.000	1	1	1	1	1	1	1
2	0.004	1	1	-1	-1	1	-1	-1
9	0.000	1	-1	1	-1	-1	1	-1
4	0.361	1	-1	-1	1	-1	-1	1
5	0.000	-1	1	1	-1	-1	-1	1
6	0.133	-1	1	-1	1	-1	1	-1
7	0.445	-1	-1	1	1	1	-1	-1
8	0.000	-1	-1	-1	-1	1	1	1
CONTRAST		-0.213	-0.669	-0.053	0.935	.0	-0.7	-0.2
SUM OF SQUARES		0.006	0.056	.000	0.109	.0	0.1	.0
SSTOTAL		0.235						
MAIN EFFECT		-0.053	-0.167	-0.013	0.234			

SOURCE	SS	DF	MS	F
FUEL	0.006	1	0.01	0.27
MOISTURE	0.056	1	0.06	2.64
LOAD	.000	1	.00	0.02
RATE	0.109	1	0.11	5.15
ERROR	0.064	3	0.02	
TOTAL	0.235	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F([illegible],[illegible],3)=5.54

ANALYSIS OF VARIANCE (ANOVA) FOR BENZO(a)PYRENE (mg/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.000	1	1	1	1	1	1	1
2	0.002	1	1	-1	-1	1	-1	-1
9	0.000	1	-1	1	-1	-1	1	-1
4	0.205	1	-1	-1	1	-1	-1	1
5	0.031	-1	1	1	-1	-1	-1	1
6	0.052	-1	1	-1	1	-1	1	-1
7	0.232	-1	-1	1	1	1	-1	-1
8	0.000	-1	-1	-1	-1	1	1	1

CONTRAST	-0.108	-0.352	0.004	0.456	-0.1	-0.4	-0.1
SUM OF SQUARES	0.001	0.015	.000	0.026	.0	.0	.0
SSTOTAL	0.065						
MAIN EFFECT	-0.027	-0.088	0.001	0.114			

SOURCE	SS	DF	MS	F
FUEL	0.001	1	.00	0.19
MOISTURE	0.015	1	0.02	2.06
LOAD	.000	1	.00	.00
RATE	0.026	1	0.03	3.46
ERROR	0.022	3	0.01	
TOTAL	0.065	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR NAPHTHALENE (mg/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	337.747	1	1	1	1	1	1	1
2	56.020	1	1	-1	-1	1	-1	-1
9	260.710	1	-1	1	-1	-1	1	-1
4	1505.154	1	-1	-1	1	-1	-1	1
5	473.598	-1	1	1	-1	-1	-1	1
6	591.945	-1	1	-1	1	-1	1	-1
7	2094.676	-1	-1	1	1	1	-1	-1
8	280.918	-1	-1	-1	-1	1	1	1
CONTRAST		-1281.506	-2682.147	732.694	3458.275	-62.0	-2658.1	-405.9
SUM OF SQUARES		205282.197	899239.265	67104.983	1494957.817	481.2	883204.6	20597.9
SSTOTAL		3570868.024						
MAIN EFFECT		-320.376	-670.537	183.173	864.569			

SOURCE	SS	DF	MS	F
FUEL	205282.197	1	205282.20	0.68
MOISTURE	899239.265	1	899239.27	2.98
LOAD	67104.983	1	67104.98	0.22
RATE	1494957.817	1	1494957.82	4.96
ERROR	904283.763	3	301427.92	
TOTAL	3570868.024	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PHENANTHRENE (mg/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	56.111	1	1	1	1	1	1	1
2	7.624	1	1	-1	-1	1	-1	-1
9	22.398	1	-1	1	-1	-1	1	-1
4	206.176	1	-1	-1	1	-1	-1	1
5	93.021	-1	1	1	-1	-1	-1	1
6	109.980	-1	1	-1	1	-1	1	-1
7	348.952	-1	-1	1	1	1	-1	-1
8	54.086	-1	-1	-1	-1	1	1	1
CONTRAST		-313.729	-364.875	142.618	544.090	35.2	-413.2	-79.6
SUM OF SQUARES		12303.275	16641.766	2542.481	37004.293	154.9	21341.5	791.2
SSTOTAL		90779.379						
MAIN EFFECT		-78.432	-91.219	35.654	136.023			

SOURCE	SS	DF	MS	F
FUEL	12303.275	1	12303.27	1.66
MOISTURE	16641.766	1	16641.77	2.24
LOAD	2542.481	1	2542.48	0.34
RATE	37004.293	1	37004.29	4.98
ERROR	22287.565	3	7429.19	
TOTAL	90779.379	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR FLUORANTHENE (mg/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	10.791	1	1	1	1	1	1	1
2	1.499	1	1	-1	-1	1	-1	-1
9	2.635	1	-1	1	-1	-1	1	-1
4	70.339	1	-1	-1	1	-1	-1	1
5	18.779	-1	1	1	-1	-1	-1	1
6	41.560	-1	1	-1	1	-1	1	-1
7	116.746	-1	-1	1	1	1	-1	-1
8	7.926	-1	-1	-1	-1	1	1	1

CONTRAST	-99.747	-125.018	27.626	208.596	3.6	-144.5	-54.6
SUM OF SQUARES	1243.682	1953.680	95.401	5439.023	1.7	2608.3	372.7
SSTOTAL	11714.455						
MAIN EFFECT	-24.937	-31.254	6.907	52.149			

SOURCE	SS	DF	MS	F
FUEL	1243.682	1	1243.68	1.25
MOISTURE	1953.680	1	1953.68	1.97
LOAD	95.401	1	95.40	0.10
RATE	5439.023	1	5439.02	5.47
ERROR	2982.668	3	994.22	
TOTAL	11714.455	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PYRENE (mg/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	7.913	1	1	1	1	1	1	1
2	1.579	1	1	-1	-1	1	-1	-1
9	2.800	1	-1	1	-1	-1	1	-1
4	65.498	1	-1	-1	1	-1	-1	1
5	15.940	-1	1	1	-1	-1	-1	1
6	32.378	-1	1	-1	1	-1	1	-1
7	92.303	-1	-1	1	1	1	-1	-1
8	6.994	-1	-1	-1	-1	1	1	1
CONTRAST		-69.826	-109.785	12.508	170.780	-7.8	-125.2	-32.7
SUM OF SQUARES		609.465	1506.586	19.557	3645.736	7.7	1960.5	133.8
SSTOTAL		7883.262						
MAIN EFFECT		-17.457	-27.446	3.127	42.695			

SOURCE	SS	DF	MS	F
FUEL	609.465	1	609.47	0.87
MOISTURE	1506.586	1	1506.59	2.15
LOAD	19.557	1	19.56	0.03
RATE	3645.736	1	3645.74	5.20
ERROR	2101.918	3	700.64	
TOTAL	7883.262	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR CHRYSENE (mg/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	5.755	1	1	1	1	1	1	1
2	0.540	1	1	-1	-1	1	-1	-1
9	0.000	1	-1	1	-1	-1	1	-1
4	17.529	1	-1	-1	1	-1	-1	1
5	4.925	-1	1	1	-1	-1	-1	1
6	8.100	-1	1	-1	1	-1	1	-1
7	31.197	-1	-1	1	1	1	-1	-1
8	0.000	-1	-1	-1	-1	1	1	1

CONTRAST	-20.397	-29.405	15.707	57.116	6.9	-40.3	-11.6
SUM OF SQUARES	52.006	108.084	30.839	407.773	6.0	203.4	16.9
SSTOTAL	824.996						
MAIN EFFECT	-5.099	-7.351	3.927	14.279			

SOURCE	SS	DF	MS	F
FUEL	52.006	1	52.01	0.69
MOISTURE	108.084	1	108.08	1.43
LOAD	30.839	1	30.84	0.41
RATE	407.773	1	407.77	5.41
ERROR	226.294	3	75.43	
TOTAL	824.996	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR BENZO(B)FLUORANTHENE (mg/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.000	1	1	1	1	1	1	1
2	0.121	1	1	-1	-1	1	-1	-1
9	0.000	1	-1	1	-1	-1	1	-1
4	19.206	1	-1	-1	1	-1	-1	1
5	0.000	-1	1	1	-1	-1	-1	1
6	10.638	-1	1	-1	1	-1	1	-1
7	30.232	-1	-1	1	1	1	-1	-1
8	0.000	-1	-1	-1	-1	1	1	1
CONTRAST		-21.542	-38.679	0.266	59.955	0.5	-38.9	-21.8
SUM OF SQUARES		58.009	187.004	0.009	449.327	.0	189.4	59.3
SSTOTAL		943.062						
MAIN EFFECT		-5.386	-9.670	0.066	14.989			

SOURCE	SS	DF	MS	F
FUEL	58.009	1	58.01	0.70
MOISTURE	187.004	1	187.00	2.26
LOAD	0.009	1	0.01	.00
RATE	449.327	1	449.33	5.42
ERROR	248.713	3	82.90	
TOTAL	943.062	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR BENZO(a)PYRENE (mg/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.000	1	1	1	1	1	1	1
2	0.067	1	1	-1	-1	1	-1	-1
9	0.000	1	-1	1	-1	-1	1	-1
4	10.885	1	-1	-1	1	-1	-1	1
5	1.480	-1	1	1	-1	-1	-1	1
6	4.149	-1	1	-1	1	-1	1	-1
7	15.759	-1	-1	1	1	1	-1	-1
8	0.000	-1	-1	-1	-1	1	1	1
CONTRAST		-10.436	-20.947	2.138	29.246	-0.7	-24.0	-7.6
SUM OF SQUARES		13.615	54.847	0.571	106.914	0.1	72.3	7.2
SSTOTAL		255.499						
MAIN EFFECT		-2.609	-5.237	0.534	7.311			

SOURCE	SS	DF	MS	F
FUEL	13.615	1	13.61	0.51
MOISTURE	54.847	1	54.85	2.07
LOAD	0.571	1	0.57	0.02
RATE	106.914	1	106.91	4.03
ERROR	79.551	3	26.52	
TOTAL	255.499	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR ACENAPHTHYLENE (mg/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	3.697	1	1	1	1	1	1	1
2	2.142	1	1	-1	-1	1	-1	-1
9	5.110	1	-1	1	-1	-1	1	-1
4	22.855	1	-1	-1	1	-1	-1	1
5	46.707	-1	1	1	-1	-1	-1	1
6	9.634	-1	1	-1	1	-1	1	-1
7	52.223	-1	-1	1	1	1	-1	-1
8	23.248	-1	-1	-1	-1	1	1	1
CONTRAST		-98.009	-41.257	49.857	11.201	-3.0	-82.2	27.4
SUM OF SQUARES		1200.709	212.765	310.720	15.684	1.1	845.3	93.8
SSTOTAL		2680.177						
MAIN EFFECT		-24.502	-10.314	12.464	2.800			

