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In-Home Performance of Exempt Pellet Stoves in Medford, Oregon

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Prepared by: Stockton G. Barnett
Paula G. Fields
OMNI Environmental Services, Inc.
10950 SW Fifth Street, Suite 160
Beaverton, Oregon 97005-3400

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Executive Summary

Pellet stoves that are considered “exempt” operate at an air-to-fuel ratio in excess of 35:1. They therefore qualify for exemption from the emissions certification process. A primary goal of this project was to determine how a sample of such stoves, operated in homes, would perform compared to their certified “cousins,” which were evaluated the previous year. In-home performance data documenting emissions from exempt stoves and net delivered efficiencies was particularly desired.

This project evaluated six pellet stoves representing three major brands in Medford, Oregon. There were three Breckwell model P24FS, one Horizon Eclipse, one Horizon Destiny, and one Earth Stove TP40. The stoves were monitored for four week-long intervals in January and February 1991, for a total of 24 tests. Evaluations were conducted for particulate, CO (carbon monoxide) and PAH (polycyclic aromatic hydrocarbon) emissions and net efficiency. Monitoring was conducted using the AWES (automated woodstove emissions sampler) sampling system. A new data logger, developed for this project, was used to control the AWES and record real time data.

Results and Conclusions

- Average particulate emissions were 1.95 g/hr, about twice that of the certified pellet stoves. The small sample size makes it difficult to draw definitive, comparative conclusions between these two pellet stove groups. For example, the 95% confidence limit is ± 0.95 g/hr, and a *t* test indicates exempt and certified stoves are significantly different at the 90% probability level, but not at the 95% level.
- The exempt pellet stove emissions represent a $\frac{2}{3}$ reduction compared to the 1990-certified Phase II cordwood stoves and 90% reduction compared to conventional cordwood stoves as measured in houses.
- Particulate emissions by stove model ranged from a low of 1.5 g/hr for the Breckwells to 2.6 g/hr for the Horizons.
- CO emissions averaged 13 g/hr, nearly identical to the certified pellet stoves and about 90% lower than conventional woodstoves.

- PAH emissions from the Breckwells and Horizons were very low (the Earth Stove was not sampled). They were 40 $\mu\text{g/hr}$ and 86 $\mu\text{g/hr}$, respectively. The carcinogenic compounds Benzo(a)pyrene and Dibenzo(a,h)anthracene were below detection limits. PAH analyses conducted at two laboratories of replicate samples were in close agreement with one another.
- Average net delivered efficiency was 55.5%, significantly lower than the certified pellet stoves. Variation in efficiency was large. The Breckwell was 62.8%, the Horizon was 55.5%, and the Earth Stove was 33.4%.
- An in-depth analysis of efficiency indicates that the lower efficiencies of the exempt stoves are primarily related to larger amounts of excess air and secondarily to higher stack gas temperatures.
- A pellet stoves¹ total impact on energy usage is a function of both efficiency and the way the appliance is operated. Compared to woodstoves, pellet stoves can be operated so as to “target” energy output better. Pellet stoves also burn more evenly. Both aspects contribute to less energy wastage in the form of overheating. Pellet stoves also can be burned at lower rates such that on warm days they can “target” energy output considerably better than woodstoves, which either burn too hot, are subjected to frequent start-ups, or are not burned at all. These efficiency of operation aspects of pellet stoves probably significantly contribute to the lower net energy outputs of pellet stoves (6140 Btu/hr for exempt and 8727 Btu/hr for certified stoves) compared to the 10,000-13,000 Btu/hr range of woodstoves as operated in the field.
- Two important issues remain unresolved. First, product durability has only begun to be evaluated. One two-year-old Breckwell performed very well. Follow-up studies of the certified and exempt stoves over years of use are necessary to evaluate this issue. Second, the lower efficiencies of exempt pellet stoves pose questions of cost for the homeowner. At a current average fuel cost of about \$150 per ton, pellet burning is relatively expensive even in efficient stoves. Inefficient burning of the fuel compounds the expense to the homeowner. Since high-quality, low-ash fuel is becoming in short supply, there is additional incentive to burn the fuel efficiently. Heightened awareness

of the fuel supply shortage and lower than expected pellet stove efficiencies places increased emphasis on the need to evaluate long-term fuel supply stability as well as the cost of owning and operating a pellet stove. These issues take on added importance if regulations encourage the increased use of pellet stoves by imposing tighter g/hr limits on residential biomass burning or by implementing pellet stove purchase incentive programs.

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Introduction

This report summarizes the work conducted by OMNI Environmental Services, Inc. on an in-home evaluation of residential pellet stove performance. The work was completed under contract to the Oregon Department of Environmental Quality (DEQ) and funded by the U.S. Department of Energy, Oregon Department of Energy, and the Tennessee Valley Authority (TVA). The current project is the second phase of a two-part study. In the first project, certified appliances were investigated in homes during the 1989-1990 heating season in Medford and Klamath Falls, Oregon¹. The current report summarizes a 1990-1991 heating season evaluation of pellet stoves that are exempt from certification.

Pellet stove use has increased rapidly in recent years in the Pacific Northwest, making this the region in the United States where those stoves are most abundant. There are two significant differences between pellet stoves typical residential woodstoves: (1) pellet stoves continually introduce small amounts of fuel (densified low ash biomass pellets) into the combustion chamber instead of "batch-burning" a single fuel load, and (2) pellet stoves use mechanically generated draft (induced or forced) to control air flow into the combustion chamber. These features provide substantial theoretical improvements in combustion efficiency and thereby offer the potential to produce lower particulate, CO (carbon monoxide), and PAH (polycyclic aromatic hydrocarbons) emission rates relative to conventional cordwood stoves.

The current pellet stove projects were developed to test the hypothesis that pellet stoves might significantly improve efficiency and reduce emissions compared to certified woodstoves. Certified pellet stoves were evaluated in-home 1989-1990 and exempt units were evaluated in the current project.

Pellet stoves that operate at an air-to-fuel ratio in excess of 35:1 qualify for exemption from the emissions certification process. The 35:1 cutoff line was not established with pellet stoves in mind. Instead, it was established to separate woodstoves from fireplaces. Only later did it become clear that this definition created a line through the various models of pellet stoves.

A primary goal of the current project was to determine whether a sample of exempt stoves, operated in homes, would perform similarly to their certified "cousins", which had performed well in last year's project with an average of 1.04 g/hr particulate emissions.

The exempt pellet stoves were tested at only one elevation because the emissions performance of the certified stoves was shown to be insensitive to the elevation difference between Medford (elevation 1300 ft) and Klamath Falls (elevation 4200 ft).

Documentation of the in-home emissions performance of pellet-fueled stoves was conducted by using OMNI's Automated Woodstove Emissions Sampler (AWES) and data logger systems. This sampling system has been used in many in-home cordwood woodstove studies.²⁻²¹ The pellet stove sampling program included modifications of the existing AWES/data logger systems to effectively sample the more dilute pellet stove flue gases caused by higher flue gas oxygen and lower particulate emissions compared to cordwood stoves. As part of the current project, prior to field sampling, a new data logger was developed to record temperatures and flue oxygen concentrations as well as control the sampling equipment. This system worked very well throughout the project.

In addition to the collection of particulates with the modified AWES sampling system and the collection of CO and CO₂ with the flue gas collection system, PAH samples were collected. One sampling sequence was conducted on a Breckwell pellet stove and the other on a Horizon. Because condensation, agglomeration, volatilization, and secondary chemical reactions in air can all modify the character of source particles, OMNI used a dilution/cooling tunnel system which mixed the flue gases with ambient air for the collection of samples for PAH analyses. Each filter was split in half and sent to two laboratories for interlab comparability analysis. EPA Method 8270 was used by each lab.

Stove model selection criteria for this project were (1) select models with the greatest market share, (2) select the most reliable units as reported to us by dealers and distributors, and (3) select models that have a sufficient number of stoves already installed in homes to monitor. The selected models did have the greatest market share, but the project had to be moved from Klamath Falls to Medford to find enough stoves already in place.

Three Breckwell model P24FS, one Horizon Eclipse, one Horizon Destiny[†], and one Earth Stove model TP40 were studied. All stoves were current models representing the latest technology, installed new by local dealers for the current heating season except for one Breckwell, PM01, which was installed prior

[†] The difference between the two Horizon models is that the Eclipse has a damper which can be used to manually reduce air when the stove burns at low burn rates.

to the 1989-90 heating season. For details, see Table 1. All stoves had been installed prior to initiation of this project.

Golden Fire pellet fuel was used for both certified and exempt pellet stoves. The proximate and ultimate analysis of the fuel are shown in Appendix B.

Table 1. Stoves Used in the Exempt Pellet Stove Project

House	Stove Brand	Model	When Manufactured	When Installed
PM01	Breckwell	P24FS	1988	3/89
PM02	Horizon	Destiny	8/90	12/90
PM03	Breckwell	P24Fs	1989	11/90
PM04	Breckwell	P24FS	1989	11/90
PM05	Horizon	Eclipse	10/89?	11/90
PM06	Earth Stove	IP40	1990	Fall 1990

Objectives

- To compare the field emissions performance of the exempt pellet stove models with the performance of the certified stoves evaluated last year.
- To gain a broader perspective of pellet stove emissions performance by measuring PAH and CO emissions.
- To compare net thermal efficiencies of certified and exempt pellet stoves using an in-depth analysis to isolate factors that have an effect on efficiency.

Methodology

Emissions Sampling

The Modified AWES Emission Sampling System

AWES (automated woodstove emissions sampler) samplers modified for sampling pellet stove emissions were used in the field. Figure 1 shows a schematic of the modified AWES/data logger system. The AWES unit draws flue gases through a 38 cm (15 in) long, 1.0 cm ($3/8$ in) O.D. stainless steel probe which samples from the center of the flue pipe 30 cm (1 ft) above the flue collar. The sample then travels through a 1.0 cm O.D. Teflon line, and a heated U.S. EPA Method 5-type filter for collection of particulate matter, followed by a sorbent resin (XAD-2) trap for semi-volatile hydrocarbons. Water vapor is removed by a silica gel trap. Flue gas oxygen concentrations, which are used to determine flue gas volume, were measured by an electrochemical cell. The oxygen cell used in the AWES was manufactured by Lynn Instruments. The AWES uses a critical orifice (Millipore #XX500001) to maintain a nominal sampling rate of 1.0 liters per minute (0.035 cfm). Each AWES critical orifice is calibrated to determine the exact sampling rate.

The AWES unit returns particle-free exhaust gas to the stack via a 0.6 cm ($1/4$ in) Teflon line and a 38 cm (15 in) stainless steel probe inserted approximately 38 cm (15 in) downstream from the sampling probe. Some flue gas exiting the AWES is pumped into a Tedlar bag (for later gas analysis) under positive pressure, since the inlet to the bag is on the positive side of the pump. The flow to the bag is controlled by a solenoid valve connected to the pump circuit, a temperature controller, and a rotameter with a flow controlling orifice. The solenoid valve is open only when the pump is activated and the temperature of the stack exceeds 100° F. The rate of flow into the bag is controlled by the rotameter, which was adjusted to acquire the optimum amount of gas over the entire test without over-pressurizing the bag.

The Data Logger System

The data logger system, known as the CONLOG data logger system, is a second-generation data logging and emission sampler controlling system developed in 1990 by OMNI under funding by the TVA to

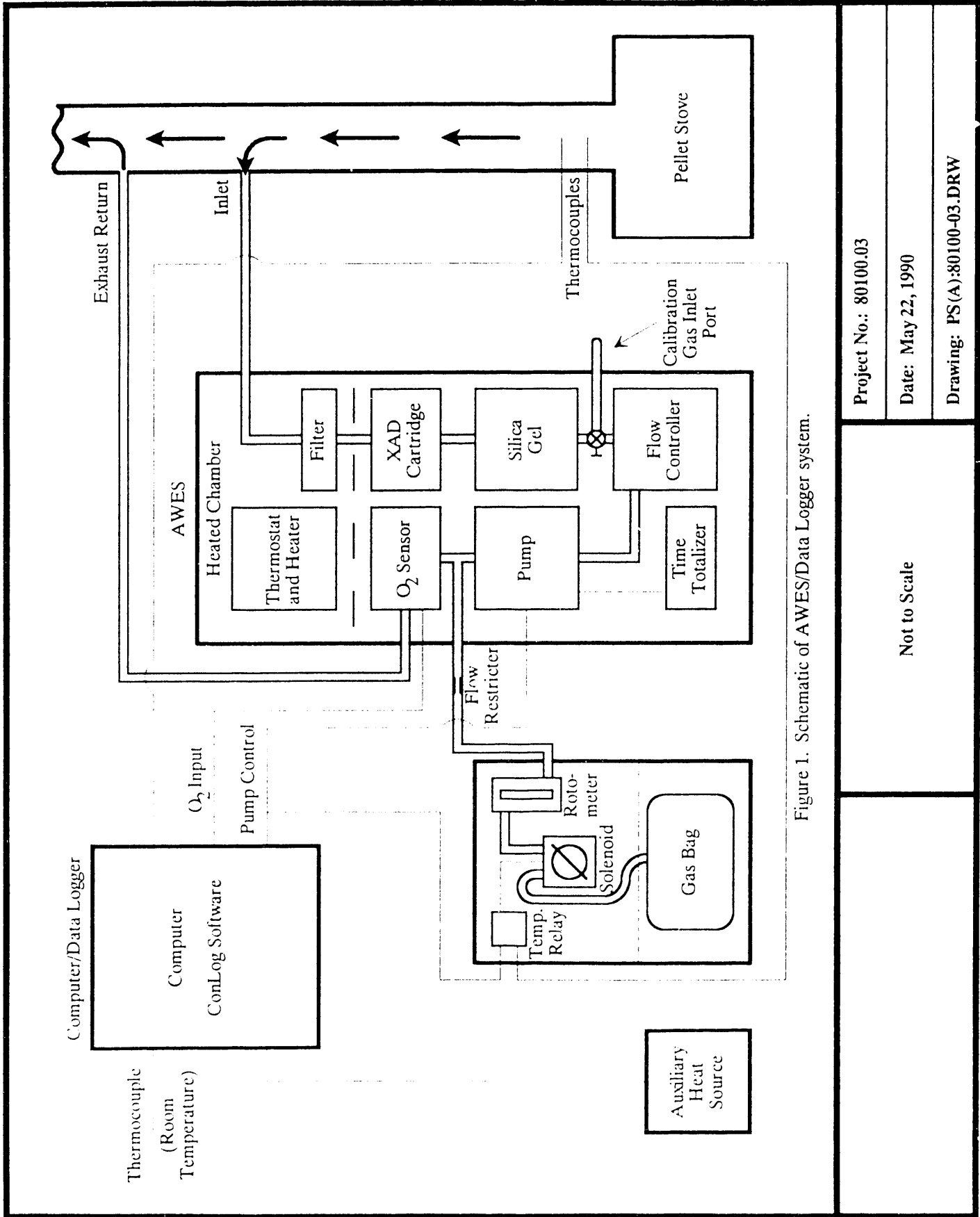


Figure 1. Schematic of AWES/Data Logger system.

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Not to Scale

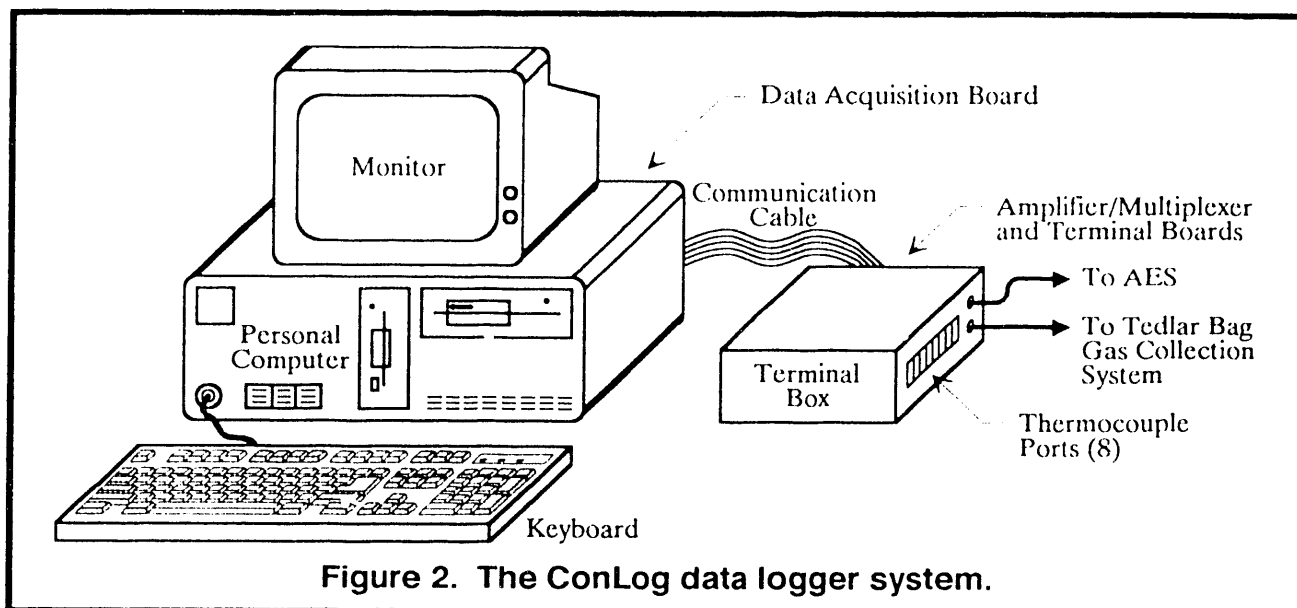


Figure 2. The ConLog data logger system.

conduct continuous emissions monitoring for this project. The system (Figure 2) consists of a host personal computer (PC) containing a data processing board, a terminal box, and specialized data acquisition software.

The CONLOG software is written in a high-level programming language (C) and can be programmed to control, collect, and store the following software settings and data:

- Establish starting and ending date and length of sampling period
- Establish pump cycle length and thermocouple (TC) cycle recording interval
- Establish auxiliary heat trip point
- Record date and time at pre-selected intervals
- Record three temperatures, including flue gas temperature, averaged over pre-selected intervals
- Record ambient temperature (room temperature), averaged over pre-selected intervals
- Record flue gas oxygen measurements, averaged over pre-selected intervals
- Record auxiliary heat “on” or “off”, recorded at pre-selected intervals
- Save file as an ASCII file with PRN suffix on 3.5" disk

Instantaneous readings of real-time data are also displayed on the system status screen of date, time, temperature for TCs 1 through 4, and flue gas oxygen percent. The most recent 15 sets of recorded data are also displayed.

The CONLOG system uses external sensors which generate analog voltages that are processed by the PC microprocessor's data acquisition board. For this project, a type K ground-isolated, stainless-steel-sheathed TC (Pyrocom 1K-27-5-U) was used to monitor flue gas temperature at 30 cm (1 ft) above the pellet stove's flue collar in the center of the flue gas stream.

The keyboard and screen were left installed in the home during the sample period. The presence of the display screen's real-time data generated considerable interest on the part of the participants in the project and was a positive experience. The CONLOG program was software-locked to prevent possible interference. However, on a few occasions homeowners were given the password and "walked" through minor program modifications over the telephone to solve a problem that may have occurred during a sampling period. This proved successful and saved considerable field technician time.