SOURCE	SS	DF	MS	F
FUEL	1200.709	1	1200.71	3.83
MOISTURE	212.765	1	212.77	0.68
LOAD	310.720	1	310.72	0.99
RATE	15.684	1	15.68	0.05
ERROR	940.299	3	313.43	
TOTAL	2680.177	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) % Ca IN CARBON FREE ASH

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	30.003	1	1	1	1	1	1	1
2	29.360	1	1	-1	-1	1	-1	-1
9	30.556	1	-1	1	-1	-1	1	-1
4	27.451	1	-1	-1	1	-1	-1	1
5	12.098	-1	1	1	-1	-1	-1	1
6	11.361	-1	1	-1	1	-1	1	-1
7	10.394	-1	-1	1	1	1	-1	-1
8	11.088	-1	-1	-1	-1	1	1	1
CONTRAST		72.429	3.334	3.791	-3.892	-0.6	3.7	-1.0
SUM OF SQUARES		655.739	1.390	1.796	1.894	.0	1.7	0.1
SSTOTAL		662.716						
MAIN EFFECT		18.107	0.834	0.948	-0.973			

SOURCE	SS	DF	MS	F
FUEL	655.739	1	655.74	1037.27
MOISTURE	1.390	1	1.39	2.20
LOAD	1.796	1	1.80	2.84
RATE	. 1.894	1	1.89	3.00
ERROR	1.897	3	0.63	
TOTAL	662.716	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PHENANTHRENE (mg/kg WET WOOD)

RUN NO	VALUE	FUEL	MOIS	LOAD	RATE	AB	AC	AD
		A	B	C	D	CD	BD	BC
1	7.793	1	1	1	1	1	1	1
2	6.092	1	1	-1	-1	1	-1	-1
9	10.072	1	-1	1	-1	-1	1	-1
4	30.170	1	-1	-1	1	-1	-1	1
5	49.660	-1	1	1	-1	-1	-1	1
6	20.728	-1	1	-1	1	-1	1	-1
7	50.456	-1	-1	1	1	1	-1	-1
8	24.971	-1	-1	-1	-1	1	1	1
CONTRAST		-91.686	-31.395	36.019	18.353	-21.3	-72.8	25.2
SUM OF SQUARES		1050.790	123.206	162.173	42.102	56.8	662.7	79.7
SSTOTAL		2177.481						
MAIN EFFECT		-22.921	-7.849	9.005	4.588			

SOURCE	SS	DF	MS	F
FUEL	1050.790	1	1050.79	3.94
MOISTURE	123.206	1	123.21	0.46
LOAD	162.173	1	162.17	0.61
RATE	42.102	1	42.10	0.16
ERROR	799.210	3	266.40	
TOTAL	2177.481	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR ANTHRACENE (mg/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.849	1	1	1	1	1	1	1
2	1.349	1	1	-1	-1	1	-1	-1
9	2.074	1	-1	1	-1	-1	1	-1
4	4.917	1	-1	-1	1	-1	-1	1
5	10.582	-1	1	1	-1	-1	-1	1
6	2.321	-1	1	-1	1	-1	1	-1
7	9.812	-1	-1	1	1	1	-1	-1
8	4.521	-1	-1	-1	-1	1	1	1

CONTRAST	-18.047	-6.222	10.210	-0.625	-3.4	-16.9	5.3
SUM OF SQUARES	40.712	4.840	13.030	0.049	1.4	35.7	3.5
SSTOTAL	99.257						
MAIN EFFECT	-4.512	-1.556	2.552	-0.156			

SOURCE	SS	DF	MS	F
FUEL	40.712	1	40.71	3.01
MOISTURE	4.840	1	4.84	0.36
LOAD	13.030	1	13.03	0.96
RATE	0.049	1	0.05	.00
ERROR	40.626	3	13.54	
TOTAL	99.257	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR NAPHTHALENE (mg/kg DRY WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	8.014	1	1	1	1	1	1	1
2	44.048	1	1	-1	-1	1	-1	-1
3	80.983	1	-1	1	-1	-1	1	-1
4	49.509	1	-1	-1	1	-1	-1	1
5	158.982	-1	1	1	-1	-1	-1	1
6	24.767	-1	1	-1	1	-1	1	-1
7	64.025	-1	-1	1	1	1	-1	-1
8	87.542	-1	-1	-1	-1	1	1	1
CONTRAST		-152.762	-46.249	106.137	-225.240	-110.6	-115.3	90.2
SUM OF SQUARES		2917.017	267.371	1408.144	6341.642	1529.4	1660.5	1017.6
SSTOTAL		15141.667						
MAIN EFFECT		-38.190	-11.562	26.534	-56.310			

SOURCE	SS	DF	MS	F
FUEL	2917.017	1	2917.02	2.08
MOISTURE	267.371	1	267.37	0.19
LOAD	1408.144	1	1408.14	1.00
RATE	6341.642	1	6341.64	4.52
ERROR	4207.494	3	1402.50	
TOTAL	15141.667	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PHENANTHRENE (mg/kg DRY WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	1.331	1	1	1	1	1	1	1
2	5.988	1	1	-1	-1	1	-1	-1
3	6.958	1	-1	1	-1	-1	1	-1
4	6.782	1	-1	-1	1	-1	-1	1
5	31.226	-1	1	1	-1	-1	-1	1
6	4.602	-1	1	-1	1	-1	1	-1
7	10.666	-1	-1	1	1	1	-1	-1
8	16.855	-1	-1	-1	-1	1	1	1

CONTRAST		-42.289	1.888	15.955	-37.646	-14.7	-24.9	28.0
SUM OF SQUARES		223.547	0.446	31.818	177.155	27.1	77.6	97.9
SSTOTAL		635.549						
MAIN EFFECT		-10.572	0.472	3.989	-9.412			

SOURCE	SS	DF	MS	F
FUEL	223.547	1	223.55	3.31
MOISTURE	0.446	1	0.45	0.01
LOAD	31.818	1	31.82	0.47
RATE	177.155	1	177.15	2.62
ERROR	202.583	3	67.53	
TOTAL	635.549	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR BENZO(b)FLUORANTHENE (mg/kg DRY WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.000	1	1	1	1	1	1	1
2	0.095	1	1	-1	-1	1	-1	-1
9	0.000	1	-1	1	-1	-1	1	-1
4	0.632	1	-1	-1	1	-1	-1	1
5	0.000	-1	1	1	-1	-1	-1	1
6	0.445	-1	1	-1	1	-1	1	-1
7	0.924	-1	-1	1	1	1	-1	-1
8	0.000	-1	-1	-1	-1	1	1	1
CONTRAST		-0.642	-1.015	-0.248	1.906	-0.1	-1.2	-0.8
SUM OF SQUARES		0.052	0.129	0.008	0.454	.0	0.2	0.1
SSTOTAL		0.911						
MAIN EFFECT		-0.161	-0.254	-0.062	0.476			

SOURCE	SS	DF	MS	F
FUEL	0.052	1	0.05	0.58
MOISTURE	0.129	1	0.13	1.44
LOAD	0.008	1	0.01	0.09
RATE	0.454	1	0.45	5.06
ERROR	0.269	3	0.09	
TOTAL	0.911	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) % Al IN CARBON FREE ASH

RUN NO	VALUE	FUEL	MOIS	LOAD	RATE	AB	AC	AD
		A	B	C	D	CD	BD	BC
1	0.219	1	1	1	1	1	1	1
2	0.091	1	1	-1	-1	1	-1	-1
9	0.000	1	-1	1	-1	-1	1	-1
4	0.182	1	-1	-1	1	-1	-1	1
5	0.454	-1	1	1	-1	-1	-1	1
6	0.294	-1	1	-1	1	-1	1	-1
7	0.190	-1	-1	1	1	1	-1	-1
8	0.183	-1	-1	-1	-1	1	1	1

CONTRAST	-0.630	0.504	0.114	0.156	-0.2	-0.2	0.5
SUM OF SQUARES	0.050	0.032	0.002	0.003	.0	.0	.0
SSTOTAL	0.126						
MAIN EFFECT	-0.158	0.126	0.028	0.039			

SOURCE	SS	DF	MS	F
FUEL	0.050	1	0.05	3.68
MOISTURE	0.032	1	0.03	2.35
LOAD	0.002	1	.00	0.12
RATE	0.003	1	.00	0.23
ERROR	0.040	3	0.01	
TOTAL	0.126	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) % Ba IN CARBON FREE ASH

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.269	1	1	1	1	1	1	1
2	0.256	1	1	-1	-1	1	-1	-1
9	0.189	1	-1	1	-1	-1	1	-1
4	0.173	1	-1	-1	1	-1	-1	1
5	0.189	-1	1	1	-1	-1	-1	1
6	0.249	-1	1	-1	1	-1	1	-1
7	0.071	-1	-1	1	1	1	-1	-1
8	0.119	-1	-1	-1	-1	1	1	1
CONTRAST		0.260	0.411	-0.079	0.008	-0.1	0.1	.0
SUM OF SQUARES		0.008	0.021	0.001	.000	.0	.0	.0
SSTOTAL		0.034						
MAIN EFFECT		0.065	0.103	-0.020	0.002			

SOURCE	SS	DF	MS	F
FUEL	0.008	1	0.01	7.68
MOISTURE	0.021	1	0.02	19.29
LOAD	0.001	1	.00	0.71
RATE	.000	1	.00	0.01
ERROR	0.003	3	.00	
TOTAL	0.034	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) % Ca IN CARBON FREE ASH

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	30.003	1	1	1	1	1	1	1
2	29.360	1	1	-1	-1	1	-1	-1
9	30.556	1	-1	1	-1	-1	1	-1
4	27.451	1	-1	-1	1	-1	-1	1
5	12.098	-1	1	1	-1	-1	-1	1
6	11.361	-1	1	-1	1	-1	1	-1
7	10.394	-1	-1	1	1	1	-1	-1
8	11.088	-1	-1	-1	-1	1	1	1
CONTRAST		72.429	3.334	3.791	-3.892	-0.6	3.7	-1.0
SUM OF SQUARES		655.739	1.390	1.796	1.894	.0	1.7	0.1
SSTOTAL		662.716						
MAIN EFFECT		18.107	0.834	0.948	-0.973			

SOURCE	SS	DF	MS	F
FUEL	655.739	1	655.74	1037.27
MOISTURE	1.390	1	1.39	2.20
LOAD	1.796	1	1.80	2.84
RATE	1.894	1	1.89	3.00
ERROR	1.897	3	0.63	
TOTAL	662.716	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) % Fe IN CARBON FREE ASH

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.075	1	1	1	1	1	1	1
2	0.081	1	1	-1	-1	1	-1	-1
9	0.074	1	-1	1	-1	-1	1	-1
4	0.019	1	-1	-1	1	-1	-1	1
5	0.217	-1	1	1	-1	-1	-1	1
6	0.111	-1	1	-1	1	-1	1	-1
7	0.043	-1	-1	1	1	1	-1	-1
8	0.058	-1	-1	-1	-1	1	1	1
CONTRAST		-0.181	0.289	0.140	-0.182	-0.2	.0	0.1
SUM OF SQUARES		0.004	0.010	0.002	0.004	.0	.0	.0
SSTOTAL		0.025						
MAIN EFFECT		-0.045	0.072	0.035	-0.045			

SOURCE	SS	DF	MS	F
FUEL	0.004	1	.00	2.98
MOISTURE	0.010	1	0.01	7.63
LOAD	0.002	1	.00	1.79
RATE	0.004	1	.00	3.02
ERROR	0.004	3	.00	
TOTAL	0.025	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) % Mg IN CARBON FREE ASH

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	1.930	1	1	1	1	1	1	1
2	1.870	1	1	-1	-1	1	-1	-1
9	1.597	1	-1	1	-1	-1	1	-1
4	1.434	1	-1	-1	1	-1	-1	1
5	3.959	-1	1	1	-1	-1	-1	1
6	3.782	-1	1	-1	1	-1	1	-1
7	2.533	-1	-1	1	1	1	-1	-1
8	3.410	-1	-1	-1	-1	1	1	1
CONTRAST		-6.853	2.566	-0.476	-1.158	-1.0	0.9	1.0
SUM OF SQUARES		5.870	0.823	0.028	0.168	0.1	0.1	0.1
SSTOTAL		7.241						
MAIN EFFECT		-1.713	0.642	-0.119	-0.289			

SOURCE	SS	DF	MS	F
FUEL	5.870	1	5.87	50.07
MOISTURE	0.823	1	0.82	7.02
LOAD	0.028	1	0.03	0.24
RATE	0.168	1	0.17	1.43
ERROR	0.352	3	0.12	
TOTAL	7.241	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) % Mn IN CARBON FREE ASH

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.840	1	1	1	1	1	1	1
2	0.794	1	1	-1	-1	1	-1	-1
9	1.190	1	-1	1	-1	-1	1	-1
4	0.961	1	-1	-1	1	-1	-1	1
5	2.428	-1	1	1	-1	-1	-1	1
6	2.810	-1	1	-1	1	-1	1	-1
7	1.630	-1	-1	1	1	1	-1	-1
8	1.810	-1	-1	-1	-1	1	1	1
CONTRAST		-4.892	1.281	-0.286	0.020	-2.3	0.8	-0.4
SUM OF SQUARES		2.992	0.205	0.010	.000	0.7	0.1	.0
SSTOTAL		3.984						
MAIN EFFECT		-1.223	0.320	-0.072	0.005			

SOURCE	SS	DF	MS	F
FUEL	2.992	1	2.99	11.56
MOISTURE	0.205	1	0.21	0.79
LOAD	0.010	1	0.01	0.04
RATE	.000	1	.00	.00
ERROR	0.776	3	0.26	
TOTAL	3.984	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) % Sr IN CARBON FREE ASH

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.326	1	1	1	1	1	1	1
2	0.332	1	1	-1	-1	1	-1	-1
9	0.165	1	-1	1	-1	-1	1	-1
4	0.165	1	-1	-1	1	-1	-1	1
5	0.102	-1	1	1	-1	-1	-1	1
6	0.108	-1	1	-1	1	-1	1	-1
7	0.044	-1	-1	1	1	1	-1	-1
8	0.063	-1	-1	-1	-1	1	1	1
CONTRAST		0.670	0.431	-0.031	-0.020	0.2	.0	.0
SUM OF SQUARES		0.056	0.023	.000	.000	.0	.0	.0
SSTOTAL		0.086						
MAIN EFFECT		0.168	0.108	-0.008	-0.005			

SOURCE	SS	DF	MS	F
FUEL	0.056	1	0.06	26.39
MOISTURE	0.023	1	0.02	10.92
LOAD	.000	1	.00	0.06
RATE	.000	1	.00	0.02
ERROR	0.006	3	.00	
TOTAL	0.086	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) % Zn IN CARBON FREE ASH

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.039	1	1	1	1	1	1	1
2	0.000	1	1	-1	-1	1	-1	-1
9	0.047	1	-1	1	-1	-1	1	-1
4	0.000	1	-1	-1	1	-1	-1	1
5	0.144	-1	1	1	-1	-1	-1	1
6	0.104	-1	1	-1	1	-1	1	-1
7	0.093	-1	-1	1	1	1	-1	-1
8	0.109	-1	-1	-1	-1	1	1	1
CONTRAST		-0.364	0.039	0.110	-0.063	-0.1	0.1	.0
SUM OF SQUARES		0.017	.000	0.001	0.001	.0	.0	.0
SSTOTAL		0.020						
MAIN EFFECT		-0.091	0.010	0.027	-0.016			

SOURCE	SS	DF	MS	F
FUEL	0.017	1	0.02	43.31
MOISTURE	.000	1	.00	0.49
LOAD	0.001	1	.00	3.93
RATE	0.001	1	.00	1.32
ERROR	0.001	3	.00	
TOTAL	0.020	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) Fe/K RATIO IN CARBON FREE ASH

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.010	1	1	1	1	1	1	1
2	0.010	1	1	-1	-1	1	-1	-1
9	0.007	1	-1	1	-1	-1	1	-1
4	0.003	1	-1	-1	1	-1	-1	1
5	0.030	-1	1	1	-1	-1	-1	1
6	0.017	-1	1	-1	1	-1	1	-1
7	0.007	-1	-1	1	1	1	-1	-1
8	0.009	-1	-1	-1	-1	1	1	1
CONTRAST		-0.033	0.041	0.016	-0.019	.0	.0	.0
SUM OF SQUARES		.000	.000	.000	.000	.0	.0	.0
SSTOTAL		.000						
MAIN EFFECT		-0.008	0.010	0.004	-0.005			

SOURCE	SS	DF	MS	F
FUEL	.000	1	.00	6.42
MOISTURE	.000	1	.00	9.58
LOAD	.000	1	.00	1.45
RATE	.000	1	.00	1.97
ERROR	.000	3	.00	
TOTAL	.000	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE Cd (mg/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.000	1	1	1	1	1	1	1
2	0.000	1	1	-1	-1	1	-1	-1
9	4.716	1	-1	1	-1	-1	1	-1
4	10.669	1	-1	-1	1	-1	-1	1
5	0.000	-1	1	1	-1	-1	-1	1
6	2.336	-1	1	-1	1	-1	1	-1
7	3.929	-1	-1	1	1	1	-1	-1
8	2.532	-1	-1	-1	-1	1	1	1
CONTRAST		6.588	-19.510	-6.891	9.686	-11.3	-5.0	2.2
SUM OF SQUARES		5.426	47.579	5.936	11.728	15.8	3.1	0.6
SSTOTAL		90.275						
MAIN EFFECT		1.647	-4.877	-1.723	2.422			

SOURCE	SS	DF	MS	F
FUEL	5.426	1	5.43	0.83
MOISTURE	47.579	1	47.58	7.28
LOAD	5.936	1	5.94	0.91
RATE	11.728	1	11.73	1.79
ERROR	19.607	3	6.54	
TOTAL	90.275	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE K (mg/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	2511.251	1	1	1	1	1	1	1
2	1163.680	1	1	-1	-1	1	-1	-1
9	1432.208	1	-1	1	-1	-1	1	-1
4	4658.034	1	-1	-1	1	-1	-1	1
5	0.000	-1	1	1	-1	-1	-1	1
6	594.916	-1	1	-1	1	-1	1	-1
7	1378.886	-1	-1	1	1	1	-1	-1
8	379.742	-1	-1	-1	-1	1	1	1

CONTRAST	7411.630	-3579.021	-1474.026	6167.458	-1251.6	-2282.5	2979.3
SUM OF SQUARES	6866531.940	1601174.210	271594.154	4754691.510	195812.3	651216.1	1109555.4
SSTOTAL	15450575.571						
MAIN EFFECT	1852.907	-894.755	-368.507	1541.864			

SOURCE	SS	DF	MS	F
FUEL	6866531.940	1	6866531.94	10.53
MOISTURE	1601174.210	1	1601174.21	2.46
LOAD	271594.154	1	271594.15	0.42
RATE	4754691.510	1	4754691.51	7.29
ERROR	1956583.757	3	652194.59	
TOTAL	15450575.571	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE Mn (mg/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	5.869	1	1	1	1	1	1	1
2	2.203	1	1	-1	-1	1	-1	-1
9	3.957	1	-1	1	-1	-1	1	-1
4	12.279	1	-1	-1	1	-1	-1	1
5	16.858	-1	1	1	-1	-1	-1	1
6	33.639	-1	1	-1	1	-1	1	-1
7	22.531	-1	-1	1	1	1	-1	-1
8	15.362	-1	-1	-1	-1	1	1	1
CONTRAST		-64.082	4.440	-14.268	35.938	-20.8	5.0	-12.0
SUM OF SQUARES		513.307	2.464	25.448	161.444	53.9	3.1	17.9
SSTOTAL		777.533						
MAIN EFFECT		-16.020	1.110	-3.567	8.985			

SOURCE	SS	DF	MS	F
FUEL	513.307	1	513.31	20.57
MOISTURE	2.464	1	2.46	0.10
LOAD	25.448	1	25.45	1.02
RATE	161.444	1	161.44	6.47
ERROR	74.870	3	24.96	
TOTAL	777.533	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE S (mg/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS 8	LOAD C	RATE D	AB CD	AC 8D	AD BC
1	851.516	1	1	1	1	1	1	1
2	381.738	1	1	-1	-1	1	-1	-1
9	267.794	1	-1	1	-1	-1	1	-1
4	1896.897	1	-1	-1	1	-1	-1	1
5	0.000	-1	1	1	-1	-1	-1	1
6	274.409	-1	1	-1	1	-1	1	-1
7	1096.478	-1	-1	1	1	1	-1	-1
8	0.000	-1	-1	-1	-1	1	1	1