Equipment Preparation and Sample Processing Procedures

Prior to emissions testing, each AWES unit was cleaned and prepared with a new fiberglass filter and XAD-2 sorbent resin cartridge. This was done in OMNI's laboratory facility at Beaverton, Oregon. After each sampling period, the stainless steel sampling probe, Teflon sampling line, filter holder, and XAD-2 cartridges were removed from the home and transported to OMNI's laboratory for processing. The components of the AWES samplers were processed as follows:

1. Filters: The glass fiber filters (102 mm in diameter) were removed from the AWES filter housings and placed in petri dishes for desiccation and gravimetric analysis for particulate catch.
2. XAD-2 sorbent resin: The sorbent resin cartridges were extracted in the Soxhlet extractor with dichloromethane for 24 hours. The extraction solvent was transferred to a tared glass beaker. The solvent was evaporated in an ambient air dryer, the beaker and residue were desiccated, and the extractable residue was weighed on a Mettler AE160 balance.
3. AWES hardware: All hardware which was in the sample stream (stainless steel probe, Teflon sampling line, stainless steel filter housing, and all other Teflon and stainless steel fittings) through the base of the sorbent resin cartridge was rinsed with a 50/50 mixture

of dichloromethane and methanol solvents. The solvents were placed in tared glass beakers. The solvents were evaporated in an ambient air dryer, desiccated, and weighed to determine the residue fraction weight.

EPA Method 5 procedures for desiccation and the weighing time schedule were followed for 1 through 3 above. After cleaning, the AWES units were reassembled for field use. The intake port, sampling probe, and sampling line were sealed for transportation to the home and unsealed immediately prior to installation.

OMNI personnel serviced the sampling equipment at the start and end of each sampling period. At the start of each sampling period, the AWES unit was installed; leak checks were performed; the thermocouples, woodbasket/scale unit, and oxygen cell were calibrated; and the data logger was programmed with the proper sampling interval and start/stop times. Data loggers were programmed to activate the AWES units for one minute on and nine minutes off for seven consecutive days. At the end of each sampling period, final calibration, and leak-check procedures were performed, and the AWES, sampling line, filter housing, XAD-2 cartridge, and sampling probe were removed and sent to the lab.

Data Processing and Quality Assurance

Data files stored on the data logger's 3.5" computer diskette were sent to OMNI's lab for computer analysis. Each data file was reviewed immediately to check for proper equipment operation. The data logger data files, log books, and records maintained by field staff were reviewed to ensure sample integrity. Any parameter or calibration objective that did not meet OMNI's in-house quality control criteria was flagged and noted. The data for those emission rate calculations which incorporated a flagged quality assurance parameter were carefully reviewed.

Data logger files were used in conjunction with the AWES particulate sample and the pellet fuel analysis to calculate particulate emission rates, daily temperature profiles of the various stove temperatures, stove operation time, burn rates, etc. In addition, computer program outputs for each file include graphical representations of parameters and parameter interrelationships (see Appendix A for graphical output for all tests for all stoves).

Particulate Emissions Calculations

The basic particulate emissions equation produces grams per dry kilogram of fuel burned (g/kg). This value is multiplied by burn rate, expressed as dry kilograms of fuel per hour (kg/h), to yield grams per hour emissions (g/h). See Appendix C for complete details of emissions calculations. The basic g/kg equation includes the following components:

1. Particulate mass. The total mass, in grams, of particulate caught on the filter, XAD-2 resin trap, and in the probe rinse. Particulate mass averages about 0.03 grams but varies considerably.
2. Sample time: The number of minutes the sampler operated during the sampling week when the stack temperature was greater than 38°C (100°F).
3. Sampler's flow rate: This is controlled by the critical orifice in the sampler. Flow values vary slightly for the various samplers and average about one liter per minute.
4. Stoichiometric volume: The volume of smoke produced by combusting one dry kilogram of pellets. This value averages about 5,000 liters at standard temperature and pressure for pellet stoves.
5. Dilution factor: The degree to which the sampled combustion gases have been diluted in the stack by the presence of excess air. The dilution factor is obtained by using the sample period's average oxygen value in the following equation. Dilution factors range from about 2.5 to 10.

$$\text{Dilution Factor} = ((20.9 / (20.9 - \text{Average oxygen})))$$

The basic emissions equation is expressed as follows using these components:

$$\text{Emissions (g/kg)} = \frac{(\text{Particulates})(\text{Stoich. Vol.})(\text{Dilution Factor})}{(\text{Sample Time})(\text{Sampler Flow})}$$

Uncertainty in Emissions Results

Particulate emissions values are presented along with associated uncertainty levels. Each measurement used in the emissions calculations has some degree of uncertainty associated with it, and these uncertainties are propagated to determine the amount of uncertainty attached to each calculated particulate emission rate. Appendix C summarizes the criteria, procedures, and calculations used in evaluating uncertainty. Within the low range of emissions values encountered in this project, uncertainty is generally about 20% of the stated value. This was verified independently during the certified pellet stove project by operating five AWES sampling systems simultaneously while burning a pellet stove.

The issue of sample blank-induced error was investigated at length in the 1988-1989 Northeast Cooperative Woodstove Study. The values determined in that study have been used here. They include a probable error at the 95% confidence level of ± 4.88 mg and an average blank value of 3.9 mg.

Oxygen-cell-induced error was also investigated in the 1989 NCWS study. The 95% confidence level probable error of $\pm 7\%$ is used in this study.

For a detailed treatment of these and other sources of uncertainty, see Appendix C.

Efficiency Calculations

Woodstove efficiency was determined using the “Condar Method”²². This method uses g/kg particulate emissions, CO emissions, stack dilution factor (based on excess air), stack temperature, wood type, and wood moisture to calculate combustion, heat transfer, and overall efficiencies, as well as net output in Btu/hr.

It should be noted that this method was originally intended for use in situations where flue gas temperatures are taken at the point of exit of the stove’s single-wall pipe from the home’s heated space or about 1.5 meters above the flue collar. Temperatures taken in the current study were taken at 0.3 meters height, a location representative of many pellet stove installations. For other pellet stove installations which utilize about 1.5 meters of interior exposed flue pipe for additional heat transfer, efficiencies would be somewhat higher than stated herein, an amount dependent primarily on the stack temperature.

AWES Modifications for Pellet Stove Emissions Testing

Three fundamental differences between cordwood stoves and pellet stoves are fuel and fueling systems, lower particulate emission rates in pellet stoves, and higher flue gas oxygen content as compared to conventional cordwood stoves. Because the AWES (automated woodstove emissions sampler) system was designed for cordwood sampling, small modifications were necessary to make it completely compatible for pellet stove sampling.

The electronic scale/wood basket approach used to determine fuel mass with cordwood stoves was not used for pellet stoves, since pellet bags are nominally 40 pounds each. Homeowners were asked to keep a log of their loading activities. Wood moisture measurements were not required for each test since pellet moisture content was determined by proximate/ultimate analysis of the fuel at the beginning of the project.

The sampling period was also modified to accommodate the low emissions of the pellet stoves. A sampling frequency of one minute of sampling out of every fifteen minutes at a flow rate of one liter per minute has been found to provide optimal sample catches for analysis from clean-burning cordwood stoves during a one-week period. Due to the lower particulate emission rates characteristic of pellet stoves, a shorter sampling frequency of one minute out of ten minutes at the same flow rate was selected to obtain optimal sample catch from one week of pellet stove sampling.

The final modification was the addition of a flue gas collection system (Figure 3). Carbon dioxide, carbon monoxide, and oxygen data are generated from this system, allowing for calculation of carbon monoxide emission factors and a potentially more accurate calculation of all emissions factors when the flue oxygen levels exceed about 18%. Such high oxygen values were not encountered with certified pellet stoves but were with the exempt stoves.

PAH Determinations

Polycyclic aromatic hydrocarbons (PAH) represent a class of compounds that have long been associated with particulate emissions from combustion sources. Some PAH compounds have been identified as being carcinogenic. Particulate samples collected by OMNI used a dilution source sampling system (DSS). The system is described in detail here because PAH sampling systems used historically are not all the same, making interpretation of results difficult.

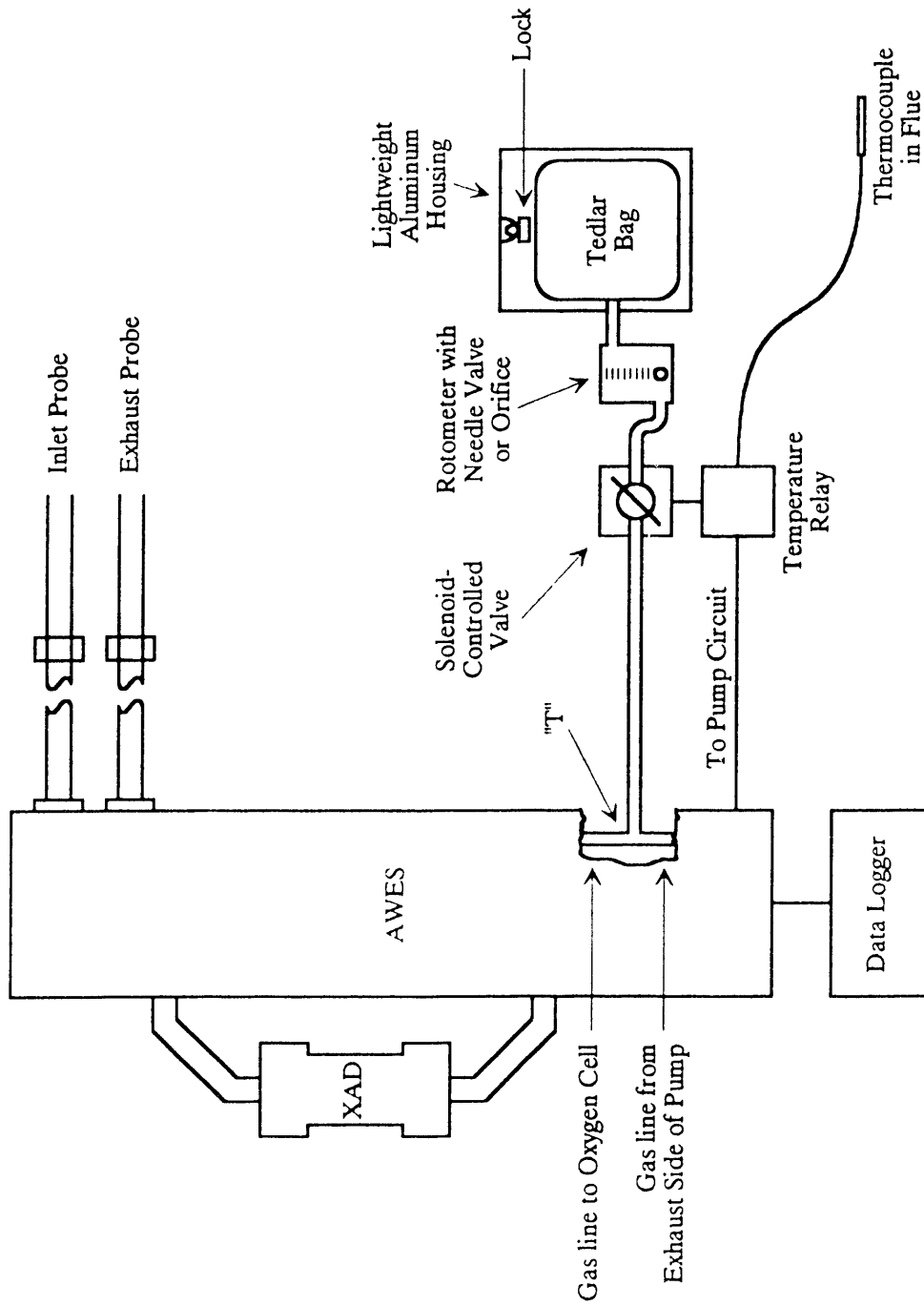


Figure 3. Schematic of AWES system modified for pellet stove application.

Figure 4 is a general schematic of the dilution source sampling system (DSS). Several different dilution chamber and inlet geometries were available to pragmatically position the sampler adjacent to each appliance, since it was desirable to minimize the inlet probe length, as it has been found that the principal area of particle loss by sidewall impact is within the sampling probe and inlet line. The dilution system was designed to be “broken down” to be easily transported and cleaned in the field. The system has interchangeable dilution chamber lengths and bends, as well as various diameters and lengths of inlet probes. The dilution chamber components are constructed of light gauge 316 stainless steel to minimize sample contamination.

Characteristic temperatures, flow rates, particulate loading, and water vapor content (condensed water is deleterious to sample collection) vary dramatically with source type; consequently, the dilution ratio is adjustable (approximately 10:1 to 100:1) for general application. Additionally, because of the high ambient air/sample ratio, the dilution air is filtered to prevent sample contamination. The dilution ratio is adjustable at any reasonable inlet flow by the combined control of an inlet blower and outlet vacuum pump. Both are controlled by variable transformers (Variacs). Inlet air is filtered with a standard high-volume 8-by-10-inch filter. The dilution ratio can be set at any predetermined value, since the inlet air flow rate is monitored with a thermal anemometer and the pressure difference between the interior of the dilution chamber and the source is monitored with a pressure gauge or manometer. The flow-versus-pressure difference is determined in the laboratory prior to field deployment. The dilution chamber temperature is monitored to ensure that the chamber temperature is within a few degrees of ambient, and for documentation of the aerosol sampling environment. An 8- \times -10-inch high-volume filter is placed in the system exhaust line to collect TSP particulate material.

Reduced pressure and flow within the dilution chamber is produced by a vacuum pump. If the blower is removed, each flow rate across the high-volume filter has a corresponding pressure drop associated with it which is determined by the filter medium. The addition of a Variac-controlled blower reduces the pressure drop and permits a wide range of combinations of dilution chamber pressure and flow rate. For example, if a high dilution flow rate (i.e., high dilution ratio) and a low pressure drop (low linear velocity in the sampling inlet) are desired, the vacuum pump would be operated at near-maximum power and the blower would be adjusted until the pressure drop across the high-volume filter was lowered to the point where low inlet velocities were obtained.

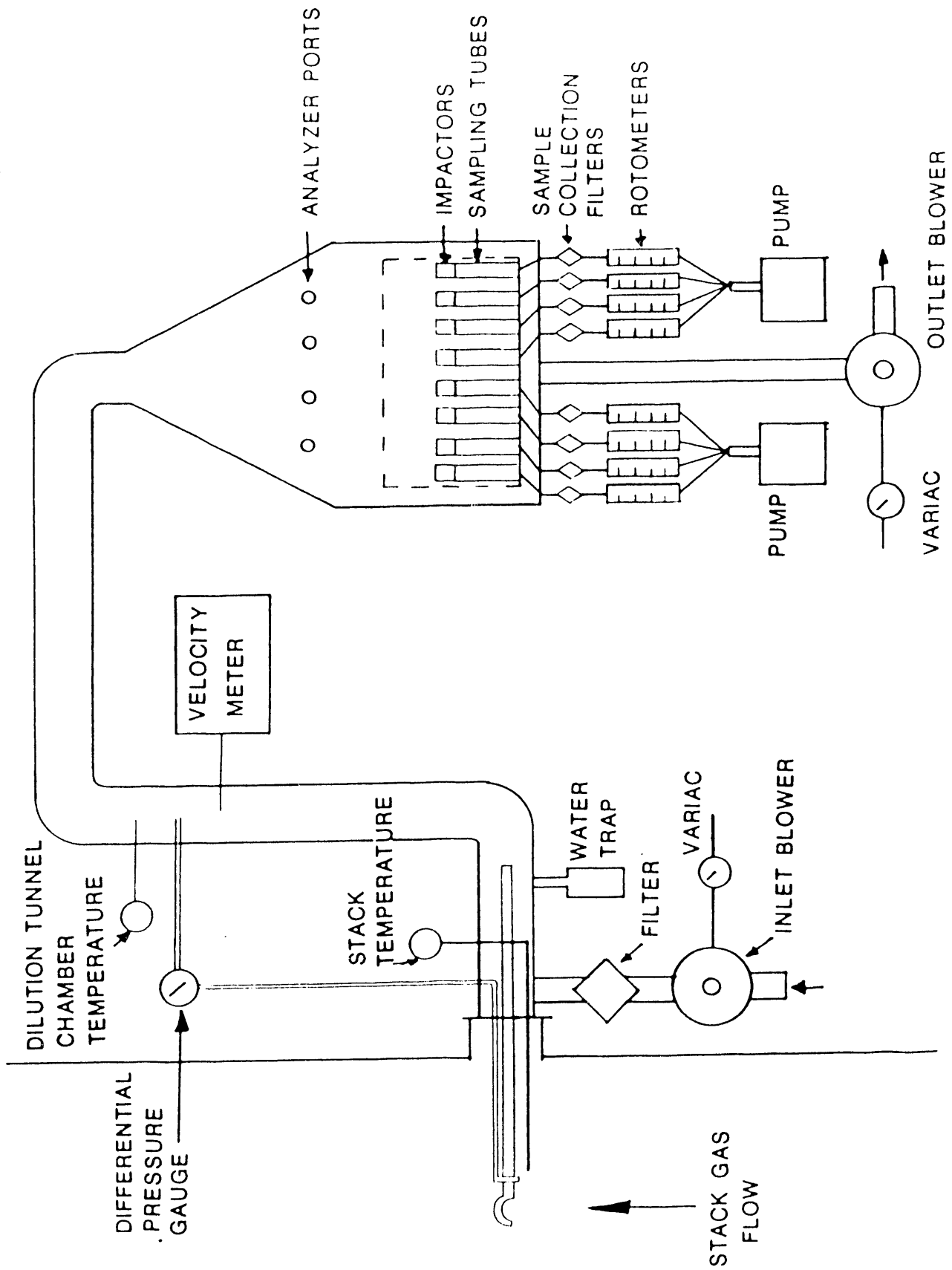


Figure 4. Schematic of the dilution sampling system.

The exposed 8- \times -10-inch high volume quartz filter was cut in half and sent to two labs (PEL and ARI) for comparability analysis. EPA Method 8270 GC/MS was used by both labs. This procedure was done to evaluate concerns that the large variation in prior PAH analyses could be at least partially attributable to interlab variation.

In last year's certified pellet stove project, the dilution source sampling system had been used to evaluate different particle size fractions using a thermal desorption GC/MS technique. Results indicated that almost all PAH matter is less than 1 micron in size (the first size fraction). Therefore, size fractionation was not employed again in the current project.

The certified pellet stove project also backed up quartz filters with an XAD-2 resin cartridge to evaluate the effectiveness of using the filter alone. Only the relatively light molecular weight naphthalene collected in significant quantities. Therefore, the XAD-2 backup was not used in this project.

Table 2. Polycyclic Aromatic Hydrocarbons (PAH) Selected for Analysis

<u>Compound</u>
1. Naphthalene
2. Acenaphthylene
3. Acenaphthene
4. Fluorene
5. Phenanthrene
6. Anthracene
7. Fluoranthene
8. Pyrene
9. Benzo(a)anthracene
10. Chrysene
11. Benzo(b)fluoranthene
12. Benzo(k)fluoranthene
13. Benzo(a)pyrene
14. Benzo(g,h,i)perylene
15. Dibenzo(a,h)anthracene
16. Indeno(1,2,3-cd)pyrene
17. 2-Methylnaphthalene ^a
18. Dibenzofuran ^a

a. Not measured in the certified pellet stove project.

Results and Discussion

Particulate Emissions

The overall average particulate emissions for the six pellet stoves (three Breckwells, two Horizons, and one Earth Stove) were 1.95 g/hr or 3.5 g/kg (Tables 3 and 4). These emissions are about twice as high as for the certified pellet stoves. However, the 95% confidence limit is ± 0.95 g/hr and a *t* test indicates exempt and certified stoves are significantly different at the 90% probability level, but not at the 95% level. The exempt stove values are about 65 to 75% lower than field-generated values for EPA Phase II cordwood stoves and about 90% lower than most conventional woodstoves (Figure 5).