CONTRAST	2027.058	-1753.506	-337.256	3469.770	-109.4	-1981.4	728.0
SUM OF SQUARES	513620.367	384348.021	14217.684	1504912.610	1495.2	490740.6	66247.0
SSTOTAL	2975581.512						
MAIN EFFECT	506.764	-438.377	-84.314	867.442			

SOURCE	SS	DF	MS	F
FUEL	513620.367	1	513620.37	2.76
MOISTURE	384348.021	1	384348.02	2.06
LOAD	14217.684	1	14217.68	0.08
RATE	1504912.610	1	1504912.61	8.08
ERROR	558482.831	3	186160.94	
TOTAL	2975581.512	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE Zn (mg/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.000	1	1	1	1	1	1	1
2	0.000	1	1	-1	-1	1	-1	-1
9	0.000	1	-1	1	-1	-1	1	-1
4	129.837	1	-1	-1	1	-1	-1	1
5	62.527	-1	1	1	-1	-1	-1	1
6	259.770	-1	1	-1	1	-1	1	-1
7	330.785	-1	-1	1	1	1	-1	-1
8	22.497	-1	-1	-1	-1	1	1	1

CONTRAST	-545.742	-160.822	-18.791	635.368	-98.9	-240.9	-375.7
SUM OF SQUARES	37229.295	3232.974	44.137	50461.559	1221.5	7253.1	17643.2
SSTOTAL	117085.749						
MAIN EFFECT	-136.436	-40.206	-4.698	158.842			

SOURCE	SS	DF	MS	F
FUEL	37229.295	1	37229.30	4.28
MOISTURE	3232.974	1	3232.97	0.37
LOAD	44.137	1	44.14	0.01
RATE	50461.559	1	50461.56	5.80
ERROR	26117.783	3	8705.93	
TOTAL	117085.749	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE Cd (mg/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.000	1	1	1	1	1	1	1
2	0.000	1	1	-1	-1	1	-1	-1
9	0.129	1	-1	1	-1	-1	1	-1
4	0.567	1	-1	-1	1	-1	-1	1
5	0.000	-1	1	1	-1	-1	-1	1
6	0.187	-1	1	-1	1	-1	1	-1
7	0.267	-1	-1	1	1	1	-1	-1
8	0.064	-1	-1	-1	-1	1	1	1

CONTRAST	0.179	-0.841	-0.422	0.827	-0.6	-0.5	.0
SUM OF SQUARES	0.004	0.089	0.022	0.085	.0	.0	.0
SSTOTAL	0.264						
MAIN EFFECT	0.045	-0.210	-0.106	0.207			

SOURCE	SS	DF	MS	F
FUEL	0.004	1	.00	0.19
MOISTURE	0.089	1	0.09	4.14
LOAD	0.022	1	0.02	1.04
RATE	0.085	1	0.09	4.00
ERROR	0.064	3	0.02	
TOTAL	0.264	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE K (mg/hr)

RUN NO	VALUE	FUEL	MOIS	LOAD	RATE	AB	AC	AD
		A	B	C	D	CD	BD	BC
1	228.829	1	1	1	1	1	1	1
2	26.566	1	1	-1	-1	1	-1	-1
9	39.301	1	-1	1	-1	-1	1	-1
4	247.731	1	-1	-1	1	-1	-1	1
5	0.000	-1	1	1	-1	-1	-1	1
6	47.544	-1	1	-1	1	-1	1	-1
7	93.637	-1	-1	1	1	1	-1	-1
8	9.671	-1	-1	-1	-1	1	1	1

CONTRAST	391.575	-87.402	30.255	542.203	24.1	-42.6	279.2
SUM OF SQUARES	19166.360	954.898	114.418	36748.005	72.8	226.7	9742.9
SSTOTAL	67026.062						
MAIN EFFECT	97.894	-21.851	7.564	135.551			

SOURCE	SS	DF	MS	F
FUEL	19166.360	1	19166.36	5.73
MOISTURE	954.898	1	954.90	0.29
LOAD	114.418	1	114.42	0.03
RATE	36748.005	1	36748.00	10.98
ERROR	10042.380	3	3347.46	
TOTAL	67026.062	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE Mn (mg/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.535	1	1	1	1	1	1	1
2	0.051	1	1	-1	-1	1	-1	-1
9	0.109	1	-1	1	-1	-1	1	-1
4	0.653	1	-1	-1	1	-1	-1	1
5	0.811	-1	1	1	-1	-1	-1	1
6	2.688	-1	1	-1	1	-1	1	-1
7	1.530	-1	-1	1	1	1	-1	-1
8	0.391	-1	-1	-1	-1	1	1	1
CONTRAST		-4.073	1.402	-0.800	4.045	-1.8	0.7	-2.0
SUM OF SQUARES		2.073	0.246	0.080	2.045	0.4	0.1	0.5
SSTOTAL		5.380						
MAIN EFFECT		-1.018	0.350	-0.200	1.011			

SOURCE	SS	DF	MS	F
FUEL	2.073	1	2.07	6.64
MOISTURE	0.246	1	0.25	0.79
LOAD	0.080	1	0.08	0.26
RATE	2.045	1	2.04	6.55
ERROR	0.936	3	0.31	
TOTAL	5.380	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE S (mg/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	77.591	1	1	1	1	1	1	1
2	8.803	1	1	-1	-1	1	-1	-1
9	7.349	1	-1	1	-1	-1	1	-1
4	100.884	1	-1	-1	1	-1	-1	1
5	0.000	-1	1	1	-1	-1	-1	1
6	21.930	-1	1	-1	1	-1	1	-1
7	74.460	-1	-1	1	1	1	-1	-1
8	0.000	-1	-1	-1	-1	1	1	1

CONTRAST	98.237	-74.368	27.783	258.714	30.7	-77.3	65.9
SUM OF SQUARES	1206.315	691.325	96.486	8366.602	117.7	746.5	543.4
SSTOTAL	11768.350						
MAIN EFFECT	24.559	-18.592	6.946	64.678			

SOURCE	SS	DF	MS	F
FUEL	1206.315	1	1206.32	2.57
MOISTURE	691.325	1	691.33	1.47
LOAD	96.486	1	96.49	0.21
RATE	8366.602	1	8366.60	17.83
ERROR	1407.622	3	469.21	
TOTAL	11768.350	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE Zn (mg/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.000	1	1	1	1	1	1	1
2	0.000	1	1	-1	-1	1	-1	-1
9	0.000	1	-1	1	-1	-1	1	-1
4	6.905	1	-1	-1	1	-1	-1	1
5	3.006	-1	1	1	-1	-1	-1	1
6	20.760	-1	1	-1	1	-1	1	-1
7	22.463	-1	-1	1	1	1	-1	-1
8	0.573	-1	-1	-1	-1	1	1	1

CONTRAST	-39.897	-6.175	-2.769	46.549	-7.6	-11.0	-32.7
SUM OF SQUARES	198.973	4.766	0.958	270.851	7.3	15.2	134.0
SSTOTAL	632.051						
MAIN EFFECT	-9.974	-1.544	-0.692	11.637			

SOURCE	SS	DF	MS	F
FUEL	198.973	1	198.97	3.81
MOISTURE	4.766	1	4.77	0.09
LOAD	0.958	1	0.96	0.02
RATE	270.851	1	270.85	5.19
ERROR	156.504	3	52.17	
TOTAL	632.051	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE Cd (mg/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.000	1	1	1	1	1	1	1
2	0.000	1	1	-1	-1	1	-1	-1
9	0.058	1	-1	1	-1	-1	1	-1
4	0.083	1	-1	-1	1	-1	-1	1
5	0.000	-1	1	1	-1	-1	-1	1
6	0.035	-1	1	-1	1	-1	1	-1
7	0.039	-1	-1	1	1	1	-1	-1
8	0.030	-1	-1	-1	-1	1	1	1
CONTRAST		0.038	-0.174	-0.051	0.069	-0.1	.0	.0
SUM OF SQUARES		.000	0.004	.000	0.001	.0	.0	.0
SSTOTAL		0.006						
MAIN EFFECT		0.009	-0.044	-0.013	0.017			

SOURCE	SS	DF	MS	F
FUEL	.000	1	.00	0.35
MOISTURE	0.004	1	.00	7.57
LOAD	.000	1	.00	0.65
RATE	0.001	1	.00	1.18
ERROR	0.002	3	.00	
TOTAL	0.006	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE K (mg/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	31.782	1	1	1	1	1	1	1
2	21.329	1	1	-1	-1	1	-1	-1
9	17.673	1	-1	1	-1	-1	1	-1
4	36.251	1	-1	-1	1	-1	-1	1
5	0.000	-1	1	1	-1	-1	-1	1
6	8.961	-1	1	-1	1	-1	1	-1
7	13.539	-1	-1	1	1	1	-1	-1
8	4.465	-1	-1	-1	-1	1	1	1
CONTRAST		80.071	-9.857	-8.012	47.065	8.2	-8.2	11.0
SUM OF SQUARES		801.411	12.145	8.025	276.895	8.5	8.5	15.1
SSTOTAL		1130.541						
MAIN EFFECT		20.018	-2.464	-2.003	11.766			

SOURCE	SS	DF	MS	F
FUEL	801.411	1	801.41	74.98
MOISTURE	12.145	1	12.15	1.14
LOAD	8.025	1	8.02	0.75
RATE	276.895	1	276.89	25.91
ERROR	32.065	3	10.69	
TOTAL	1130.541	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE Mn (mg/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.074	1	1	1	1	1	1	1
2	0.041	1	1	-1	-1	1	-1	-1
9	0.049	1	-1	1	-1	-1	1	-1
4	0.096	1	-1	-1	1	-1	-1	1
5	0.433	-1	1	1	-1	-1	-1	1
6	0.507	-1	1	-1	1	-1	1	-1
7	0.221	-1	-1	1	1	1	-1	-1
8	0.181	-1	-1	-1	-1	1	1	1
CONTRAST		-1.081	0.509	-0.047	0.194	-0.6	.0	.0
SUM OF SQUARES		0.146	0.032	.000	0.005	.0	.0	.0
SSTOTAL		0.224						
MAIN EFFECT		-0.270	0.127	-0.012	0.049			