Emissions during each test varied from a low of 0.27 g/hr, generated by one of the Breckwells (PM01) on the last run to a high of 4.5 to 4.6 g/hr, generated by a Breckwell (PM03) and a Horizon (PM05). Figure 6 indicates that the two lowest emitters are Breckwells, but that the three highest emitters also include a Breckwell (PM03). This stove has a serial number within 30 of the stove in house PM04, a stove that had significantly lower emissions. This information suggests that there is some performance sensitivity to stove operation. The fact that PM04 was cleaned daily and PM03 was cleaned infrequently may have significance.

There are no statistically significant trends for g/hr or g/kg emissions over the testing period (Figure 7). While there was a positive correlation between high emissions and frequent shutdowns and startups for certified stoves, no such relationship is exhibited with the exempt stoves (Figure 8).

Some indication of durability of the Breckwell is evidenced by the fact that the stove in PM01 has been burned two seasons and yet still performed the best of the three Breckwells.

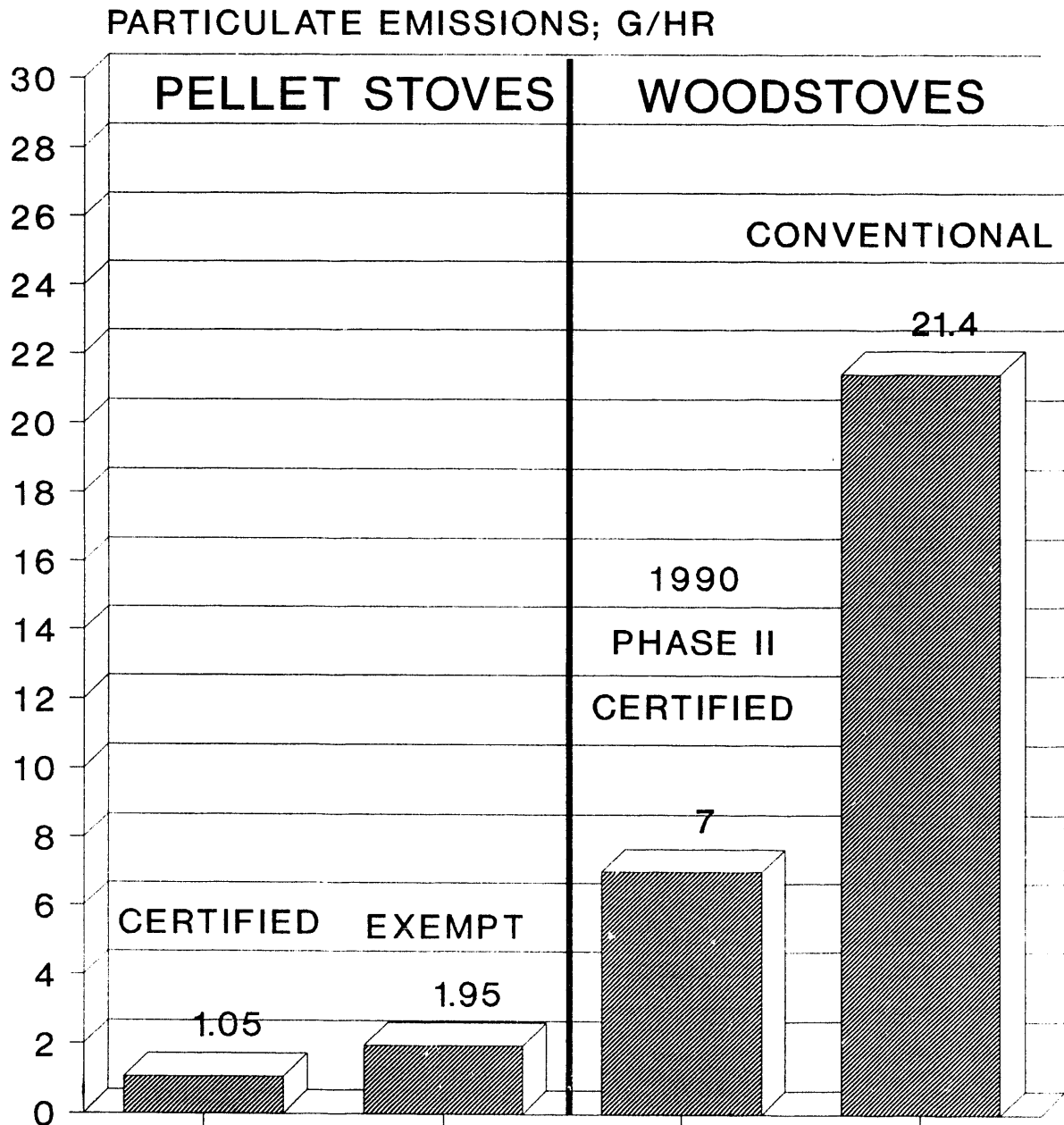
Comparison Between the Three Stove Models

While the average emissions of the Breckwell are lower than those of the Horizon, the large variation in Breckwell emissions noted above (Figure 6) indicates that the sample size is too small to distinguish between these models. Since there is only one Earth Stove in the project and its emissions are within the general cluster of the other models' emissions, it is not possible to rank its performance as a model.

Table 3. Summary of Particulate Emissions and Burn Rate Data: 1991 Pellet Stove In-Home Testing

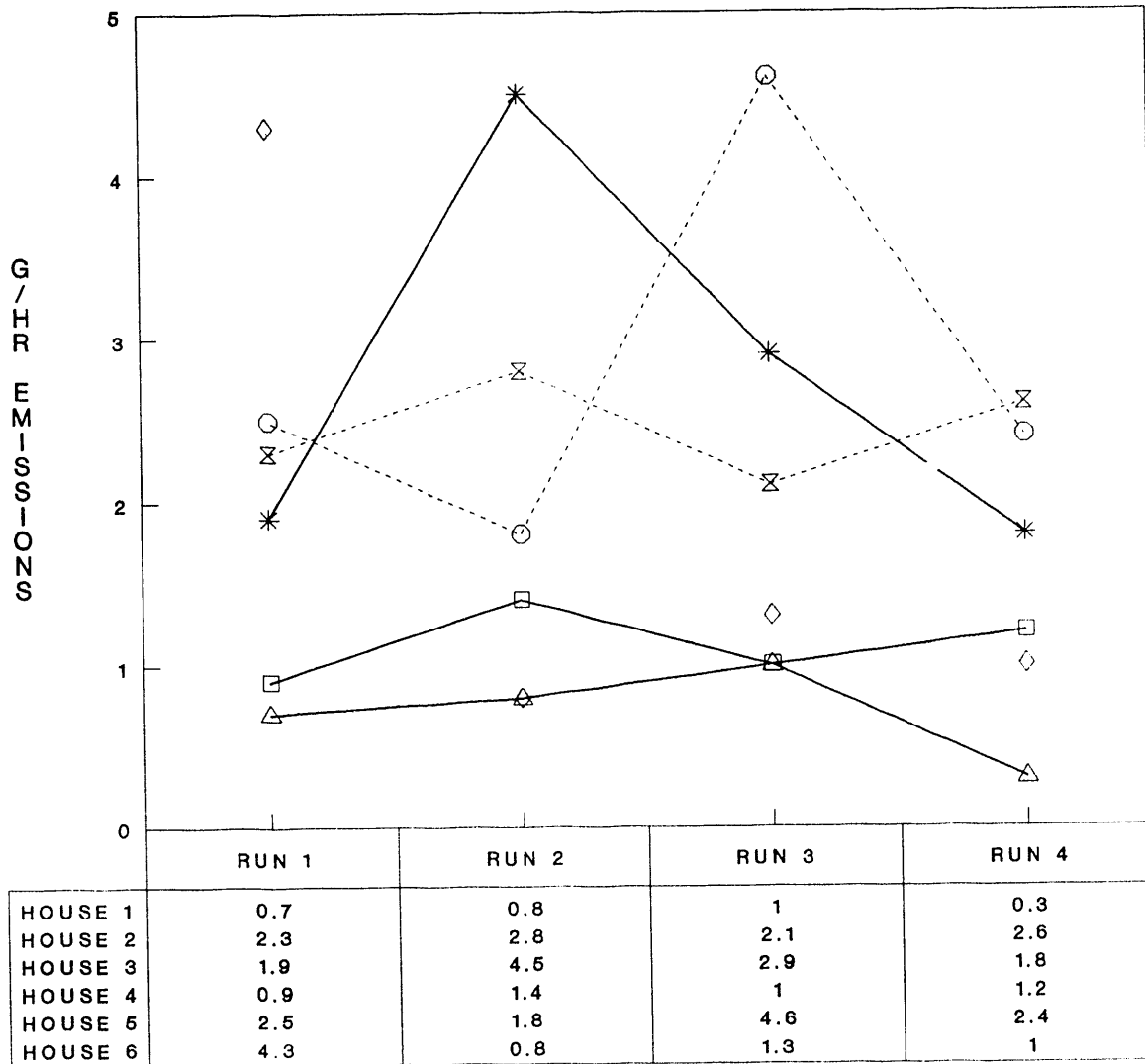
Stove Brand	House #	Emissions (g/hr)				Emissions (g/kg)				Burn Rate (kg/hr)				Averages			
		Run 1	Run 2	Run 3	Run 4	Run 1	Run 2	Run 3	Run 4	Run 1	Run 2	Run 3	Run 4	g/hr	g/kg	Burn Rate	
Breckwell	1	0.7	0.8	1.0	0.3	0.6	1.5	1.6	0.6	1.06	0.54	0.66	0.47	0.7	1.1	0.68	
	3	1.9	4.5	2.9	1.8	3.4	8.1	6.0	5.3	0.54	0.55	0.48	0.34	2.3	5.7	0.48	
	4	0.9	1.4	1.9	1.2	1.6	2.7	2.6	2.3	0.52	0.52	0.41	0.51	1.1	2.3	0.50	
Horizon	2	2.3	2.8	2.1	2.6	2.0	3.6	2.7	4.0	1.11	0.79	0.79	0.66	2.5	3.1	0.84	
	5	2.5	1.8	4.6	2.4	4.2	3.4	9.1	4.4	0.59	0.53	0.51	0.53	2.8	5.3	0.54	
Earth Stove	6	4.3	0.8	1.3	1.0	7.2	1.8	3.1	2.4	0.60	0.45	0.41	0.43	1.8	3.6	0.47	
Run Average		2.08	2.02	2.16	1.54	3.19	3.50	4.16	3.16	0.74	0.56	0.54	0.49				
Stove Brand	Brand Averages (g/hr)		Brand Averages (g/kg)				Brand Averages: Burn Rate										
	Run 1	Run 2	Run 3	Run 4	Run 1	Run 2	Run 3	Run 4	Run 1	Run 2	Run 3	Run 4					
	1.13	2.23	1.66	1.08	1.90	4.09	3.38	2.73	0.71	0.54	0.52	0.44					
	2.37	2.31	3.36	2.49	3.13	3.48	5.85	4.22	0.85	0.66	0.65	0.60					
Earth Stove (N=1)	4.32	0.79	1.26	1.02	7.16	1.76	3.1	2.35	0.6	0.45	0.41	0.43					
Overall Averages (g/hr)		Overall Averages (g/kg)				Overall Averages: Burn Rate											
Breckwell (N=3)	1.52	3.03				0.55											
Horizon (N=2)	2.63	4.17				0.69											
Earth Stove (N=1)	1.85	3.59				0.47											
Overall Average	1.95	3.50				0.58											

PARTICULATE EMISSIONS: PELLET STOVES AND WOODSTOVES



ALL VALUES WERE OBTAINED IN HOMES.

TRENDS: G/HR PARTICULATE EMISSIONS EXEMPT PELLET STOVES; 1991 TESTS



△ HOUSE 1 X HOUSE 2 * HOUSE 3
 □ HOUSE 4 ○ HOUSE 5 ◇ HOUSE 6

BRECKWELL= SOLID LINES
 HORIZON= DASHED LINES
 EARTH=DOTTED LINE

Figure 6

TRENDS IN AVERAGE G/HR, G/KG PARTICULATE EMISSIONS AND BURN RATE. EXEMPT PELLET STOVES

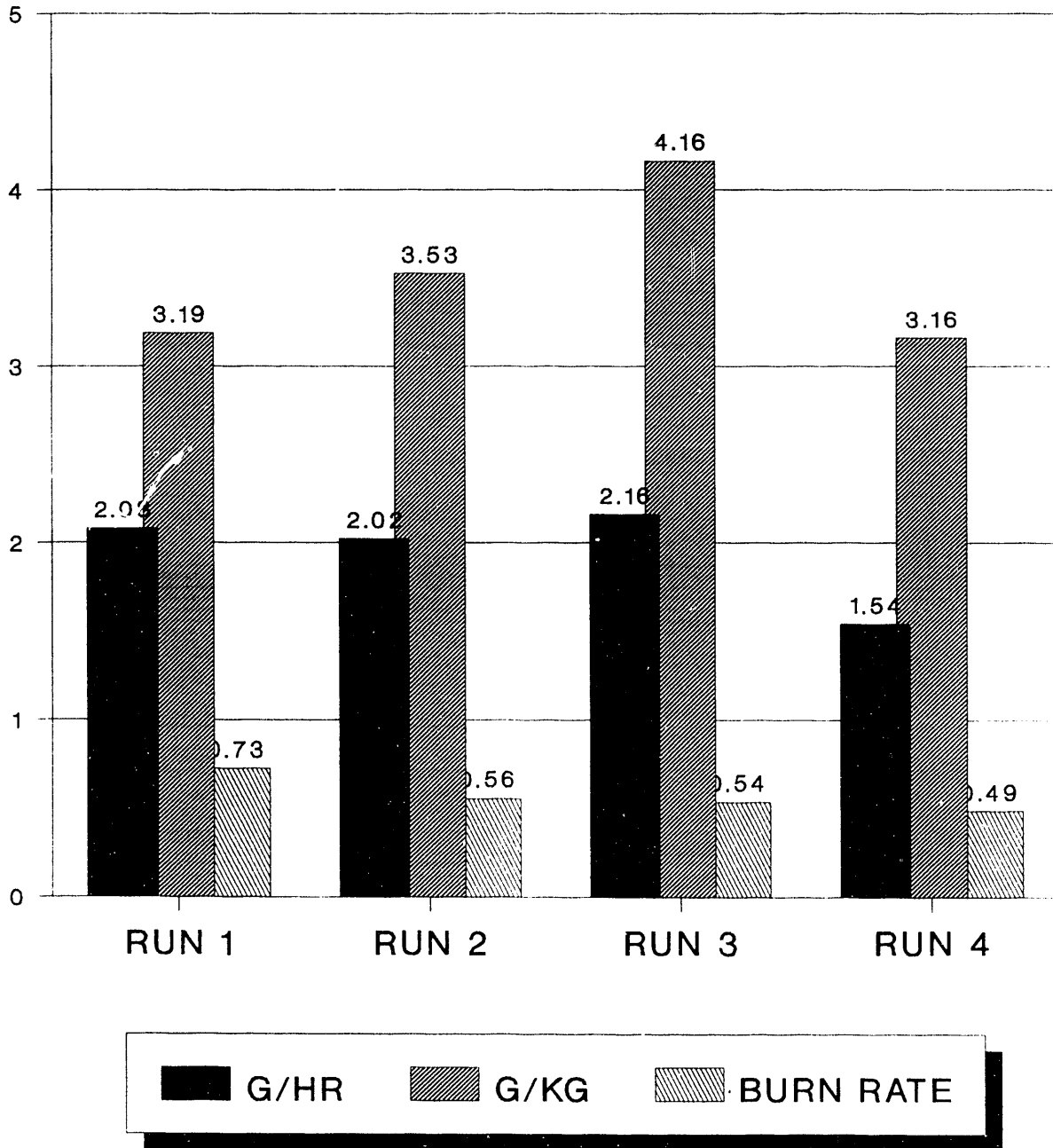


Figure 7

% TIME STOVE OPERATED VS G/HR EMISSIONS EXEMPT PELLET STOVES

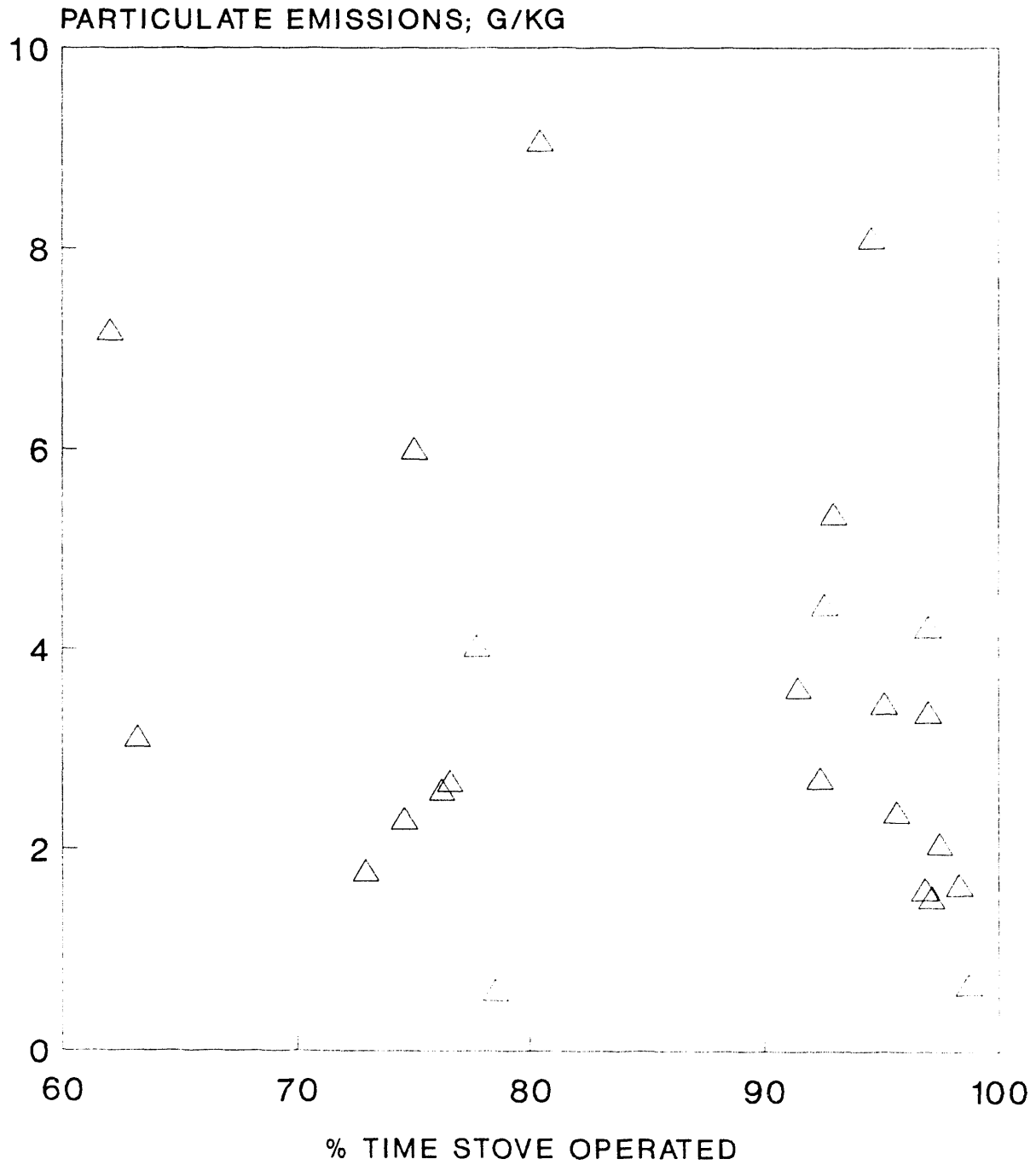


Figure 8

CO Emissions

CO (carbon monoxide) emissions averaged a low 13.1 g/hr or 24.7 g/kg over the test period. These values are about the same as for the certified pellet stoves and much lower than either conventional or Phase II certified woodstoves (Figure 9). The relationship between CO and particulates is shown in Figure 10. The correlation coefficient is 0.73, indicating a moderate level of correlation. Incorporation of the exempt with the certified stove data reduces the correlation coefficient compared to using the certified data alone¹.

PAH Emissions

PAH (polycyclic aromatic hydrocarbon) emissions were very low for the exempt pellet stoves. Average emissions (Tables 5 and 6) were 40 $\mu\text{g/hr}$ for the Breckwell (PM01, the stove with the lowest particulate emissions) and 86 $\mu\text{g/hr}$ for the Horizon (PM05, the stove with the highest particulate emissions). Additionally, the carcinogenic compounds benzo(a)pyrene and dibenzo(a,h)anthracene were not detected. These exempt stove PAH values are close to those of the certified Crossfire and much lower than those of the Whitfield (Table 5). Caution should be exercised in comparing the certified and exempt stoves,

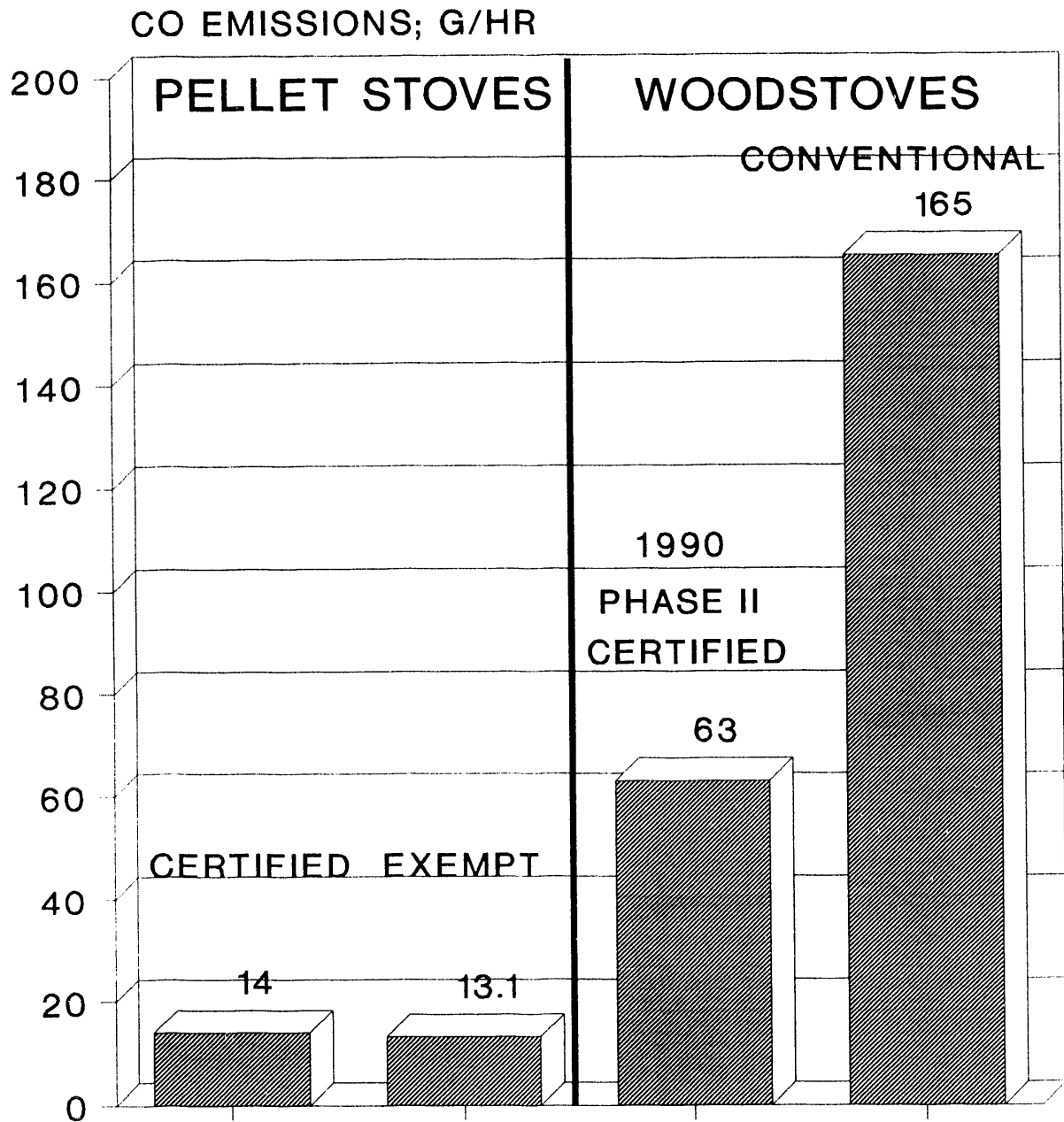
Table 5. PAH Emissions from Certified and Exempt Pellet Stoves

Stove Brand	House	PAH Emissions ($\mu\text{g/hr}$)
Crossfire, certified	BM01	95
Whitfield, certified	BM03	2130
Breckwell, exempt	PM01	40
Horizon, exempt	PM05	86

Note: The certified stoves represent an average of two analysis methods (EPA Method 8310 and GC/MS Thermal Desorption) run at one lab. The exempt stoves represent an average of analyses run at two different labs using EPA Method 8270.

even though the dilution sampling procedures were the same, since different methods of analysis were used in each project. Also, comparisons to woodstoves are extremely difficult. Woodstove sampling reported on in the literature has generally used different sampling methods, commonly a modification of the EPA's stack sampling method No. 5. The stoves were generally burned under laboratory conditions.

CO EMISSIONS: PELLLET STOVES AND WOODSTOVES



ALL VALUES WERE OBTAINED IN HOMES.

Figure 9

PARTICULATES (G/KG) VS CO (G/KG)

EXEMPT & CERTIFIED PELLET STOVES

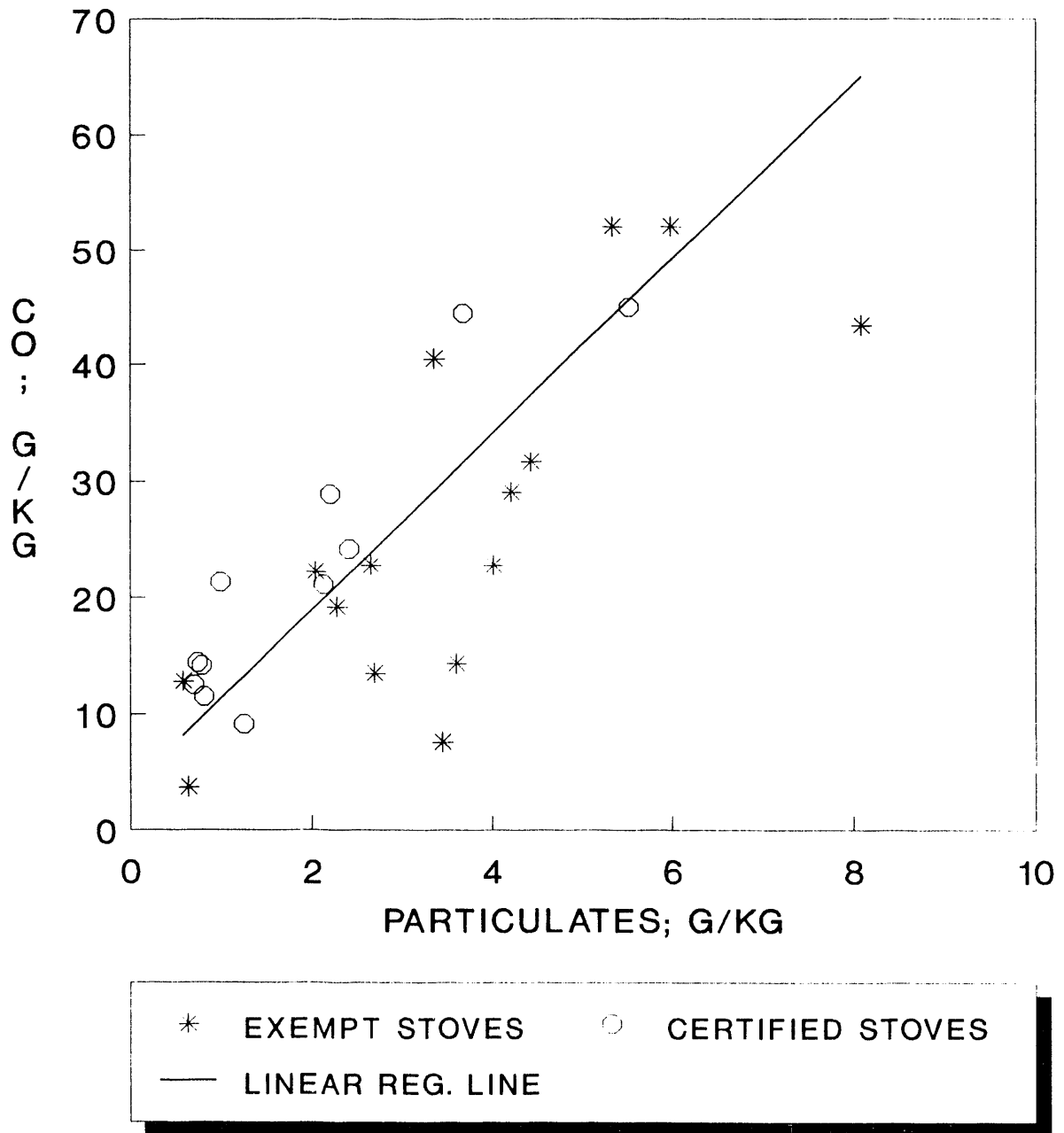


Figure 10

Table 6. PAH Emissions in Micrograms/Hour, Exempt Pellet Stoves

PAH Compound	Breckwell		Horizon		Ambient Blank	
	PEL Lab ^a	ARI Lab ^b	PEL Lab ^c	ARI Lab ^d	PEL Lab ^e	ARI Lab ^f
Naphthalene	--	--	--	--	--	--
2-Methylnaphthalene	--	--	--	--	--	--
Acenaphthylene	--	--	--	--	--	--
Acenaphthene	--	--	--	--	--	--
Dibenzofuran	--	--	--	--	--	--
Fluorene	--	--	--	--	--	--
Phenanthrene	4.3	--	14.5	--	--	--
Anthracene	--	--	--	--	--	--
Fluoranthene	6.9	5.3	27.4	22.0	--	--
Pyrene	5.2	5.3	22.0	22.0	--	--
Benzo(a)Anthracene	--	--	--	--	--	--
Chrysene	13.7	9.5	40.9	22.0	--	--
Benzo(b)Fluoranthene	15.8	14.7	--	1.9	--	--
Benzo(k)Fluoranthene	--	--	--	--	--	--
Benzo(a)Pyrene	--	--	--	--	--	--
Indeno(1,2,3-cd)Pyrene	--	--	--	--	--	--
Dibenz(a,h)Anthracene	--	--	--	--	--	--
Benzo(g,h,i)Perylene	--	--	--	--	--	--
Total	45.8	34.7	104.7	67.9	--	--
Average of both labs	40.3		86.3			
Micrograms/cu. meter	0.558	0.423	1.043	0.676	--	--

- a. Detection limit = 4 $\mu\text{g/hr}$
- b. Detection limit = 5 $\mu\text{g/hr}$
- c. Detection limit = 13 $\mu\text{g/hr}$
- d. Detection limit = 16 $\mu\text{g/hr}$
- e. Detection limit = 3 ng/m^3
- f. Detection limit = 3.8 ng/m^3

Since most of this work was done in the early 1980s, burning parameters were different than those generally accepted now and stoves either were not named by brand or were models that did not sell extensively in the marketplace. Additionally, historic variation in results has been extreme. However, the current pellet results are at the lowest end of the variation range. Making comparisons more difficult is the fact that Phase II woodstoves have not yet been evaluated for PAH.

The comparability analysis between the two laboratories was quite close. Emissions values were similar and the compounds detected overlap well (Table 6 and Figures 11 and 12). The most notable difference is that PEL detected phenanthrene and ARI did not.

Burn Rate and Heat Output

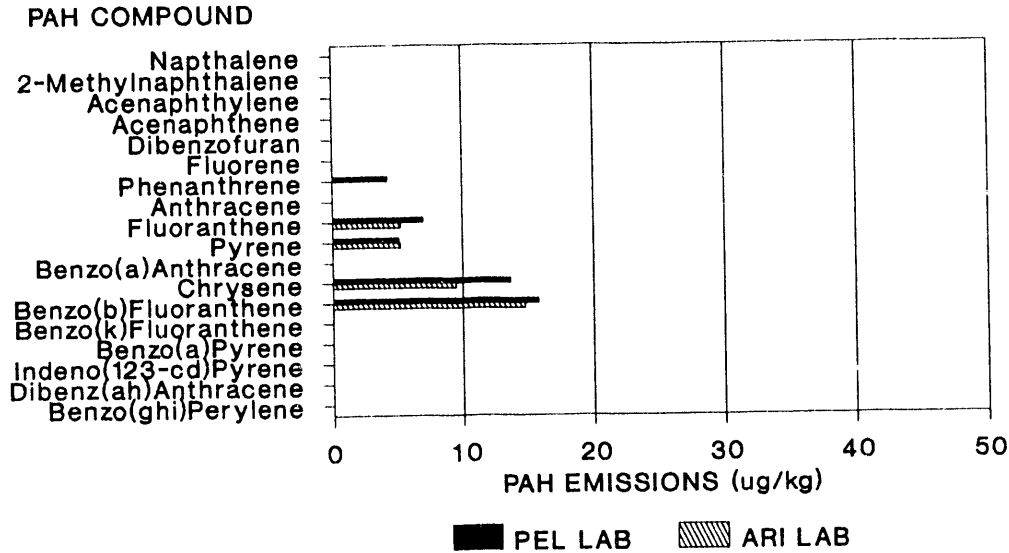
The average burn rate for all tests was 0.58 kg/hr, slightly lower than for the certified stoves (0.70 kg/hr). This decrease is possibly caused by the warmer weather in the current test period. Weekly degree days averaged 134 in 1991, compared to 188 in 1990. Burn rate declined slightly throughout the project as the weather became warmer (Figure 7).

While particulate emissions tended to decrease as burn rate increased and be lowest when a stove was operated continuously for certified stoves, no statistically significant correlation exists for either relationship for the exempt stoves (Figures 13 and 8).

Average net heat output of 6140 BTU/hr was also lower than the 8727 BTU/hr for the certified stoves. These outputs are both considerably lower than the 10,000-13,000 Btu per hour output range reported for most cordwood field studies. The lower outputs from pellet stoves are probably caused by the steadier output of pellet stoves compared to most cordwood stoves. The pellet stove homeowner is better able to “target” energy output to match heat demand than with woodstoves. Additionally, pellet stoves burn more evenly than woodstoves. Both of these features significantly reduce energy wastage from overheating. This effect was quantified in the 1982 New York-Ohio “in-home” woodstove study¹⁶ where steady state wood burning, using an automatic combustion control device was compared to typical erratic woodstove burning. Steady state burning produced an average energy savings of 20%.

PAH EMISSIONS (G/KG & G/HR) FROM A BRECKWELL (PM01) STOVE.

Comparison of 2 lab's results is shown.
AVERAGE PAH EMISSIONS- 40.3 ug/kg

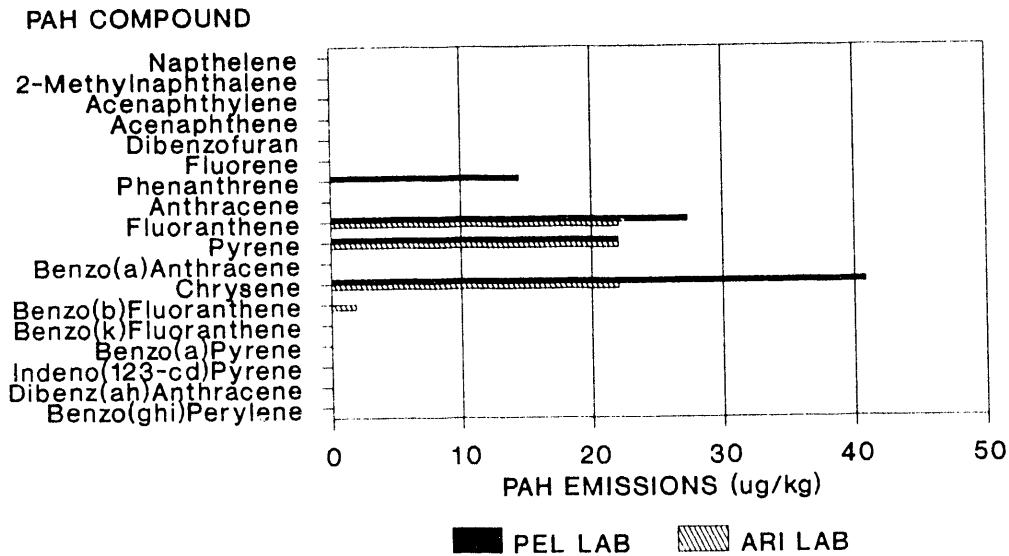


Burn rate was 1.0 kg/hr.
Therefore, g/hr and g/kg are equal.

Figure 11

PAH EMISSIONS (G/KG & G/HR) FROM A HORIZON (PM05). PEL AND ARI LABS

Comparison of 2 lab's results is shown
AVERAGE PAH EMISSIONS- 86.3 ug/kg



Burn rate was 1.0 kg/hr.
Therefore, g/hr and g/kg are equal.