SOURCE	SS	DF	MS	F
FUEL	0.146	1	0.15	10.88
MOISTURE	0.032	1	0.03	2.41
LOAD	.000	1	.00	0.02
RATE	0.005	1	.00	0.35
ERROR	0.040	3	0.01	
TOTAL	0.224	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE S (mg/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	10.777	1	1	1	1	1	1	1
2	7.066	1	1	-1	-1	1	-1	-1
9	3.305	1	-1	1	-1	-1	1	-1
4	14.763	1	-1	-1	1	-1	-1	1
5	0.000	-1	1	1	-1	-1	-1	1
6	4.133	-1	1	-1	1	-1	1	-1
7	10.766	-1	-1	1	1	1	-1	-1
8	0.000	-1	-1	-1	-1	1	1	1
CONTRAST		21.011	-6.857	-1.115	30.068	6.4	-14.4	0.3
SUM OF SQUARES		55.180	5.878	0.155	113.011	5.1	25.9	.0
SSTOTAL		205.218						
MAIN EFFECT		5.253	-1.714	-0.279	7.517			

SOURCE	SS	DF	MS	F
FUEL	55.180	1	55.18	5.34
MOISTURE	5.878	1	5.88	0.57
LOAD	0.155	1	0.16	0.02
RATE	113.011	1	113.01	10.94
ERROR	30.994	3	10.33	
TOTAL	205.218	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE Zn (mg/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.000	1	1	1	1	1	1	1
2	0.000	1	1	-1	-1	1	-1	-1
9	0.000	1	-1	1	-1	-1	1	-1
4	1.010	1	-1	-1	1	-1	-1	1
5	1.605	-1	1	1	-1	-1	-1	1
6	3.913	-1	1	-1	1	-1	1	-1
7	3.248	-1	-1	1	1	1	-1	-1
8	0.265	-1	-1	-1	-1	1	1	1
CONTRAST		-8.020	0.995	-0.335	6.302	-3.0	-1.7	-4.3
SUM OF SQUARES		8.039	0.124	0.014	4.964	1.1	0.4	2.3
SSTOTAL		16.924						
MAIN EFFECT		-2.005	0.249	-0.084	1.575			

SOURCE	SS	DF	MS	F
FUEL	8.039	1	8.04	6.38
MOISTURE	0.124	1	0.12	0.10
LOAD	0.014	1	0.01	0.01
RATE	4.964	1	4.96	3.94
ERROR	3.783	3	1.26	
TOTAL	16.924	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE Ba (mg/kg DRY WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.000	1	1	1	1	1	1	1
2	0.000	1	1	-1	-1	1	-1	-1
3	0.034	1	-1	1	-1	-1	1	-1
4	0.008	1	-1	-1	1	-1	-1	1
5	0.076	-1	1	1	-1	-1	-1	1
6	0.000	-1	1	-1	1	-1	1	-1
7	0.000	-1	-1	1	1	1	-1	-1
8	0.035	-1	-1	-1	-1	1	1	1
CONTRAST		-0.070	.000	0.067	-0.137	-0.1	.0	0.1
SUM OF SQUARES		0.001	.000	0.001	0.002	.0	.0	.0
SSTOTAL		0.005						
MAIN EFFECT		-0.017	.000	0.017	-0.034			

SOURCE	SS	DF	MS	F
FUEL	0.001	1	.00	1.02
MOISTURE	.000	1	.00	.00
LOAD	0.001	1	.00	0.95
RATE	0.002	1	.00	3.96
ERROR	0.002	3	.00	
TOTAL	0.005	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE Cd (mg/kg DRY WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.000	1	1	1	1	1	1	1
2	0.000	1	1	-1	-1	1	-1	-1
9	0.040	1	-1	1	-1	-1	1	-1
4	0.019	1	-1	-1	1	-1	-1	1
5	0.000	-1	1	1	-1	-1	-1	1
6	0.008	-1	1	-1	1	-1	1	-1
7	0.008	-1	-1	1	1	1	-1	-1
8	0.020	-1	-1	-1	-1	1	1	1
CONTRAST		0.023	-0.079	0.002	-0.026	.0	.0	.0
SUM OF SQUARES		.000	0.001	.000	.000	.0	.0	.0
SSTOTAL		0.001						
MAIN EFFECT		0.006	-0.020	.000	-0.006			

SOURCE	SS	DF	MS	F
FUEL	.000	1	.00	0.45
MOISTURE	0.001	1	.00	5.41
LOAD	.000	1	.00	.00
RATE	.000	1	.00	0.57
ERROR	.000	3	.00	
TOTAL	0.001	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE K (mg/kg DRY WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	5.429	1	1	1	1	1	1	1
2	21.064	1	1	-1	-1	1	-1	-1
9	12.208	1	-1	1	-1	-1	1	-1
4	8.149	1	-1	-1	1	-1	-1	1
5	0.000	-1	1	1	-1	-1	-1	1
6	1.989	-1	1	-1	1	-1	1	-1
7	2.862	-1	-1	1	1	1	-1	-1
8	3.014	-1	-1	-1	-1	1	1	1

	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
CONTRAST	38.985	2.250	-13.716	-17.857	10.0	-9.4	-21.5
SUM OF SQUARES	189.979	0.633	23.518	39.857	12.6	11.1	58.0
SSTOTAL	335.621						
MAIN EFFECT	9.746	0.563	-3.429	-4.464			

SOURCE	SS	DF	MS	F
FUEL	189.979	1	189.98	6.98
MOISTURE	0.633	1	0.63	0.02
LOAD	23.518	1	23.52	0.86
RATE	39.857	1	39.86	1.46
ERROR	81.635	3	27.21	
TOTAL	335.621	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE Mn (mg/kg DRY WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.013	1	1	1	1	1	1	1
2	0.041	1	1	-1	-1	1	-1	-1
9	0.034	1	-1	1	-1	-1	1	-1
4	0.021	1	-1	-1	1	-1	-1	1
5	0.272	-1	1	1	-1	-1	-1	1
6	0.112	-1	1	-1	1	-1	1	-1
7	0.047	-1	-1	1	1	1	-1	-1
8	0.122	-1	-1	-1	-1	1	1	1
CONTRAST		-0.445	0.214	0.069	-0.275	-0.2	-0.1	0.2
SUM OF SQUARES		0.025	0.006	0.001	0.009	.0	.0	.0
SSTOTAL		0.052						
MAIN EFFECT		-0.111	0.053	0.017	-0.069			

SOURCE	SS	DF	MS	F
FUEL	0.025	1	0.02	6.22
MOISTURE	0.006	1	0.01	1.44
LOAD	0.001	1	.00	0.15
RATE	0.009	1	0.01	2.38
ERROR	0.012	3	.00	
TOTAL	0.052	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE Zn (mg/kg DRY WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.000	1	1	1	1	1	1	1
2	0.000	1	1	-1	-1	1	-1	-1
9	0.000	1	-1	1	-1	-1	1	-1
4	0.227	1	-1	-1	1	-1	-1	1
5	1.009	-1	1	1	-1	-1	-1	1
6	0.869	-1	1	-1	1	-1	1	-1
7	0.687	-1	-1	1	1	1	-1	-1
8	0.179	-1	-1	-1	-1	1	1	1
CONTRAST		-2.516	0.786	0.422	0.595	-1.2	-0.9	-0.1
SUM OF SQUARES		0.791	0.077	0.022	0.044	0.2	0.1	.0
SSTOTAL		1.225						
MAIN EFFECT		-0.629	0.196	0.105	0.149			

SOURCE	SS	DF	MS	F
FUEL	0.791	1	0.79	8.17
MOISTURE	0.077	1	0.08	0.80
LOAD	0.022	1	0.02	0.23
RATE	0.044	1	0.04	0.46
ERROR	0.290	3	0.10	
TOTAL	1.225	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR PARTICULATE Fe/K RATIO

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.009	1	1	1	1	1	1	1
2	0.003	1	1	-1	-1	1	-1	-1
9	0.133	1	-1	1	-1	-1	1	-1
4	0.000	1	-1	-1	1	-1	-1	1
5	0.000	-1	1	1	-1	-1	-1	1
6	0.033	-1	1	-1	1	-1	1	-1
7	0.012	-1	-1	1	1	1	-1	-1
8	0.021	-1	-1	-1	-1	1	1	1
CONTRAST		0.079	-0.121	0.097	-0.103	-0.1	0.2	-0.2
SUM OF SQUARES		0.001	0.002	0.001	0.001	.0	.0	.0
SSTOTAL		0.014						
MAIN EFFECT		0.020	-0.030	0.024	-0.026			

SOURCE	SS	DF	MS	F
FUEL	0.001	1	.00	0.27
MOISTURE	0.002	1	.00	0.62
LOAD	0.001	1	.00	0.40
RATE	0.001	1	.00	0.45
ERROR	0.009	3	.00	
TOTAL	0.014	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR BUP MUTAGENICITY, PWF, (kreversions/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	23.817	1	1	1	1	1	1	1
2	49.413	1	1	-1	-1	1	-1	-1
9	55.430	1	-1	1	-1	-1	1	-1
4	11.378	1	-1	-1	1	-1	-1	1
5	25.544	-1	1	1	-1	-1	-1	1
6	55.818	-1	1	-1	1	-1	1	-1
7	124.579	-1	-1	1	1	1	-1	-1
8	69.282	-1	-1	-1	-1	1	1	1
CONTRAST		-135.185	-106.077	43.477	15.924	118.9	-6.6	-155.2
SUM OF SQUARES		2284.374	1406.547	236.285	31.698	1767.7	5.4	3011.6
SSTOTAL		8743.673						
MAIN EFFECT		-33.796	-26.519	10.869	3.981			

SOURCE	SS	DF	MS	F
FUEL	2284.374	1	2284.37	1.43
MOISTURE	1406.547	1	1406.55	0.88
LOAD	236.285	1	236.28	0.15
RATE	31.698	1	31.70	0.02
ERROR	4784.769	3	1594.92	
TOTAL	8743.673	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR BUP MUTAGENICITY, PWF, (Mreversions/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	2.170	1	1	1	1	1	1	1
2	1.174	1	1	-1	-1	1	-1	-1
9	1.521	1	-1	1	-1	-1	1	-1
4	0.605	1	-1	-1	1	-1	-1	1
5	1.228	-1	1	1	-1	-1	-1	1
6	4.461	-1	1	-1	1	-1	1	-1
7	8.460	-1	-1	1	1	1	-1	-1
8	1.765	-1	-1	-1	-1	1	1	1
CONTRAST		-10.443	-3.317	5.375	10.008	5.8	-1.6	-9.8
SUM OF SQUARES		13.632	1.375	3.611	12.521	4.1	0.3	12.1
SBTOTAL		47.700						
MAIN EFFECT		-2.611	-0.829	1.344	2.502			