Figure 12

AVE. BURN RATE VS G/HR PARTICULATES EXEMPT PELLET STOVES

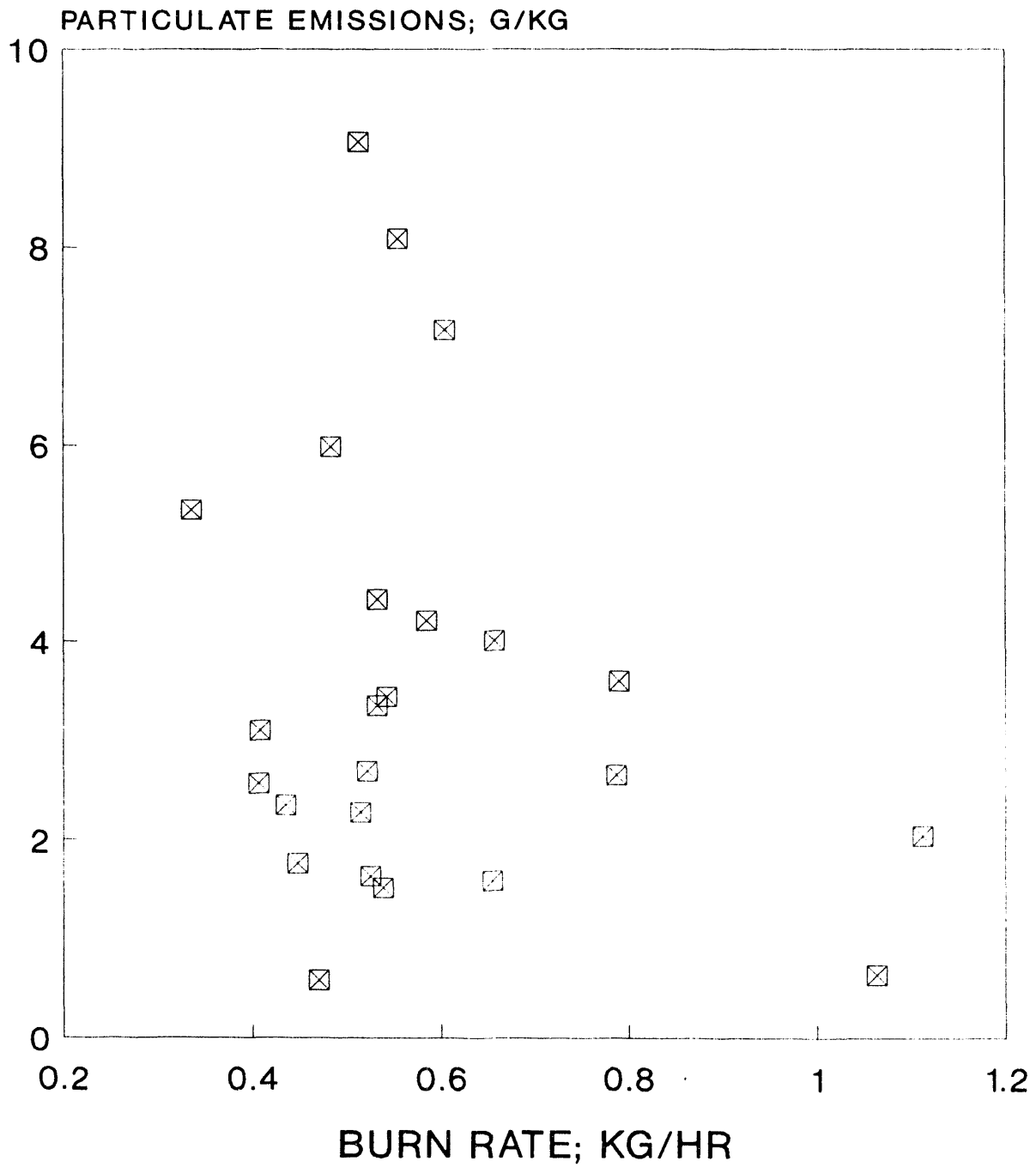


Figure 13

A second probable reason for low pellet stove heat outputs is that these stoves are capable of lower outputs than woodstoves. On warm days heat output can match heat demand, whereas on such days the woodstove would either be burned too hot for heat demand or not burned at all.

There is a weak positive correlation ($R = 0.505$) between heat output and degree days for the week-long tests (Figure 14). This indicates there is only a weak-moderate tendency for stoves to be burned at higher rates in colder weather.

The distribution of heat outputs is shown in Figure 15. A distinct clustering is evident. A significant minority of the weekly outputs are lower than cordwood stoves can attain, indicating pellet stoves are better suited for fall and spring burning.

Net Efficiency

The overall average efficiency for the pellet exempt stoves was 55.5%, considerably lower than the 68.4% average for the certified stoves. The Breckwell averaged 62.8%, the Horizon 55.5% and the Earth 33.9%. Examination of the individual stove models (Figure 16) reveals that efficiencies ranged from 74% for the certified Crossfire to 33% for the exempt Earth Stove.

An in-depth analysis was conducted to identify the causes for the marked net efficiency variations. Net efficiency is a function of both combustion efficiency and heat transfer efficiency. Since combustion efficiencies are close to 100% (98% for the certified and 96% for the exempt models) and display little individual variation between stove models, the variations in net efficiency cannot be explained by this factor. Therefore, transfer efficiency is the main cause of the net efficiency variation.

Heat transfer efficiency is related to two factors. One is the stack temperature of the flue gases as they exit the house. The hotter these gases are, the more heat that is wasted. Stack temperatures of both woodstove and pellet stoves have always been measured by OMNI at a point one foot above the flue collar. This is commonly the position of the flue's exit from the house for pellet stoves.

The second factor related to efficiency is the amount of dilution of the flue gases by excess air. The more excess air there is (a high air-to-fuel ratio), the more heat energy is lost out the stack and therefore, the lower the efficiency.

DEGREE DAYS VS HEAT OUTPUT EXEMPT PELLET STOVES

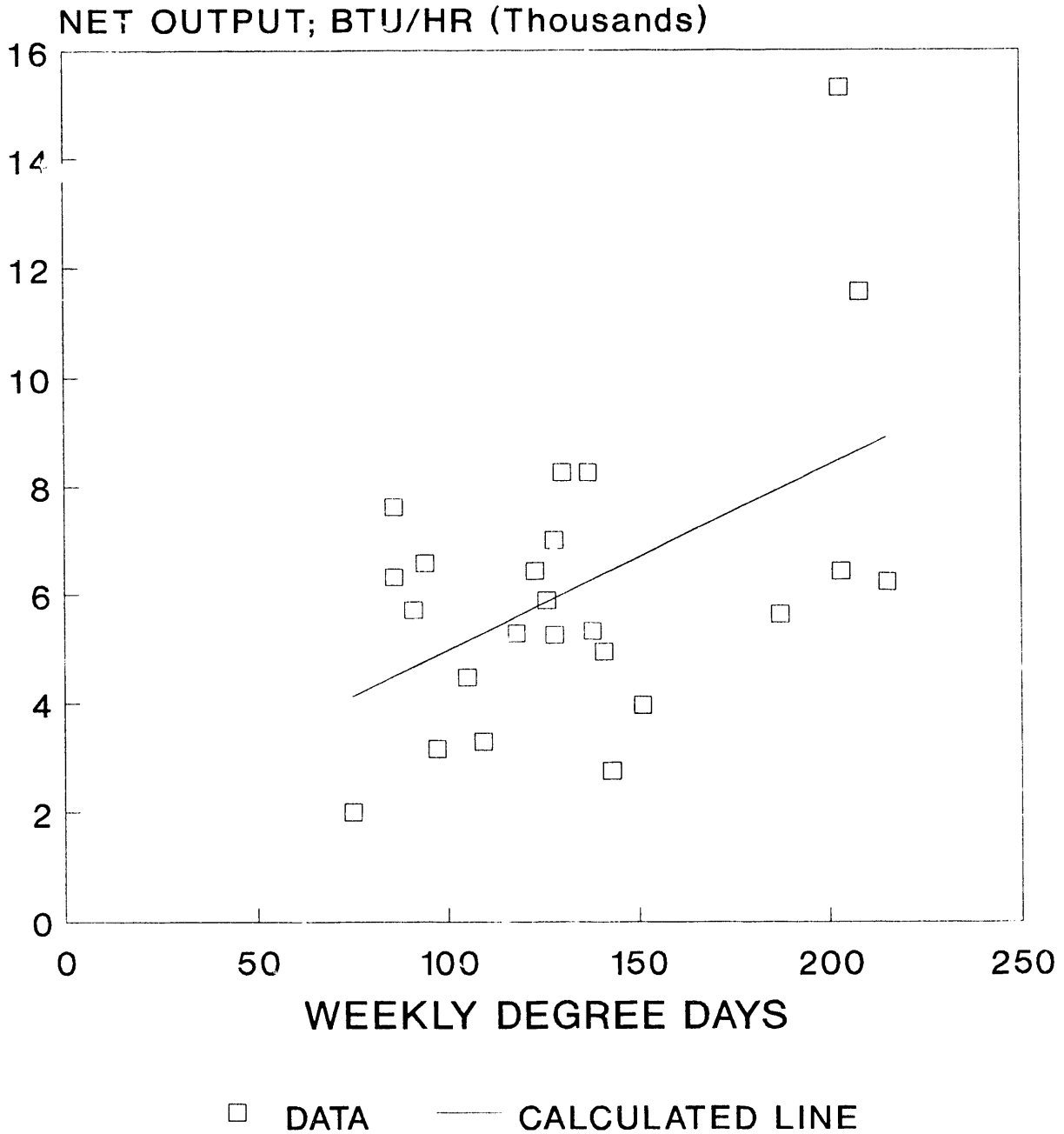


Figure 14

DISTRIBUTION OF HEAT OUTPUTS (BTU/HR) EXEMPT PELLET STOVES

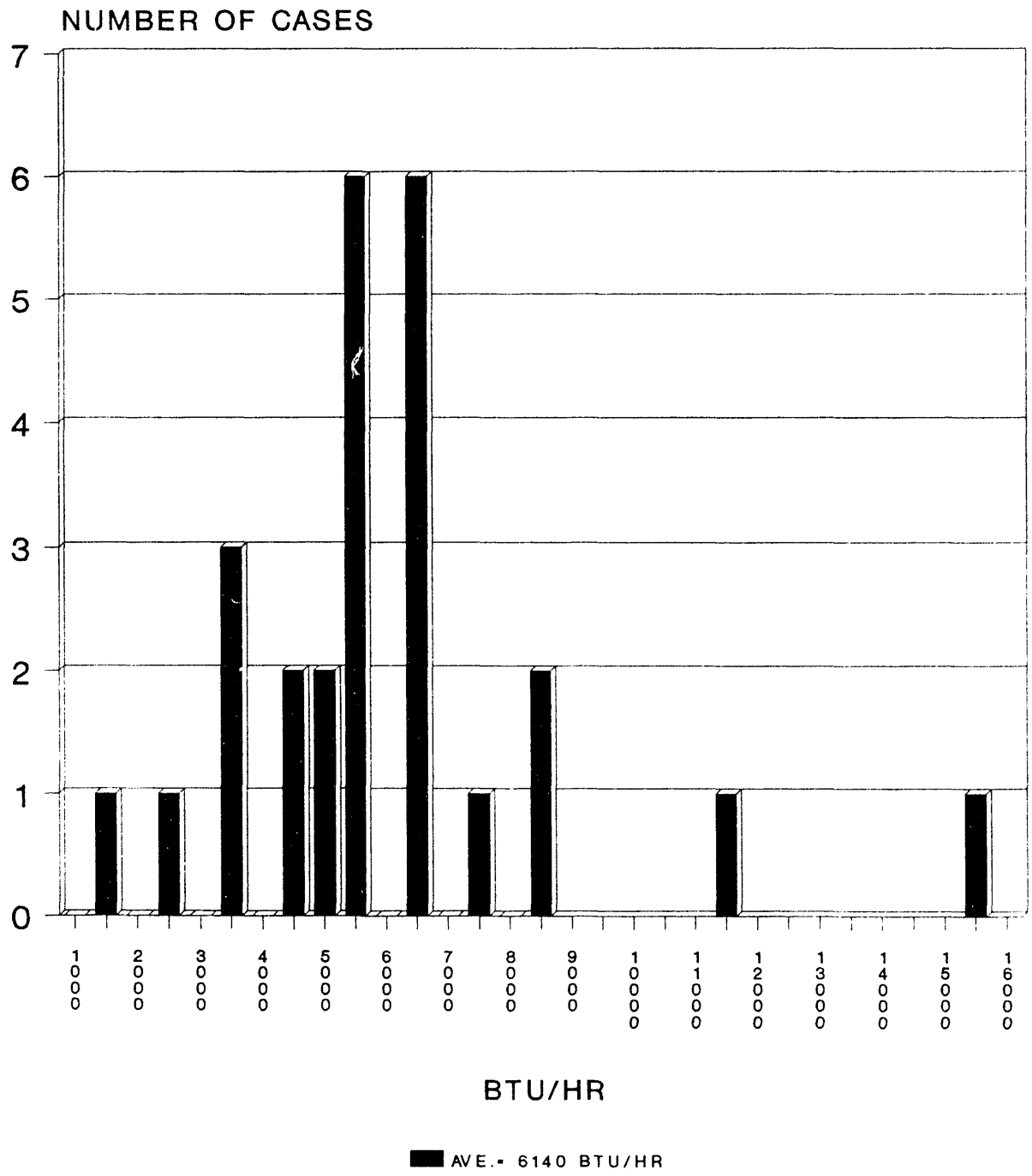


Figure 15

NET DELIVERED EFFICIENCIES OF CERTIFIED AND EXEMPT PELLET STOVES

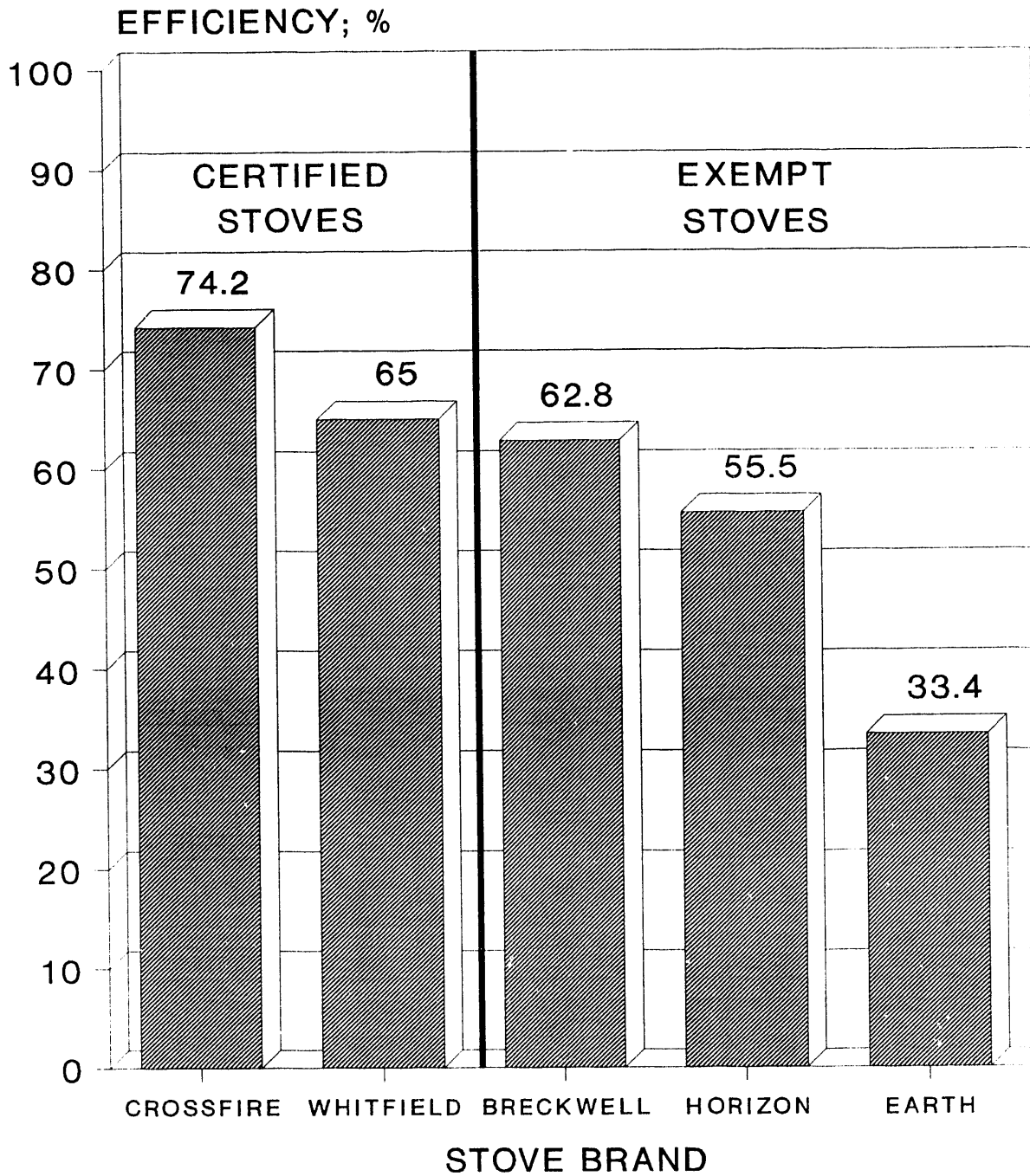


Figure 16

The heat transfer efficiency diagram in Figure 17 relates stack temperature (Y axis) and excess air (shown as stack oxygen on the X axis) to efficiency (dashed lines). Highest efficiencies (low stack temperature and low excess air) are on the lower left and low efficiencies (high stack temperature and high stack temperature) are in the upper right part of the diagram. The vertical line at an air-to-fuel ratio of 35:1 separates a “certified” zone to the left from an “exempt” zone on the right.

All of the one-week-long test runs are plotted on the graph, a letter represents each test. For example, each C represents a Crossfire test, B represents a Breckwell test, etc. Note that each stove model has its own cluster of points defining its “efficiency signature”.

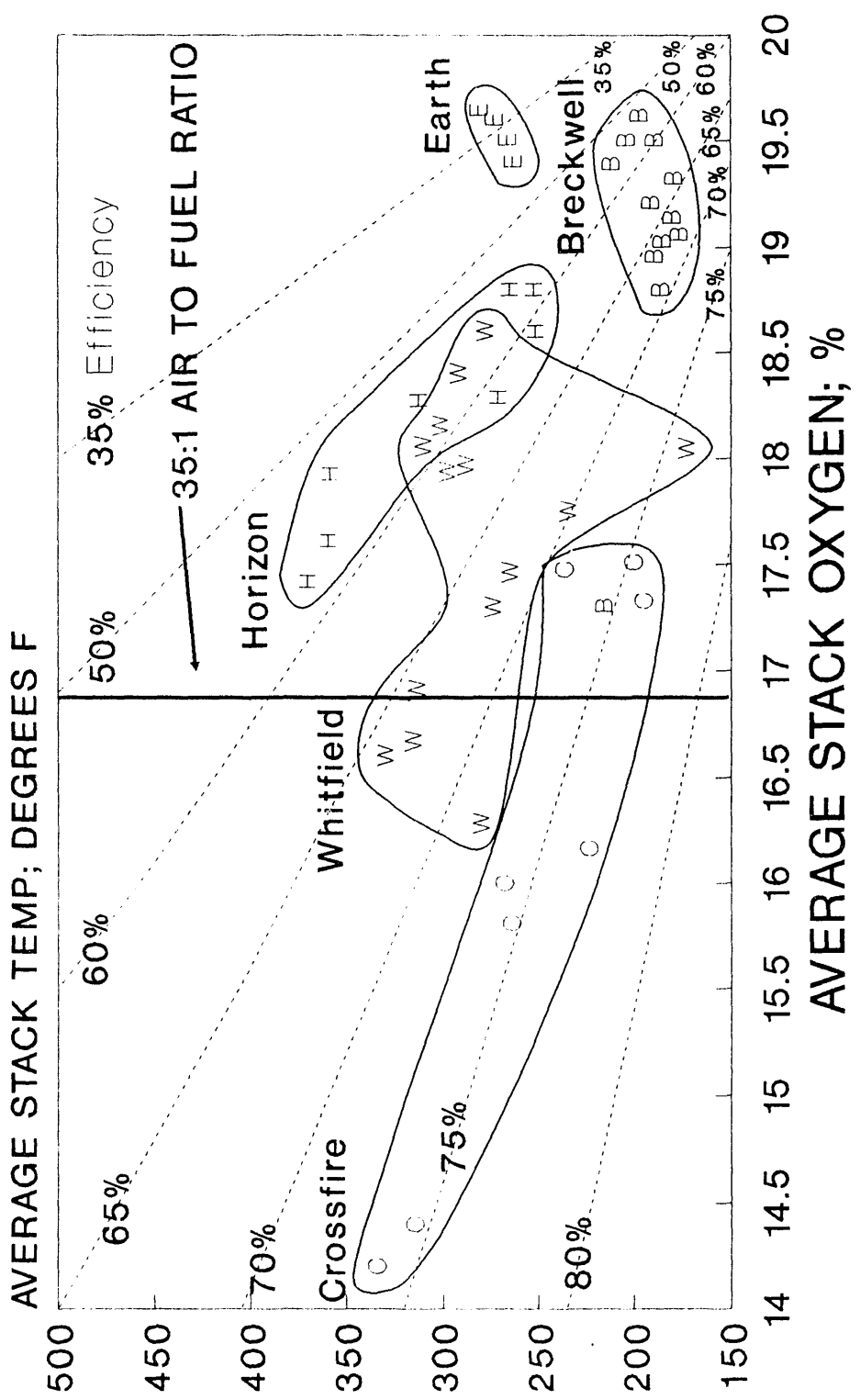
Examination of each stove’s efficiency plot for all the certified and exempt stoves reveals the causes for its efficiency level and how it could be improved. The efficient certified Crossfire is characterized by both low excess air and moderate to low stack temperatures. This stove may well represent the practical limit for a noncondensing pellet stove system. Lowering the stack temperature further could cause flue pipe condensation and decreasing the excess air could decrease combustion efficiency and possibly reduce flue gas humidity to a point where flue pipe condensation develops. This stove is no longer in production. It is not known if high efficiency in any way contributed to this.

The exempt Earth Stove displays low efficiency because it has both high amounts of excess air as well as relatively high stack temperatures. It could be brought to about 50% efficiency by decreasing stack temperatures alone but needs a reduction in excess air to achieve 70 to 75%. Unfortunately, it is difficult to draw definitive conclusions about this model since only one stove was monitored.

The exempt Horizon loses efficiency from both high stack temperatures and moderately high excess air. It could achieve about 65% efficiency via stack temperature reduction alone and achieve 70 to 75% by decreasing excess air.

The exempt Breckwell exhibits the lowest stack temperatures of the pellet stove group but its efficiency does not exceed 70% because of high excess air levels. Reducing excess air could allow it to achieve 70 to 75% efficiency.

HEAT TRANSFER EFFICIENCY DIAGRAM Certified and Exempt Pellet Stoves



Efficiencies are at 1' above stove top.
 B=Breckwell,ex;C=Crossfire,cert;E=Earth
 ex;H=Horizon,ex;W=Whitfield,cert.

Figure 17

The certified Whitfield has the least-defined cluster of efficiency points. This could have been caused by the presence of a damper shutter in the stove that allows the homeowner to adjust excess air. Stack temperatures are in the same range as the Crossfire. Its lower efficiency is caused primarily by higher excess air, which if reduced could allow the model to achieve an average of 70 to 75% efficiency.

This efficiency analysis shows that the exempt stoves have considerably higher excess air than the certified results and that this additional excess air has a significant effect on net efficiency. On the other hand, the Crossfire (which is no longer in production) demonstrates that pellet stoves can deliver about 75% efficiency by optimizing both stack temperature and excess air. Two of the four less efficient stoves could improve efficiency somewhat by lowering stack temperatures but all four would need to decrease excess air to attain 70 to 75% efficiency. Generally the exempt stoves would have to use an air-to-fuel ratio less than 35:1 to obtain 70 to 75% efficiencies. These stoves would then become certified models.

The lower efficiencies of the exempt stoves are possibly largely a byproduct of the industry's reaction to the EPA regulation whereby appliances with an air-to-fuel ratio of greater than 35:1 are exempt from certification. Lower efficiencies may have other causes as well. The president of Earth Stove indicated that high excess air was used to enhance flaming to promote stove sales. He also noted that this condition allows for burning of nut shells and other fuels.

These various strategies have probably caused a number of high excess air appliances, whose efficiencies are lower than certified appliances, to come on the market. This situation poses several important problems. At a current undelivered cost of about \$148 a ton for pellet fuel in western Oregon and Washington[†], heating with this fuel is relatively expensive compared to other home heating fuels, even for an efficient pellet stove[‡]. Burning less efficient stoves significantly increases the homeowner's operating cost.

The efficiencies of pellet stoves burned in houses are significantly lower than the 78% displayed on the EPA stove label indicating that the label is in need of some revision. Another emerging issue is the

[†] Average of a survey of 10 pellet stove dealers from Seattle to Medford conducted July 2, 1991 by OMNI. Dealers were asked what they anticipated pellet costs of Golden Fire and/or Lignetics fuel would be this coming winter.

[‡] At \$148 per ton for pellet fuel and 65% efficiency, cost per delivered million Btu is about \$14. Oregon Department of Energy's comparative cost sheet indicates for woodstoves that cordwood fir at \$135 per cord costs about \$10 per delivered million Btu at 65% and about \$13 at 50% efficiency, respectively. Central natural gas is shown as \$10.91 @ \$.60 per thermal and electric baseboard is \$14.65 at \$.05 per KWH.

growing potential shortage of the high quality, low ash content fuel that most pellet stoves burn. There appears to be a limited amount of this fuel available and increasing numbers of in-place stoves are causing this limit to be reached rapidly. There appear to be two needs: (1) stoves which burn low ash fuel should burn it efficiently, and (2) there is a need for the development of new stoves which can burn higher ash, less expensive fuels[†]. Appliances that can burn high ash fuels should probably not be used to burn low ash fuels unless they can do so efficiently.

The issues of efficiency, cost of operation, and future limited fuel supplies take on added importance if regulators regulate so as to encourage increased use of pellet stoves by imposing tight g/hr limits on residential biomass burning or by implementing various types of pellet stove purchase incentive programs.

[†] It is not known to the authors how well the stoves tested in the current projects can burn high ash content fuel.

Conclusions

Emissions of both certified and exempt pellet stoves investigated in this two-part project were low, averaging about 1 g/hr and 2 g/hr, respectively, or about 65% to 85% lower than the field performance of EPA Phase II woodstoves. However, this project reports on only twelve stoves representing five stove models. There are a growing number of certified and exempt pellet stoves that have not been evaluated, and drawing a conclusion on existing pellet stove technologies as a group is premature at this time.

The variation in particulate emissions is low compared to cordwood stoves. Existing variation appears to be more affected in most cases by how the stove was operated and maintained than the stove model.

Exempt stove emissions and burn rates displayed no statistically significant trend during the project.

PAH and CO emissions are low. The pellet stoves tested in this project demonstrate nearly complete combustion.

Net thermal efficiency averaged 55%, but individual stove models ranged widely from 33 to 63%. The lower efficiencies are related primarily by high air-to-fuel ratios and secondarily to elevated stack temperatures.

Heat outputs were considerably lower than those reported from field woodstove studies. One probable cause is the pellet stove homeowner's ability to "target" energy output to match heat demand better than with most woodstoves. Additionally, both of these features significantly reduce energy wastage from overheating. A second reason, is that since pellet stoves can be burned at lower outputs than woodstoves, pellet stoves can be burned on warm days and match heat demand, whereas woodstoves would either be burned hotter than heat demand required subjected to frequent start-up, or not be burned at all.

Durability has been evaluated in only a limited way. Four of the six certified stoves were one year old and one exempt stove was two years old. These had no higher emissions than the new stoves. Durability could become an issue with pellet stoves in the long run because the more complex designs and maintenance requirements could make them more prone to breakdown. Component durability was not analyzed in the current study.

Recommendations

The pellet stove technologies evaluated in this study demonstrated their potential to provide significant decreases in emissions compared to conventional woodstoves as well as EPA Phase II certified woodstoves. However, it would be premature to conclude that pellet stoves can provide a viable alternative to these technologies in the long term. For example, the issue of durability in pellet stoves has not yet been adequately addressed. The pellet stove industry is relatively new. As a wood heating appliance, pellet stoves are the most complex unit available to the home consumer. Many of the stove's components are beyond the ability of the homeowner to fix. Therefore, the stoves need to have an extra measure of durability built in to make pellet stoves a reliable alternative to woodstove heating. The performance of these stoves and of the certified stoves should be followed over the years to evaluate deterioration potential.

Not all pellet technologies currently available are likely to perform as well as those evaluated in this study. While the main stove selection criterion for this study was to choose stoves that had the largest market share, predicted durability was also a factor. This stove sample possibly represents some of the best of the exempt pellet stove market, and in terms of emissions these stoves may not be representative of all pellet stove technology. Future work should take into consideration a larger segment of the stove market to adequately understand emissions and efficiencies of various pellet technologies.

This study evaluated pellet stoves using only one type of pellet fuel. The field performance of pellet stoves using the variety of pellet fuels available should be documented as well. It is possible that emission rates are sensitive to fuel type.

To fully understand and characterize the health effects of pellet stoves, the following areas are also in need of evaluation.

1. Carcinogenic components of pellet stove emissions.
2. The effects of fugitive emissions of pellet stoves on indoor air quality.
3. Particle size distribution of pellet stove emissions.

Using air dispersion modeling and field data, the pollution reduction of multiple scenarios should be evaluated, for example, by replacing various percentages of conventional stoves with differing mixes of competing heat sources: pellet stoves, clean-burning cordwood stoves, electric heat, and gas appliances.

A cost analysis for pellet stoves should be conducted including purchase and operational costs. Comparisons should be made with competing forms of heat such as high technology cordwood stoves, central and space gas heat, oil heat and electric heat. These analyses should be conducted for various regions where pellet stove populations are likely to be large since competing fuel costs vary considerably.

An analysis of the security of the future supply of pellets should be conducted. For example, what effect might competing uses for sawdust, and increases in the number of in-place pellet stoves, have on pellet supply and prices? Lower grade, higher ash content fuels should be investigated and stoves developed to burn them effectively. This should broaden acceptance of pellet stoves across North America.

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Appendix A

Graphs of stove performance and Photographs of stoves and stove installations

Contents

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0.	Contents	A-i
1.	Graphs of stove performance	A-1
2.	Photographs of stoves and stove installations	A-19

Stove Performance Graph Explanation

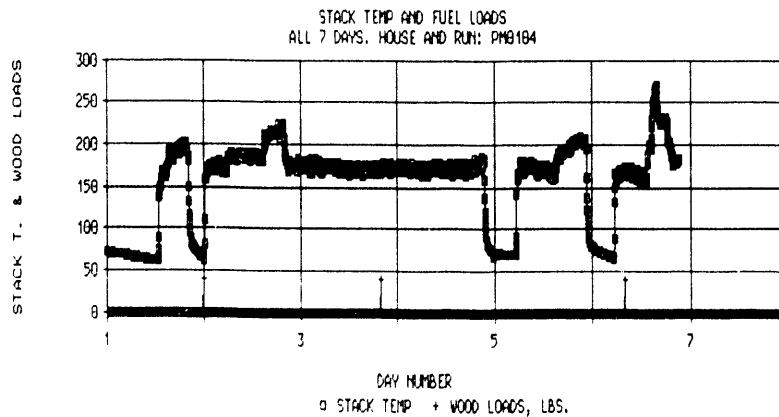
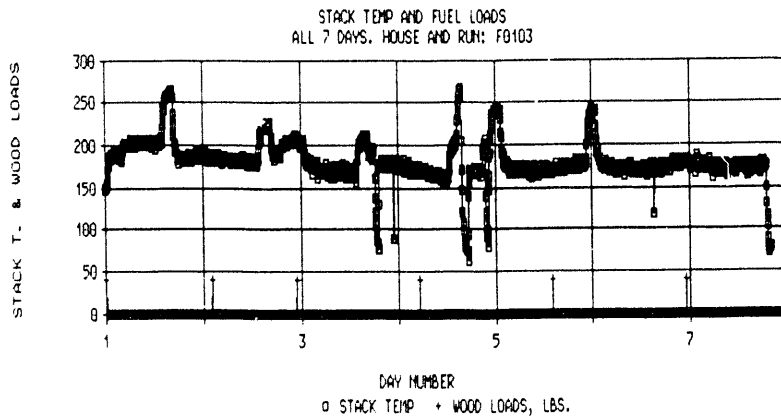
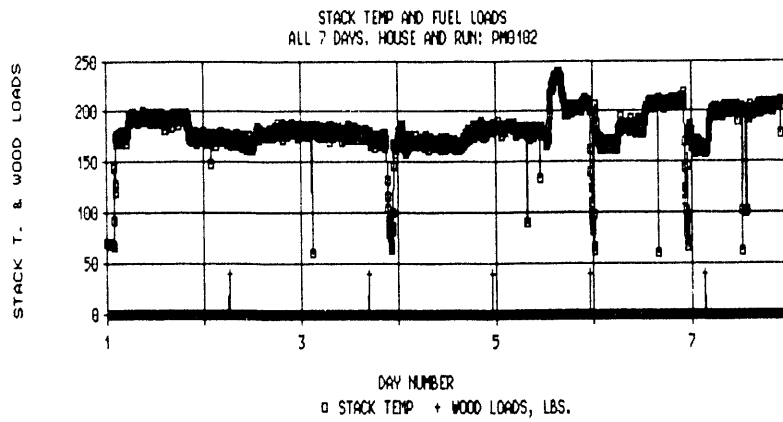
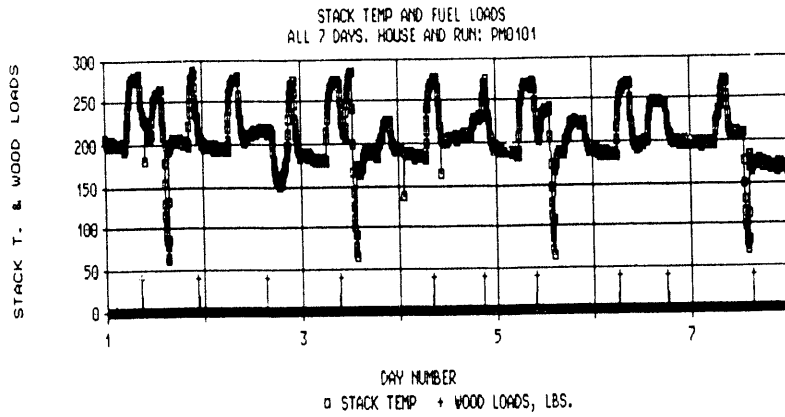
Stack temperature and fuel load graphs: The stack temperatures are shown by the continuous line. The line tends to look like a series of plateaus, each representing operation at a given setting. Stove shutdowns are depicted by the “valleys” in the profile that dip below 100°. The fuel loads are shown by the vertical spikes, the height of which is the weight of the fuel load in pounds.

Stack oxygen graphs: The oxygen content of air is 20.9%. Stack oxygen will vary from this value (during periods of no burning) to values in the teens. Since stack oxygen is highly correlated with stack temperature, lowest stack oxygen values represent periods of highest burn rate.

House ambient temperature graphs: This graph is a continuous trace of ambient temperatures in the room that is heated by the pellet stove.

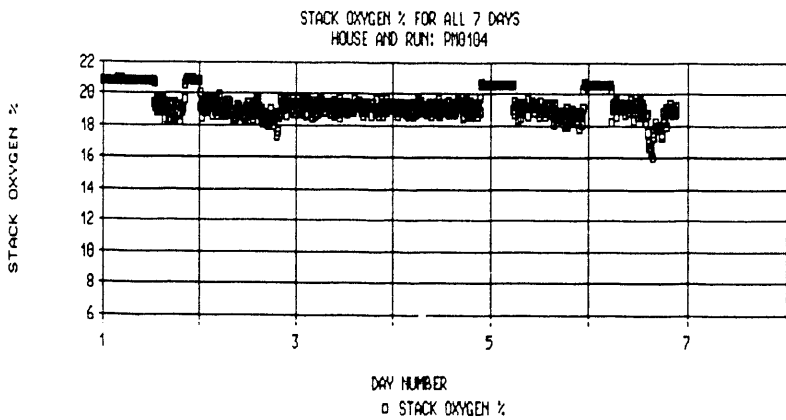
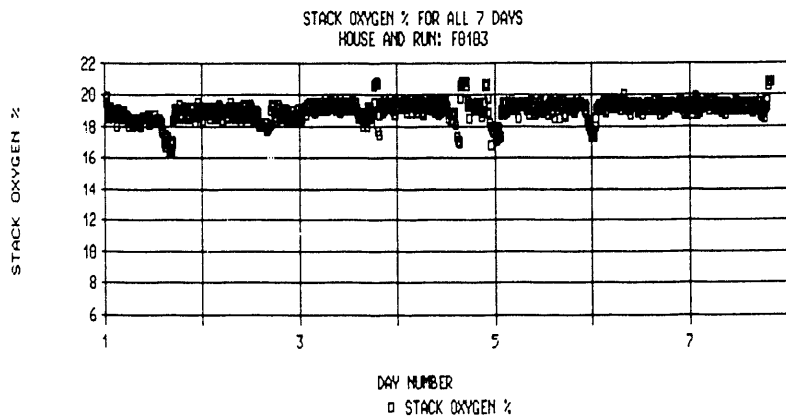
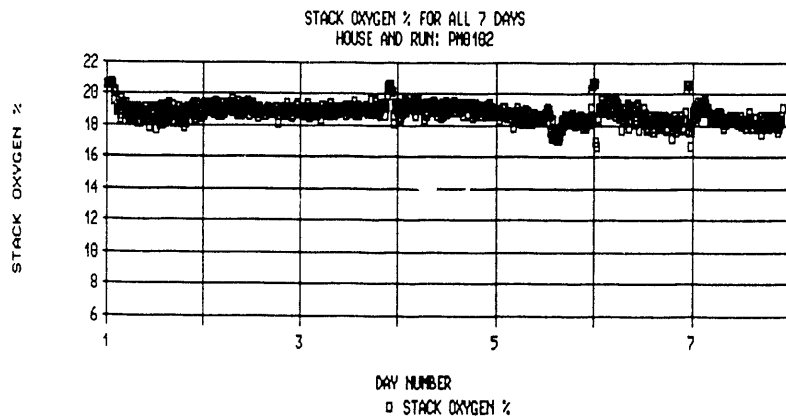
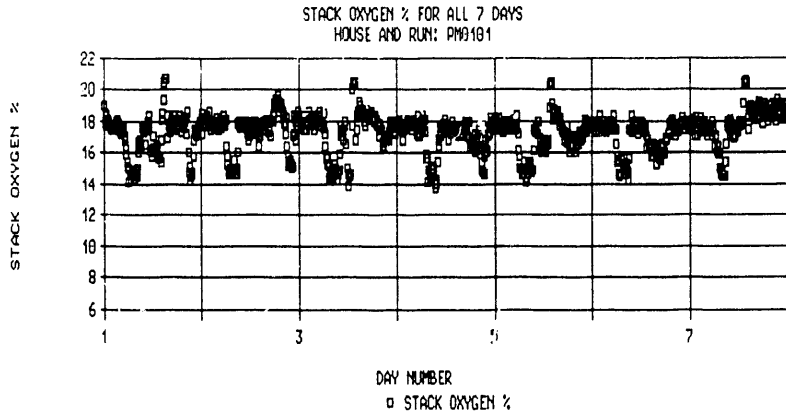
Home 1; Breckwell