SOURCE	SS	DF	MS	F
FUEL	13.632	1	13.63	2.47
MOISTURE	1.375	1	1.38	0.25
LOAD	3.611	1	3.61	0.65
RATE	12.521	1	12.52	2.27
ERROR	16.562	3	5.52	
TOTAL	47.700	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR BUP MUTAGENICITY, PWF, (Mreversions/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.301	1	1	1	1	1	1	1
2	0.942	1	1	-1	-1	1	-1	-1
9	0.684	1	-1	1	-1	-1	1	-1
4	0.089	1	-1	-1	1	-1	-1	1
5	0.656	-1	1	1	-1	-1	-1	1
6	0.841	-1	1	-1	1	-1	1	-1
7	1.223	-1	-1	1	1	1	-1	-1
8	0.815	-1	-1	-1	-1	1	1	1
CONTRAST		-1.518	-0.071	0.178	-0.642	1.0	-0.3	-1.8
SUM OF SQUARES		0.288	0.001	0.004	0.052	0.1	0.0	0.4
SSTOTAL		0.900						
MAIN EFFECT		-0.380	-0.018	0.045	-0.161			

SOURCE	SS	DF	MS	F
FUEL	0.288	1	0.29	1.56
MOISTURE	0.001	1	0.00	0.00
LOAD	0.004	1	0.00	0.02
RATE	0.052	1	0.05	0.28
ERROR	0.556	3	0.19	
TOTAL	0.900	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR BUP MUTAGENICITY, PWF, (Mreversions/kg dry WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.371	1	1	1	1	1	1	1
2	1.159	1	1	-1	-1	1	-1	-1
9	1.051	1	-1	1	-1	-1	1	-1
4	0.136	1	-1	-1	1	-1	-1	1
5	0.772	-1	1	1	-1	-1	-1	1
6	0.990	-1	1	-1	1	-1	1	-1
7	1.788	-1	-1	1	1	1	-1	-1
8	1.191	-1	-1	-1	-1	1	1	1
CONTRAST		-2.026	-0.874	0.506	-0.887	1.6	-0.3	-2.5
SUM OF SQUARES		0.513	0.096	0.032	0.098	0.3	0.0	0.8
SSTOTAL		1.843						
MAIN EFFECT		-0.506	-0.219	0.127	-0.222			

SOURCE	SS	DF	MS	F
FUEL	0.513	1	0.51	1.39
MOISTURE	0.096	1	0.10	0.26
LOAD	0.032	1	0.03	0.09
RATE	0.098	1	0.10	0.27
ERROR	1.104	3	0.37	
TOTAL	1.843	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR BUP MUTAGENICITY, CWX, (kreversions/M^3 STP WET)

```
RUN NO        VALUE          FUEL         MOIS         LOAD          RATE       AB       AC       AD
                                A            B            C             D       CD       BD       BC
  1         137.540             1            1            1             1        1        1        1
  2          87.278             1            1           -1            -1        1       -1       -1
  9           0.000             1           -1            1            -1       -1        1       -1
  4         379.785             1           -1           -1             1       -1       -1        1
  5         248.683            -1            1            1            -1       -1       -1        1
  6         193.042            -1            1           -1             1       -1        1       -1
  7         340.385            -1           -1            1             1        1       -1       -1
  8         234.035            -1           -1           -1            -1        1        1        1

CONTRAST                   -411.541     -207.662     -167.533       400.755    -22.3   -491.5    379.3
SUM OF SQUARES             21170.737    10343.647    3508.396     20890.673     62.0  30198.3  17987.2
SSTOTAL                    112160.890
MAIN EFFECT                -102.885      -71.915      -41.883       120.189


SOURCE           SS            DF           MS            F

FUEL        21170.737           1      21170.74         1.32
MOISTURE    10343.647           1      10343.65         0.64
LOAD         3508.396           1       3508.40         0.22
RATE        20890.673           1      20890.67         1.30

ERROR       48247.437           3      16082.48

TOTAL       112160.890          7


        F(0.01,1,3)=34.12
        F(0.05,1,3)=10.13
        F(0.10,1,3)= 5.54
```

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                    ANALYSIS OF VARIANCE (ANOVA) FOR BUP MUTAGENICITY, CWX, (kreversions/hr)


 RUN NO        VALUE        FUEL        MOIS        LOAD        RATE      AB      AC      AD
                               A           B           C           D      CD      BD      BC
   1          12.533           1           1           1           1       1       1       1
   2           1.790           1           1          -1          -1       1      -1      -1
   9           0.000           1          -1           1          -1      -1       1      -1
   4          20.198           1          -1          -1           1      -1      -1       1
   5          11.957          -1           1           1          -1      -1      -1       1
   6          15.427          -1           1          -1           1      -1       1      -1
   7          23.115          -1          -1           1           1       1      -1      -1
   8           5.961          -1          -1          -1          -1       1       1       1


CONTRAST                 -21.938      -7.566       4.228      51.566    -4.2   -23.1    10.3
SUM OF SQUARES            60.160       7.156       2.234     332.378     2.2    66.9    13.3
SSTOTAL                  484.350
MAIN EFFECT               -5.485      -1.892       1.057      12.891


SOURCE            SS          DF          MS           F

FUEL          60.160           1       60.16        2.19
MOISTURE       7.156           1        7.16        0.26
LOAD           2.234           1        2.23        0.08
RATE         332.378           1      332.38       12.10

ERROR         82.421           3       27.47

TOTAL        484.350           7


     F(0.01,1,3)=34.12
     F(0.05,1,3)=10.13
     F(0.10,1,3)= 5.54
```

ANALYSIS OF VARIANCE (ANOVA) FOR BUP MUTAGENICITY, CWX, (Mreversions/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	1.741	1	1	1	1	1	1	1
2	1.441	1	1	-1	-1	1	-1	-1
9	0.000	1	-1	1	-1	-1	1	-1
4	2.956	1	-1	-1	1	-1	-1	1
5	6.383	-1	1	1	-1	-1	-1	1
6	2.908	-1	1	-1	1	-1	1	-1
7	3.342	-1	-1	1	1	1	-1	-1
8	2.752	-1	-1	-1	-1	1	1	1
CONTRAST		-9.240	3.422	1.410	0.371	-3.0	-6.7	6.1
SUM OF SQUARES		10.691	1.464	0.249	0.017	1.1	5.6	4.7
SSTOTAL		23.885						
MAIN EFFECT		-2.312	0.856	0.353	0.093			

SOURCE	SS	DF	MS	F
FUEL	10.691	1	10.69	2.80
MOISTURE	1.464	1	1.46	0.38
LOAD	0.249	1	0.25	0.07
RATE	0.017	1	0.02	0.00
ERROR	11.465	3	3.82	
TOTAL	23.885	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR BUP MUTAGENICITY, CWX, (Mreversions/kg dry WOOD)

```
RUN NO          VALUE          FUEL          MOIS          LOAD          RATE      AB       AC       AD
                                  A             B             C             D      CD       BD       BC
  1             2.141             1             1             1             1       1        1        1
  2             1.772             1             1            -1            -1       1       -1       -1
  9             0.000             1            -1             1            -1      -1        1       -1
  4             4.540             1            -1            -1             1      -1       -1        1
  5             7.518            -1             1             1            -1      -1       -1        1
  6             3.425            -1             1            -1             1      -1        1       -1
  7             4.886            -1            -1             1             1       1       -1       -1
  8             4.023            -1            -1            -1            -1       1        1        1


CONTRAST                      -11.400         1.407         0.786         1.679    -2.7     -9.1      8.1
SUM OF SQUARES                 16.244         0.247         0.077         0.352     0.9     10.4      8.3
SSTOTAL                        36.503
MAIN EFFECT                    -2.850         0.352         0.196         0.420


SOURCE             SS            DF            MS             F

FUEL           16.244             1         16.24          2.49
MOISTURE        0.247             1          0.25          0.04
LOAD            0.077             1          0.08          0.01
RATE            0.352             1          0.35          0.05

ERROR          19.502             3          6.53

TOTAL          36.503             7


      F(0.01,1,3)=34.12
      F(0.05,1,3)=10.13
      F(0.10,1,3)= 5.54
```

ANALYSIS OF VARIANCE (ANOVA) FOR BUP MUTAGENICITY, TOTAL, (kreversions/M^3 STP WET)

```
 RUN NO        VALUE          FUEL         MOIS          LOAD          RATE      AB      AC      AD
                                 A            B             C             D      CD      BD      BC
    1        161.357             1            1             1             1       1       1       1
    2        136.691             1            1            -1            -1       1      -1      -1
    9         55.430             1           -1             1            -1      -1       1      -1
    4        391.163             1           -1            -1             1      -1      -1       1
    5        274.227            -1            1             1            -1      -1      -1       1
    6        248.860            -1            1            -1             1      -1       1      -1
    7        464.964            -1           -1             1             1       1      -1      -1
    8        303.317            -1           -1            -1            -1       1       1       1


CONTRAST                  -546.726     -393.739      -124.055       496.679    96.6  -498.1   224.1
SUM OF SQUARES            37363.650    19378.780     1923.713     30836.297  1167.6 31010.7  6278.6
SSTOTAL                  127959.399
MAIN EFFECT               -136.681      -98.435       -31.014       124.170


SOURCE             SS           DF           MS             F

FUEL        37363.650            1     37363.65          2.91
MOISTURE    19378.780            1     19378.78          1.51
LOAD         1923.713            1      1923.71          0.15
RATE        30836.297            1     30836.30          2.41

ERROR       38456.958            3     12818.99

TOTAL      127959.399            7


        F(0.01,1,3)=34.12
        F(0.05,1,3)=10.13
        F(0.10,1,3)= 5.54
```

ANALYSIS OF VARIANCE (ANOVA) FOR BUP MUTAGENICITY, TOTAL, (Mreversions/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	14.703	1	1	1	1	1	1	1
2	2.965	1	1	-1	-1	1	-1	-1
9	1.521	1	-1	1	-1	-1	1	-1
4	20.004	1	-1	-1	1	-1	-1	1
5	13.185	-1	1	1	-1	-1	-1	1
6	19.088	-1	1	-1	1	-1	1	-1
7	31.575	-1	-1	1	1	1	-1	-1
8	7.725	-1	-1	-1	-1	1	1	1
CONTRAST		-32.381	-10.884	9.603	61.574	1.6	-24.7	0.5
SUM OF SQUARES		131.065	14.807	11.526	473.919	0.3	76.2	0.0
SSTOTAL		707.855						
MAIN EFFECT		-8.095	-2.721	2.401	15.393			

SOURCE	SS	DF	MS	F
FUEL	131.065	1	131.06	5.14
MOISTURE	14.807	1	14.81	0.58
LOAD	11.526	1	11.53	0.45
RATE	473.919	1	473.92	18.58
ERROR	76.538	3	25.51	
TOTAL	707.855	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR BUP MUTAGENICITY, TOTAL, (Mreversions/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	2.042	1	1	1	1	1	1	1
2	2.383	1	1	-1	-1	1	-1	-1
9	0.684	1	-1	1	-1	-1	1	-1
4	3.044	1	-1	-1	1	-1	-1	1
5	7.039	-1	1	1	-1	-1	-1	1
6	3.748	-1	1	-1	1	-1	1	-1
7	4.565	-1	-1	1	1	1	-1	-1
8	3.567	-1	-1	-1	-1	1	1	1
CONTRAST		-10.766	3.352	1.589	-0.272	-2.0	-7.0	4.3
SUM OF SQUARES		14.489	1.404	0.315	0.009	0.5	6.1	2.3
SSTOTAL		25.129						
MAIN EFFECT		-2.692	0.838	0.397	-0.068			

SOURCE	SS	DF	MS	F
FUEL	14.489	1	14.49	4.88
MOISTURE	1.404	1	1.40	0.47
LOAD	0.315	1	0.32	0.11
RATE	0.009	1	0.01	0.00
ERROR	8.911	3	2.97	
TOTAL	25.129	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR BUP MUTAGENICITY, TOTAL, (Mreversions/kg dry WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	2.512	1	1	1	1	1	1	1
2	2.931	1	1	-1	-1	1	-1	-1
9	1.051	1	-1	1	-1	-1	1	-1
4	4.676	1	-1	-1	1	-1	-1	1
5	8.291	-1	1	1	-1	-1	-1	1
6	4.415	-1	1	-1	1	-1	1	-1
7	6.675	-1	-1	1	1	1	-1	-1
8	5.214	-1	-1	-1	-1	1	1	1

CONTRAST	-13.425	0.532	1.292	0.791	-1.1	-9.4	5.6
SUM OF SQUARES	22.530	0.035	0.209	0.078	0.2	11.0	4.0
SSTOTAL	37.954						
MAIN EFFECT	-3.356	0.133	0.323	0.198			

SOURCE	SS	DF	MS	F
FUEL	22.530	1	22.53	4.48
MOISTURE	0.035	1	0.04	0.01
LOAD	0.209	1	0.21	0.04
RATE	0.078	1	0.08	0.02
ERROR	15.102	3	5.03	
TOTAL	37.954	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

```
                ANALYSIS OF VARIANCE (ANOVA) FOR BUM MUTAGENICITY, PWF, (kreversions/M^3 STP WET)


RUN NO        VALUE        FUEL       MOIS       LOAD        RATE      AB      AC      AD
                              A          B          C           D      CD      BD      BC
  1           6.135           1          1          1           1       1       1       1
  2           4.986           1          1         -1          -1       1      -1      -1
  9           3.079           1         -1          1          -1      -1       1      -1
  4           5.350           1         -1         -1           1      -1      -1       1
  5           9.015          -1          1          1          -1      -1      -1       1
  6          96.102          -1          1         -1           1      -1       1      -1
  7           4.449          -1         -1          1           1       1      -1      -1
  8           4.949          -1         -1         -1          -1       1       1       1


CONTRAST                -94.966     98.412    -88.708      90.006   -93.0    86.5   -83.2
SUM OF SQUARES         1127.312   1210.604    983.642    1012.631  1081.8   934.5   864.6
SSTOTAL                7215.109
MAIN EFFECT             -23.741     24.603    -22.177      22.501


SOURCE           SS          DF         MS          F

FUEL       1127.312           1    1127.31       1.17
MOISTURE   1210.604           1    1210.60       1.26
LOAD        983.642           1     983.64       1.02
RATE       1012.631           1    1012.63       1.05

ERROR      2880.920           3     960.31

TOTAL      7215.109           7


      F(0.01,1,3)=34.12
      F(0.05,1,3)=10.13
      F(0.10,1,3)= 5.54
```

ANALYSIS OF VARIANCE (ANOVA) FOR BUM MUTAGENICITY, PWF, (Mreversions/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.559	1	1	1	1	1	1	1
2	0.136	1	1	-1	-1	1	-1	-1
9	0.085	1	-1	1	-1	-1	1	-1
4	0.285	1	-1	-1	1	-1	-1	1
5	0.433	-1	1	1	-1	-1	-1	1
6	7.680	-1	1	-1	1	-1	1	-1
7	0.302	-1	-1	1	1	1	-1	-1
8	0.126	-1	-1	-1	-1	1	1	1
CONTRAST		-7.478	8.011	-6.848	8.046	-7.4	7.3	-6.8
SUM OF SQUARES		6.990	8.023	5.861	8.092	6.8	6.6	5.8
SSTOTAL		48.166						
MAIN EFFECT		-1.869	2.003	-1.712	2.011			

SOURCE	SS	DF	MS	F
FUEL	6.990	1	6.99	1.09
MOISTURE	8.023	1	8.02	1.25
LOAD	5.861	1	5.86	0.92
RATE	8.092	1	8.09	1.26
ERROR	19.200	3	6.40	
TOTAL	48.166	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR BUM MUTAGENICITY, PWF, (Mreversions/kg WET WOOD)

```
 RUN NO        VALUE         FUEL        MOIS        LOAD        RATE      AB      AC      AD
                                A           B           C           D      CD      BD      BC
   1           0.078            1           1           1           1       1       1       1
   2           0.109            1           1          -1          -1       1      -1      -1
   9           0.038            1          -1           1          -1      -1       1      -1
   4           0.042            1          -1          -1           1      -1      -1       1
   5           0.231           -1           1           1          -1      -1      -1       1
   6           1.448           -1           1          -1           1      -1       1      -1
   7           0.044           -1          -1           1           1       1      -1      -1
   8           0.058           -1          -1          -1          -1       1       1       1


CONTRAST                   -1.515       1.684      -1.265       1.174    -1.5     1.2    -1.2
SUM OF SQUARES              0.287       0.354       0.200       0.172     0.3     0.2     0.2
SSTOTAL                     1.651
MAIN EFFECT                -0.379       0.421      -0.316       0.294


SOURCE            SS           DF          MS           F

FUEL           0.287            1        0.29        1.35
MOISTURE       0.354            1        0.35        1.67
LOAD           0.200            1        0.20        0.94
RATE           0.172            1        0.17        0.81

ERROR          0.638            3        0.21

TOTAL          1.651            7


        F(0.01,1,3)=34.12
        F(0.05,1,3)=10.13
        F(0.10,1,3)= 5.54
```

ANALYSIS OF VARIANCE (ANOVA) FOR BUM MUTAGENICITY, PWF, (Mreversions/kg DRY WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.095	1	1	1	1	1	1	1
2	0.134	1	1	-1	-1	1	-1	-1
3	0.058	1	-1	1	-1	-1	1	-1
4	0.064	1	-1	-1	1	-1	-1	1
5	0.273	-1	1	1	-1	-1	-1	1
6	1.705	-1	1	-1	1	-1	1	-1
7	0.064	-1	-1	1	1	1	-1	-1
8	0.085	-1	-1	-1	-1	1	1	1
CONTRAST		-1.775	1.936	-1.497	1.378	-1.7	1.4	-1.4
SUM OF SQUARES		0.394	0.468	0.280	0.238	0.4	0.2	0.3
SSTOTAL		2.259						
MAIN EFFECT		-0.444	0.484	-0.374	0.345			

SOURCE	SS	DF	MS	F
FUEL	0.394	1	0.39	1.34
MOISTURE	0.468	1	0.47	1.60
LOAD	0.280	1	0.28	0.96
RATE	0.238	1	0.24	0.81
ERROR	0.880	3	0.29	
TOTAL	2.259	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

```
                  ANALYSIS OF VARIANCE (ANOVA) FOR BUM MUTAGENICITY, CWX, (kreversions/M^3 STP WET)


RUN NO        VALUE        FUEL        MOIS        LOAD        RATE      AB      AC      AD
                              A           B           C           D      CD      BD      BC
   1         55.016           1           1           1           1       1       1       1
   2         57.011           1           1          -1          -1       1      -1      -1
   9         47.554           1          -1           1          -1      -1       1      -1
   4         88.616           1          -1          -1           1      -1      -1       1
   5         31.085          -1           1           1          -1      -1      -1       1
   6        217.368          -1           1          -1           1      -1       1      -1
   7         82.162          -1          -1           1           1       1      -1      -1
   8        175.526          -1          -1          -1          -1       1       1       1


CONTRAST                -257.944     -33.378    -322.705     131.986   -14.9   236.6   -53.9
SUM OF SQUARES          8316.906     139.258   13017.333    2177.537    27.8  6996.8   362.5
SSTOTAL                31038.113
MAIN EFFECT              -64.486      -8.344     -80.676      32.996


SOURCE           SS          DF          MS           F

FUEL        8316.906          1     8316.91        3.38
MOISTURE     139.258          1      139.26        0.06
LOAD       13017.333          1    13017.33        5.29
RATE        2177.537          1     2177.54        0.88

ERROR       7387.079          3     2462.36

TOTAL      31038.113          7


        F(0.01,1,3)=34.12
        F(0.05,1,3)=10.13
        F(0.10,1,3)= 5.54
```

ANALYSIS OF VARIANCE (ANOVA) FOR BUM MUTAGENICITY, CWX, (Mreversions/hr)

```
RUN NO        VALUE         FUEL          MOIS          LOAD          RATE      AB      AC      AD
                               A             B             C             D      CD      BD      BC
   1          5.013            1             1             1             1       1       1       1
   2          1.049            1             1            -1            -1       1      -1      -1
   3          1.305            1            -1             1            -1      -1       1      -1
   4          4.713            1            -1            -1             1      -1      -1       1
   5          1.495           -1             1             1            -1      -1      -1       1
   6         17.371           -1             1            -1             1      -1       1      -1
   7          5.579           -1            -1             1             1       1      -1      -1
   8          4.470           -1            -1            -1            -1       1       1       1


CONTRAST                   -16.836         8.861       -14.212        24.358    -8.8    15.3    -9.6
SUM OF SQUARES              35.430         9.814        25.247        74.163     9.6    29.4    11.6
SSTOTAL                    195.178
MAIN EFFECT                 -4.209         2.215        -3.553         6.089