Stack Temperature and Fuel Loads



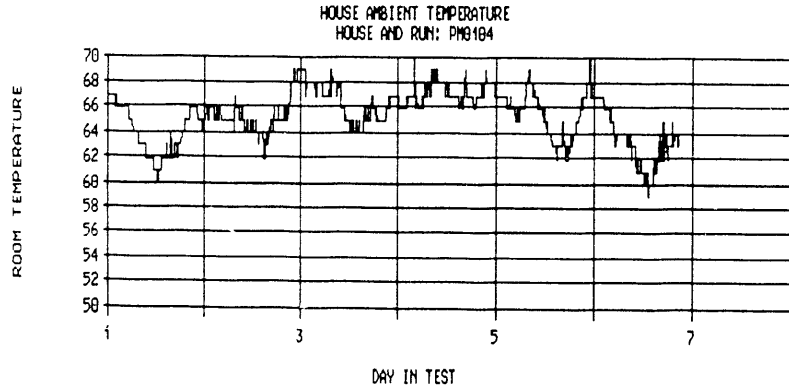
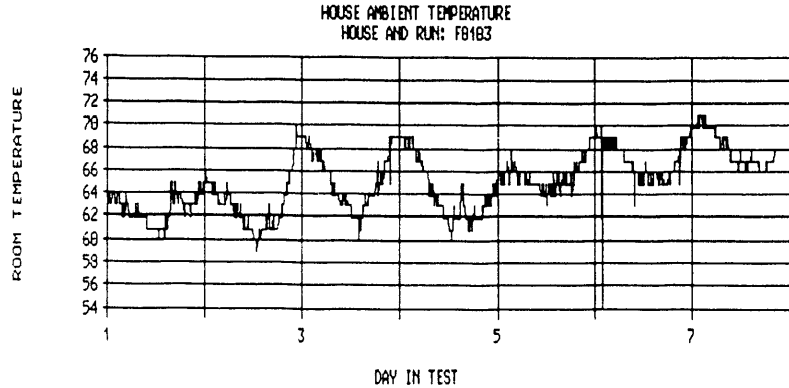
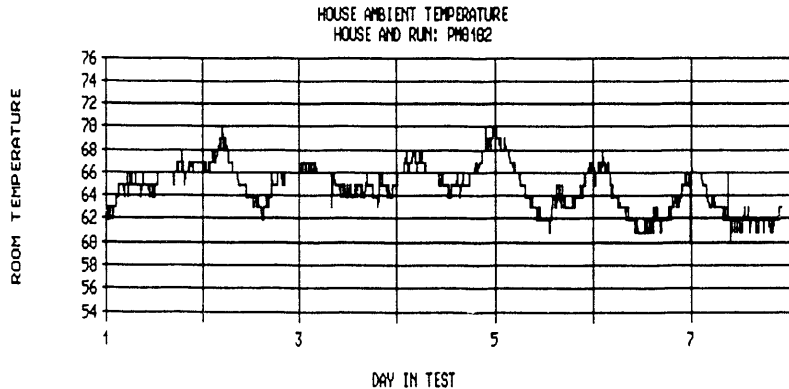
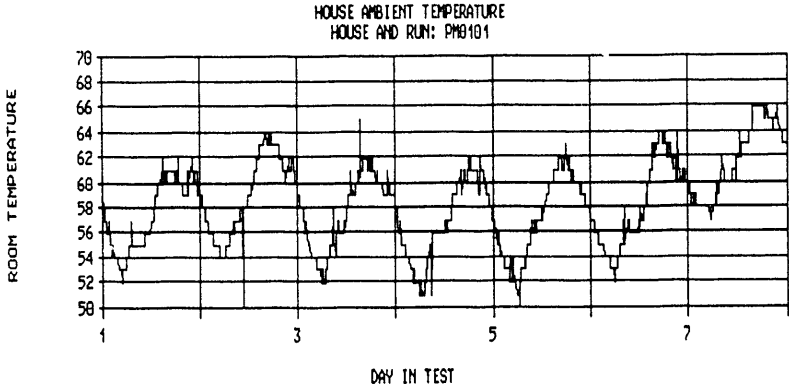
Home 1; Breckwell

Stack Oxygen



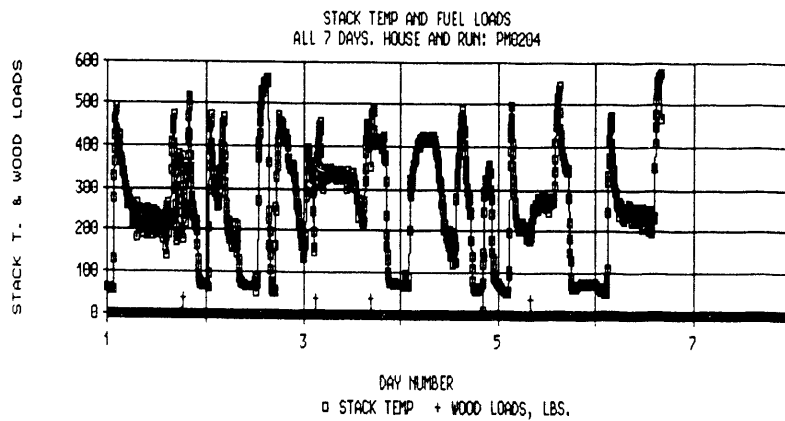
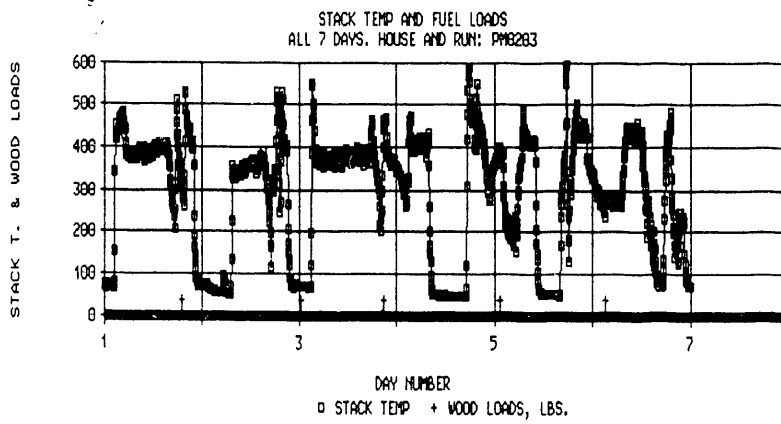
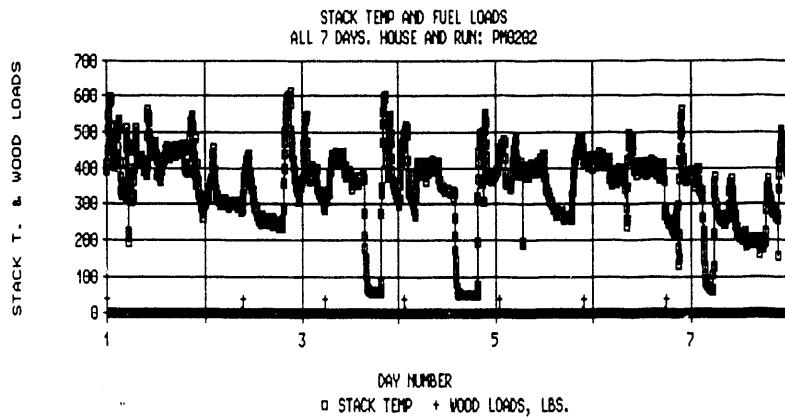
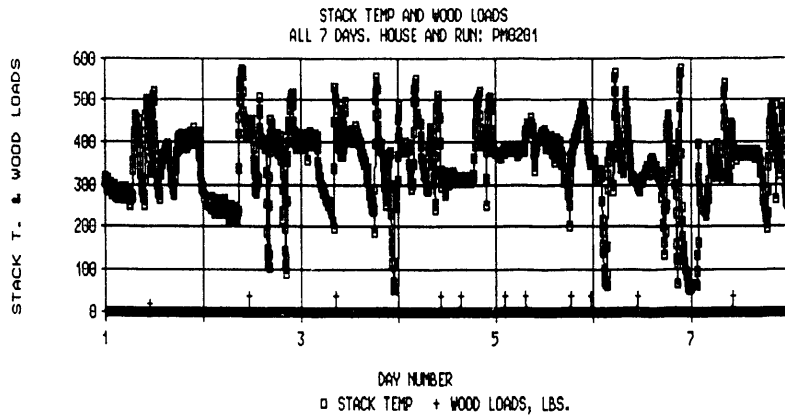
Home 1; Breckwell

House Ambient Temperature

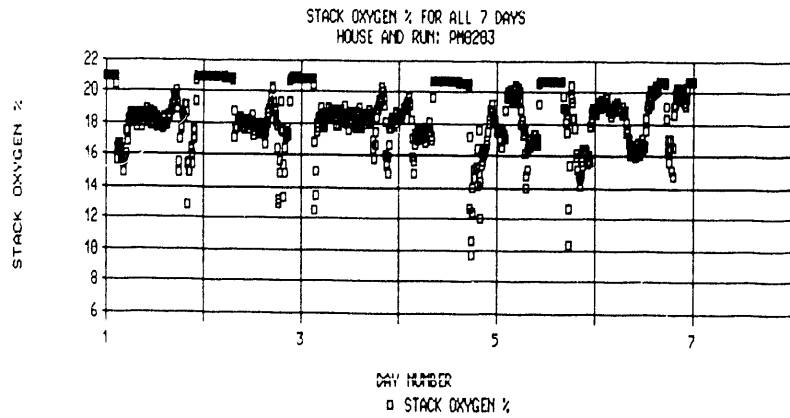
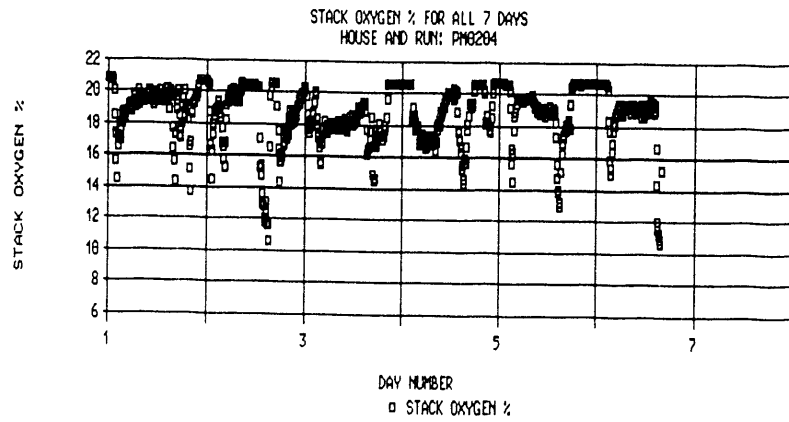
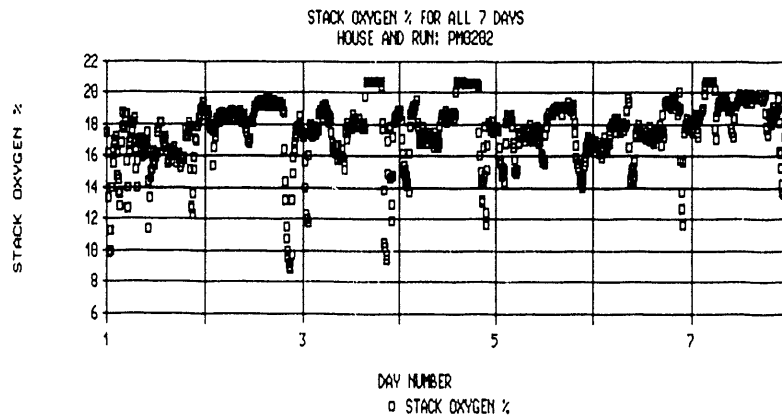
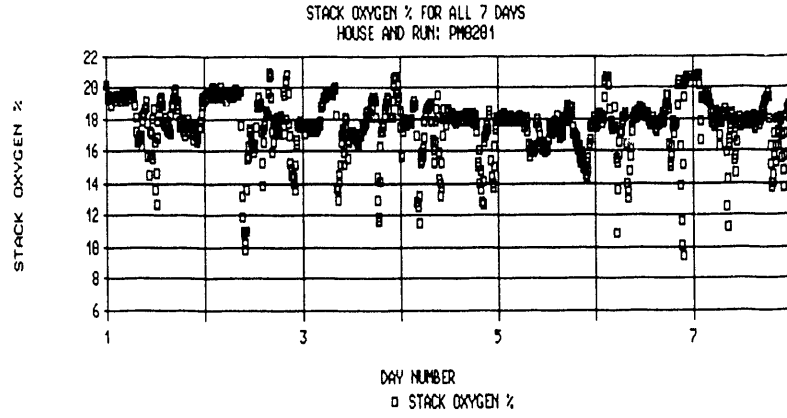


Home 2; Horizon

Stack Temperature and Fuel Loads

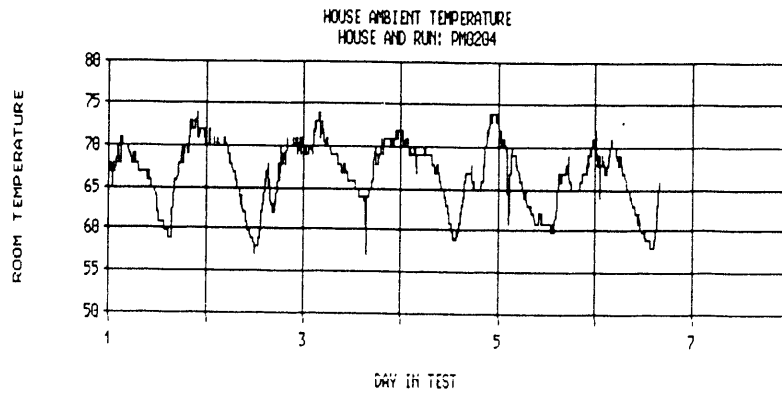
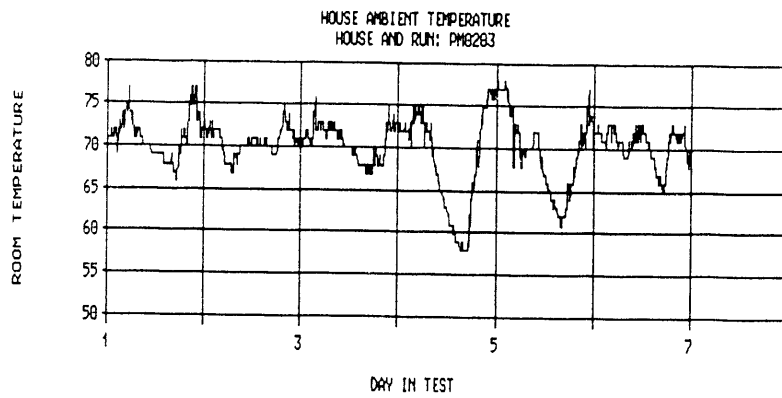
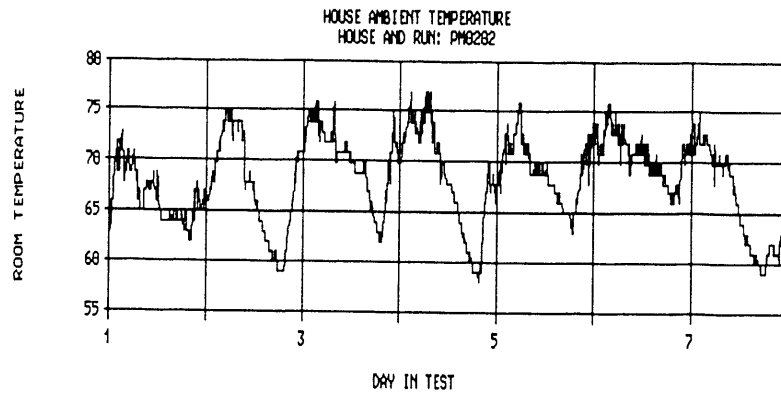
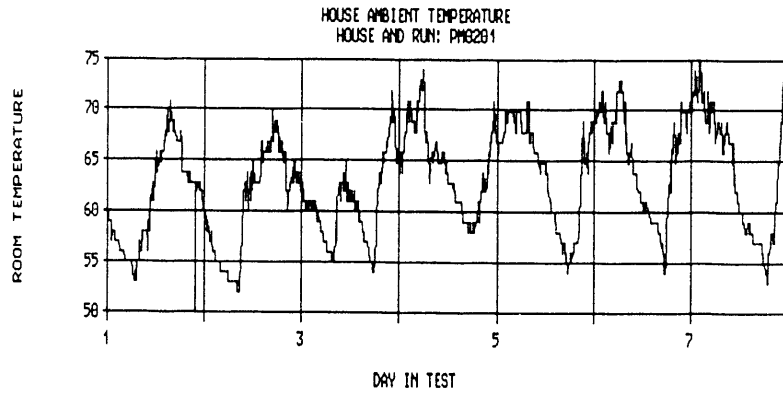


Home 2; Horizon Stack Oxygen



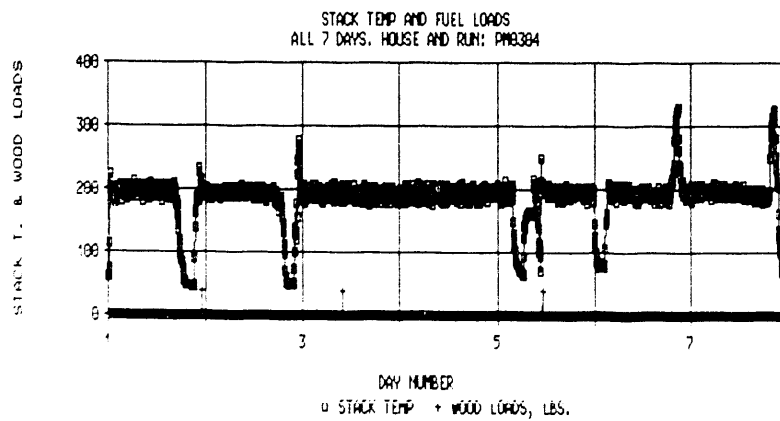
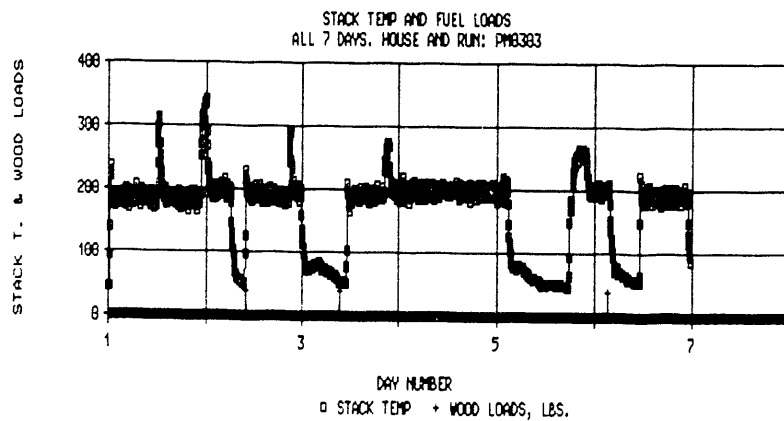
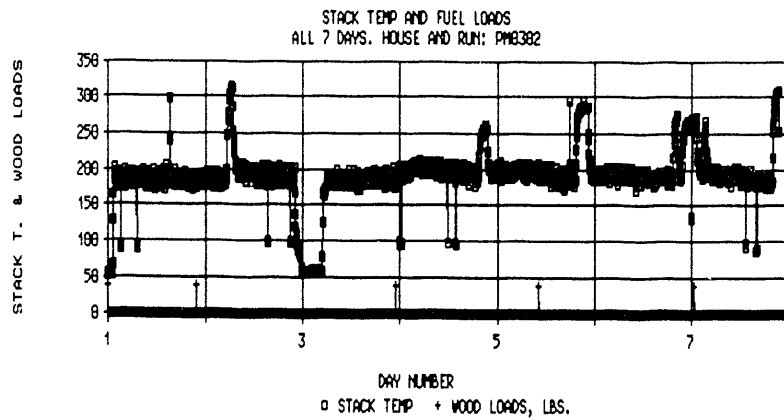
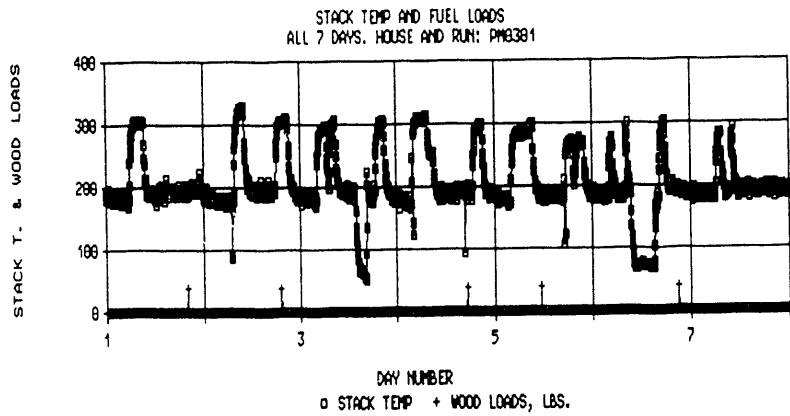
Home 2; Horizon