SOURCE           SS           DF            MS             F

FUEL         35.430            1         35.43          2.10
MOISTURE      9.814            1          9.81          0.58
LOAD         25.247            1         25.25          1.50
RATE         74.163            1         74.16          4.40

ERROR        50.523            3         16.84

TOTAL       195.178            7


       F(0.01,1,3)=34.12
       F(0.05,1,3)=10.13
       F(0.10,1,3)= 5.54
```

ANALYSIS OF VARIANCE (ANOVA) FOR BUM MUTAGENICITY, CWX, (Mreversions/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.696	1	1	1	1	1	1	1
2	0.846	1	1	-1	-1	1	-1	-1
9	0.587	1	-1	1	-1	-1	1	-1
4	0.690	1	-1	-1	1	-1	-1	1
5	0.798	-1	1	1	-1	-1	-1	1
6	3.274	-1	1	-1	1	-1	1	-1
7	0.807	-1	-1	1	1	1	-1	-1
8	2.064	-1	-1	-1	-1	1	1	1
CONTRAST		-4.124	1.467	-3.986	1.172	-0.9	3.5	-1.3
SUM OF SQUARES		2.125	0.269	1.986	0.172	0.1	1.5	0.2
SSTOTAL		6.376						
MAIN EFFECT		-1.031	0.367	-0.997	0.293			

SOURCE	SS	DF	MS	F
FUEL	2.125	1	2.13	3.50
MOISTURE	0.269	1	0.27	0.44
LOAD	1.986	1	1.99	3.27
RATE	0.172	1	0.17	0.28
ERROR	1.824	3	0.61	
TOTAL	6.376	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR BUM MUTAGENICITY, CWX, (Mreversions/kg DRY WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.856	1	1	1	1	1	1	1
2	1.041	1	1	-1	-1	1	-1	-1
3	0.901	1	-1	1	-1	-1	1	-1
4	1.059	1	-1	-1	1	-1	-1	1
5	0.940	-1	1	1	-1	-1	-1	1
6	3.856	-1	1	-1	1	-1	1	-1
7	1.179	-1	-1	1	1	1	-1	-1
8	3.017	-1	-1	-1	-1	1	1	1
CONTRAST		-5.135	0.536	-5.097	1.052	-0.7	4.4	-1.1
SUM OF SQUARES		3.296	0.036	3.248	0.138	0.1	2.4	0.2
SSTOTAL		9.358						
MAIN EFFECT		-1.284	0.134	-1.274	0.263			

SOURCE	SS	DF	MS	F
FUEL	3.296	1	3.30	3.74
MOISTURE	0.036	1	0.04	0.04
LOAD	3.248	1	3.25	3.69
RATE	0.138	1	0.14	0.16
ERROR	2.641	3	0.88	
TOTAL	9.358	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR BUM MUTAGENICITY, TOTAL, (kreversions/M^3 STP WET)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	61.151	1	1	1	1	1	1	1
2	61.997	1	1	-1	-1	1	-1	-1
3	50.633	1	-1	1	-1	-1	1	-1
4	93.966	1	-1	-1	1	-1	-1	1
5	40.101	-1	1	1	-1	-1	-1	1
6	313.470	-1	1	-1	1	-1	1	-1
7	86.611	-1	-1	1	1	1	-1	-1
8	100.475	-1	-1	-1	-1	1	1	1

CONTRAST		-352.910	65.034	-411.413	221.992	-107.9	323.1	-137.0
SUM OF SQUARES		15568.187	528.677	21157.621	6160.045	1456.3	13045.5	2346.8
SSTOTAL		60263.061						
MAIN EFFECT		-88.228	16.258	-102.853	55.498			

SOURCE	SS	DF	MS	F
FUEL	15568.187	1	15568.19	2.77
MOISTURE	528.677	1	528.68	0.09
LOAD	21157.621	1	21157.62	3.77
RATE	6160.045	1	6160.05	1.10
ERROR	16848.531	3	5616.18	
TOTAL	60263.061	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR BUM MUTAGENICITY, TOTAL, (Mreversions/hr)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	5.572	1	1	1	1	1	1	1
2	1.185	1	1	-1	-1	1	-1	-1
9	1.389	1	-1	1	-1	-1	1	-1
4	4.997	1	-1	-1	1	-1	-1	1
5	1.928	-1	1	1	-1	-1	-1	1
6	25.052	-1	1	-1	1	-1	1	-1
7	5.882	-1	-1	1	1	1	-1	-1
8	4.596	-1	-1	-1	-1	1	1	1
CONTRAST		-24.314	16.872	-21.059	32.404	-16.1	22.6	-16.4
SUM OF SQUARES		73.894	35.583	55.437	131.251	32.5	63.9	33.7
SSTOTAL		426.313						
MAIN EFFECT		-6.078	4.218	-5.265	8.101			

SOURCE	SS	DF	MS	F
FUEL	73.894	1	73.89	1.70
MOISTURE	35.583	1	35.58	0.82
LOAD	55.437	1	55.44	1.28
RATE	131.251	1	131.25	3.03
ERROR	130.147	3	43.38	
TOTAL	426.313	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR BUM MUTAGENICITY, TOTAL, (Mreversions/kg WET WOOD)

RUN NO	VALUE	FUEL A	MOIS B	LOAD C	RATE D	AB CD	AC BD	AD BC
1	0.774	1	1	1	1	1	1	1
2	0.955	1	1	-1	-1	1	-1	-1
9	0.625	1	-1	1	-1	-1	1	-1
4	0.731	1	-1	-1	1	-1	-1	1
5	1.029	-1	1	1	-1	-1	-1	1
6	4.722	-1	1	-1	1	-1	1	-1
7	0.850	-1	-1	1	1	1	-1	-1
8	2.122	-1	-1	-1	-1	1	1	1
CONTRAST		-5.638	3.151	-5.252	2.346	-2.4	4.7	-2.5
SUM OF SQUARES		3.974	1.241	3.447	0.688	0.7	2.7	0.8
SSTOTAL		13.585						
MAIN EFFECT		-1.410	0.788	-1.313	0.586			

SOURCE	SS	DF	MS	F
FUEL	3.974	1	3.97	2.81
MOISTURE	1.241	1	1.24	0.88
LOAD	3.447	1	3.45	2.44
RATE	0.688	1	0.69	0.49
ERROR	4.235	3	1.41	
TOTAL	13.585	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

ANALYSIS OF VARIANCE (ANOVA) FOR BURN MUTAGENICITY, TOTAL, (Mreversions/kg DRY WOOD)

RUN NO	VALUE	FUEL	MOIS	LOAD	RATE	AB	AC	AD
		A	B	C	D	CD	BD	BC
1	0.952	1	1	1	1	1	1	1
2	1.175	1	1	-1	-1	1	-1	-1
9	0.960	1	-1	1	-1	-1	1	-1
4	1.123	1	-1	-1	1	-1	-1	1
5	1.212	-1	1	1	-1	-1	-1	1
6	5.561	-1	1	-1	1	-1	1	-1
7	1.243	-1	-1	1	1	1	-1	-1
8	3.102	-1	-1	-1	-1	1	1	1
CONTRAST		-6.910	2.472	-6.595	2.430	-2.4	5.8	-2.5
SUM OF SQUARES		5.968	0.764	5.436	0.738	0.7	4.2	0.8
SSTOTAL		18.665						
MAIN EFFECT		-1.727	0.618	-1.649	0.608			

SOURCE	SS	DF	MS	F
FUEL	5.968	1	5.97	3.11
MOISTURE	0.764	1	0.76	0.40
LOAD	5.436	1	5.44	2.83
RATE	0.738	1	0.74	0.38
ERROR	5.759	3	1.92	
TOTAL	18.665	7		

F(0.01,1,3)=34.12
F(0.05,1,3)=10.13
F(0.10,1,3)= 5.54

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-89-025

2.

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE Effects of Burn Rate, Wood Species, Moisture Content and Weight of Wood Loaded on Woodstove Emissions

5. REPORT DATE May 1989

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S) K. E. Leese and S. M. Harkins

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Research Triangle Institute
P. O. Box 12194
Research Triangle Park, North Carolina 27709

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO. 68-02-3992, Tasks 7 and 37

12. SPONSORING AGENCY NAME AND ADDRESS
EPA, Office of Research and Development
Air and Energy Engineering Research Laboratory
Research Triangle Park, NC 27711

13. TYPE OF REPORT AND PERIOD COVERED Task final; 12/84 - 12/85

14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES AEERL project officer is Robert C. McCrillis, Mail Drop 61, 919/541-2733.

16. ABSTRACT The report gives results of tests of four woodstove operating parameters (burn rate, wood moisture, wood load, and wood species) at two levels each using a half factorial experimental test design to determine statistically significant effects on the emission components CO, CO2, particulate matter, total extractable organics (TEOs), polycyclic aromatic hydrocarbons (PAHs), C1-C7 hydrocarbons, metals, and the Ames plate incorporation bioassay mutagenic potential. Results showed that increasing burn rate lowered CO, particulate matter, TEO, and C1-C7 hydrocarbon emission rates. Increasing burn rate raised emission rates of individual PAHs and several metals, and also the mutagenic potential of the emissions. All of these effects were significant at the 90% or better confidence interval. At the 90% or better confidence interval, reducing wood moisture increased the particulate emission factor, while concentrations of several PAHs in the stack gas were lowered. Changing from pine to oak increased K emissions at the 90% confidence interval. Effects just under the 90% confidence interval included reductions in emission factors for several PAHs and a decrease in mutagenic activity. Increasing the weight of the initial wood load increased particulate emissions, significant at the 90% confidence interval. A decrease in mutagenic activity was significant at just below 90%.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Carbon Dioxide	Pollution Control	13B	
Stoves	Particles	Stationary Sources	13A	
Wood	Organic Compounds	Woodstoves	11L	07C
Combustion	Bioassay	Particulate	21B	06A, 06E
Emission	Aromatic Polycyclic Hydrocarbons		14G	
Carbon Monoxide			07B	

18. DISTRIBUTION STATEMENT **Release to Public**

19. SECURITY CLASS *(This Report)* Unclassified

20. SECURITY CLASS *(This page)* Unclassified

21. NO. OF PAGES 398

22. PRICE

EPA Form 2220-1 (9-73)

U.S. ENVIRONMENTAL PROTECTION AGENCY
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Publication No. EPA-600/2-89-025