House Ambient Temperature



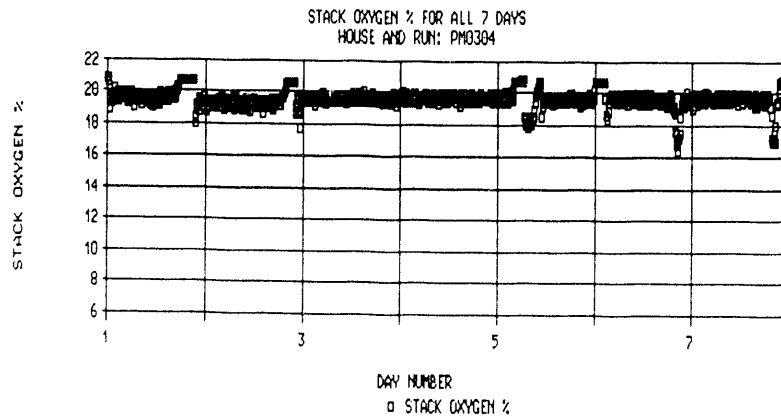
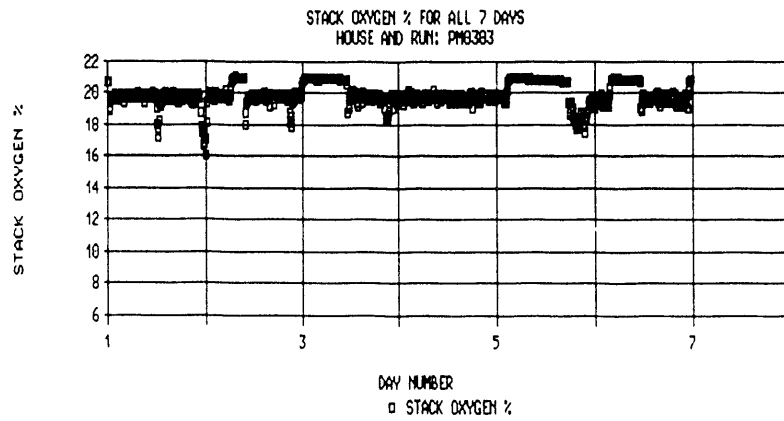
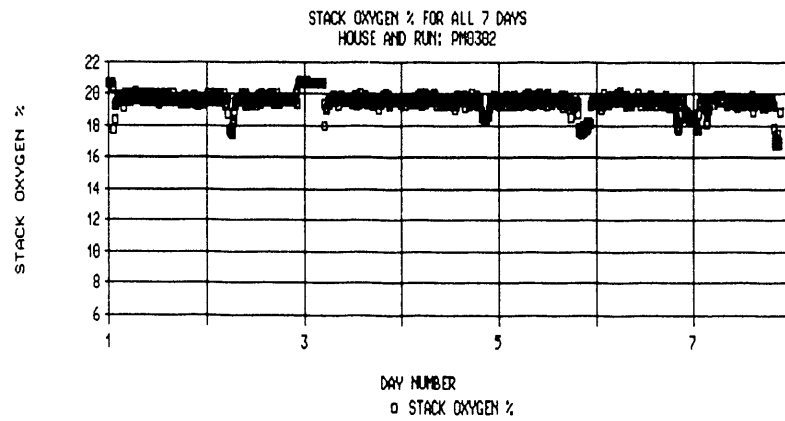
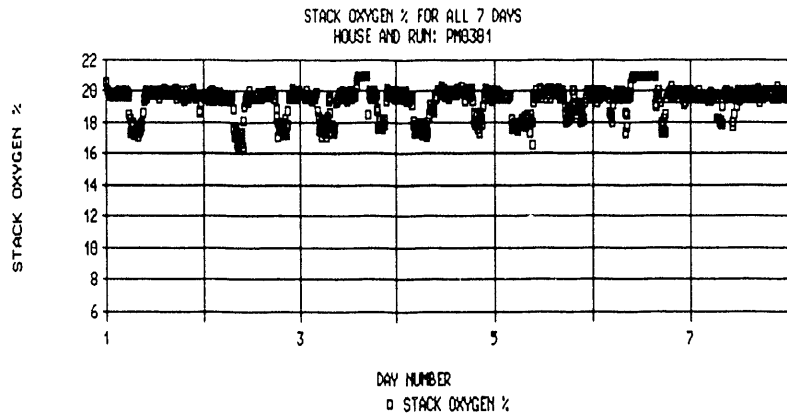
Home 3; Breckwell

Stack Temperature and Fuel Loads



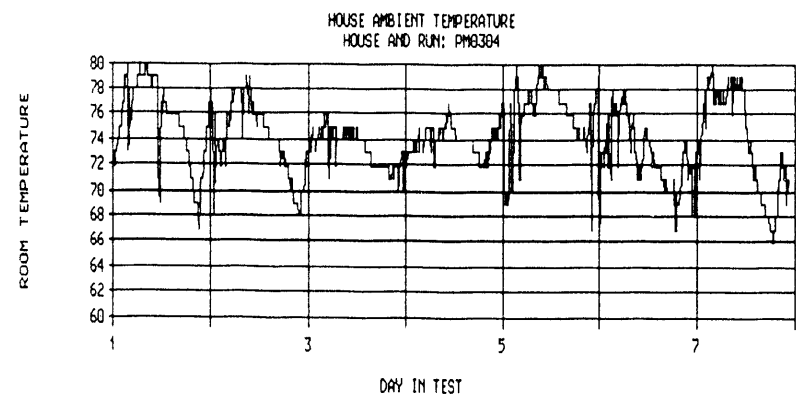
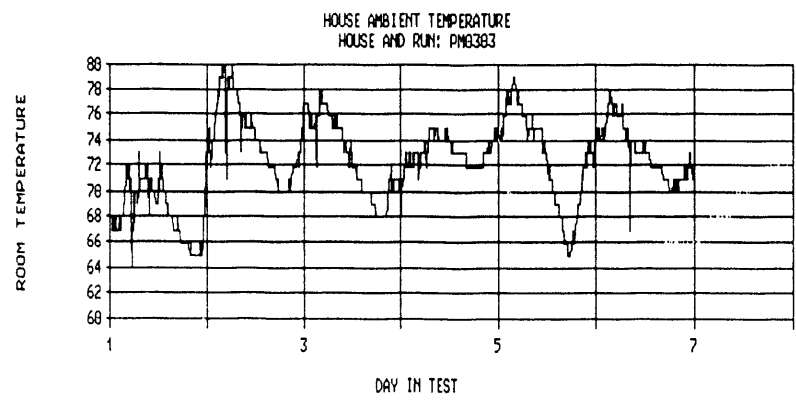
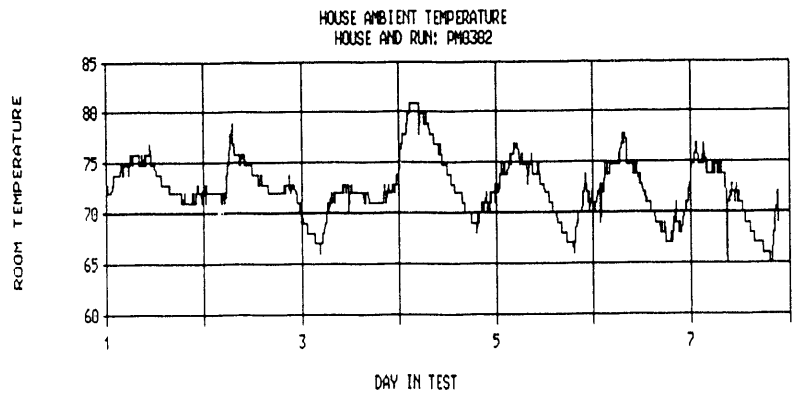
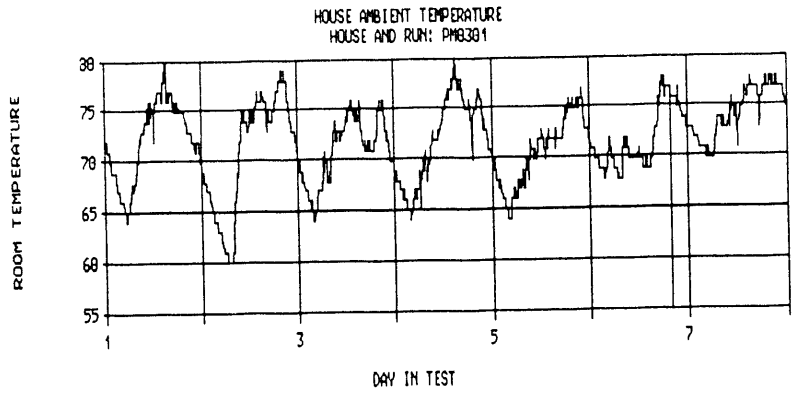
Home 3; Breckwell

Stack Oxygen



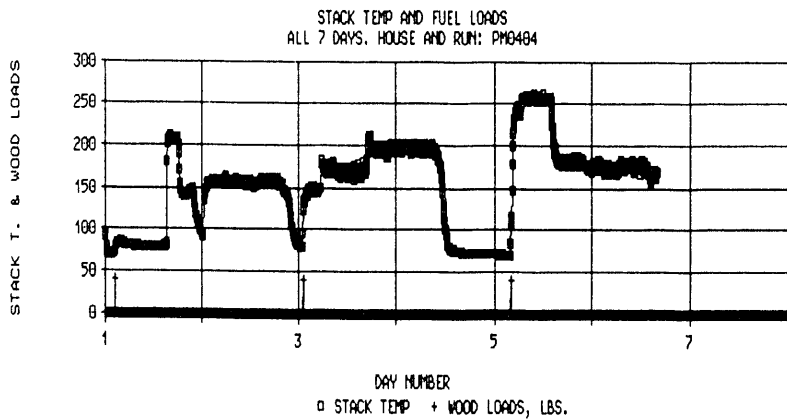
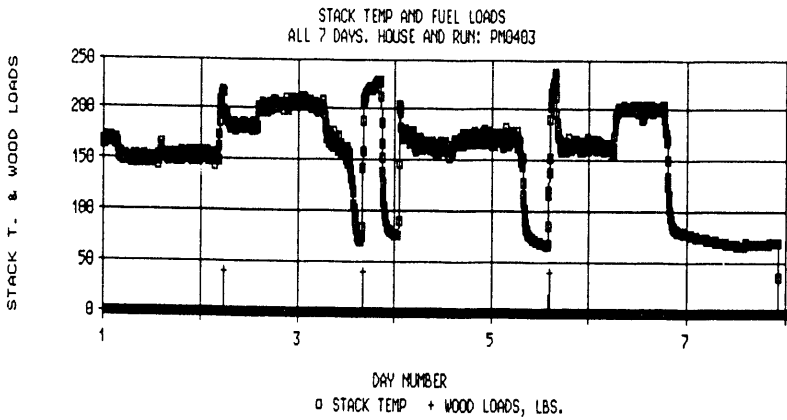
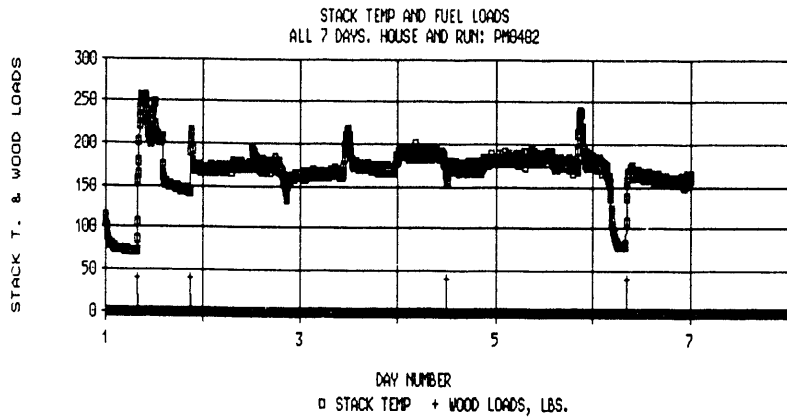
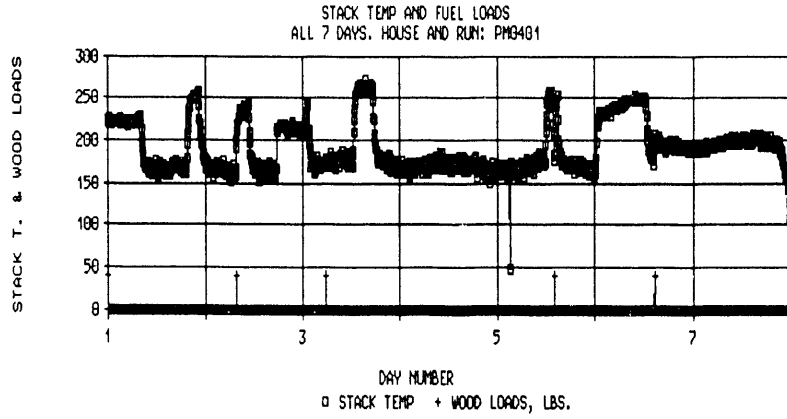
Home 3; Breckwell

House Ambient Temperature



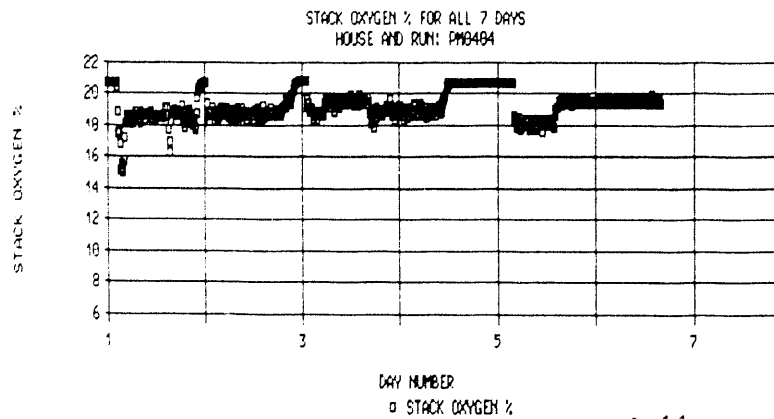
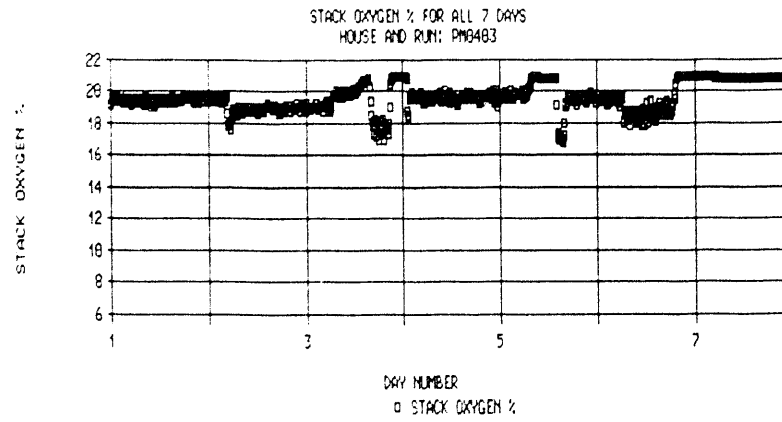
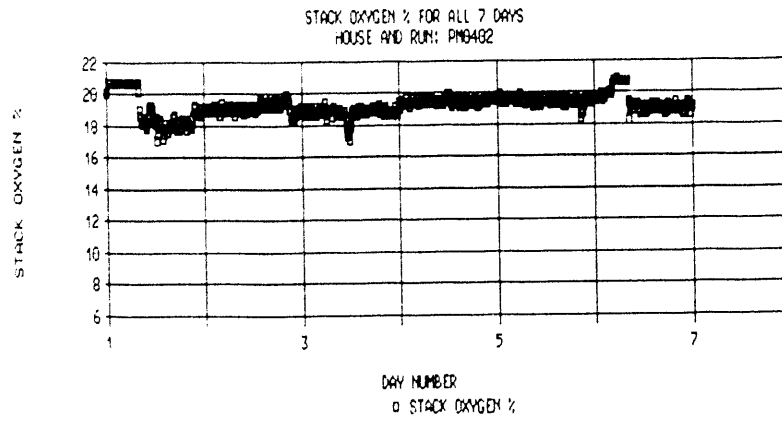
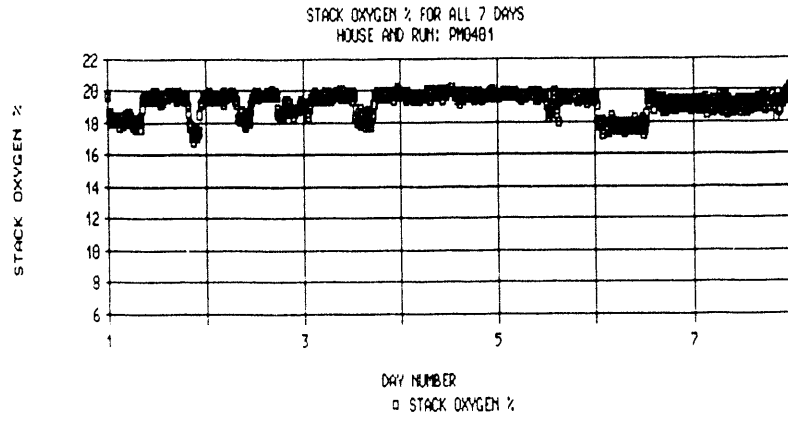
Home 4; Breckwell

Stack Temperature and Fuel Loads



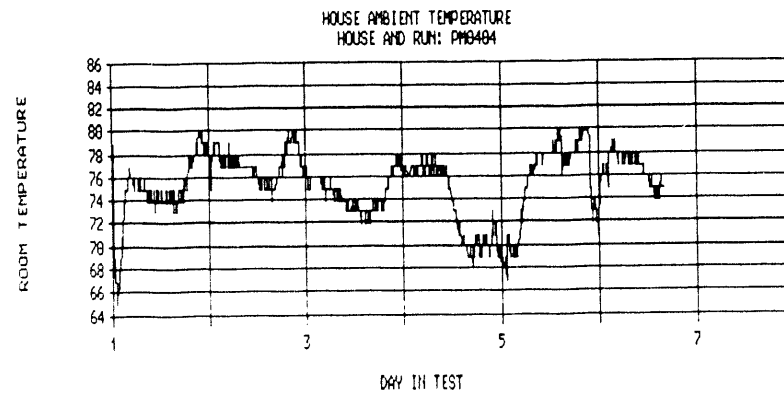
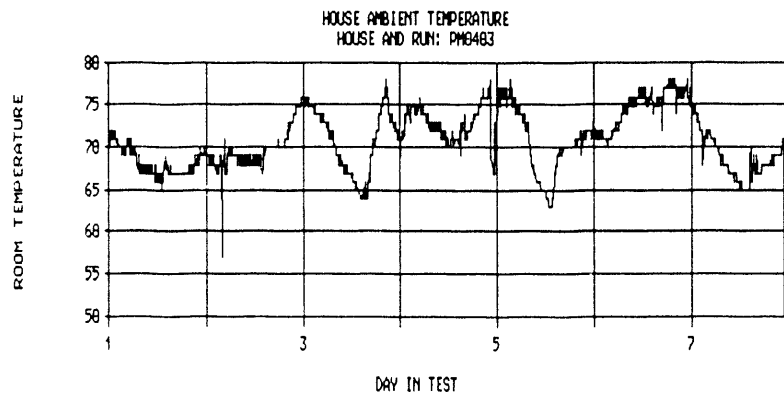
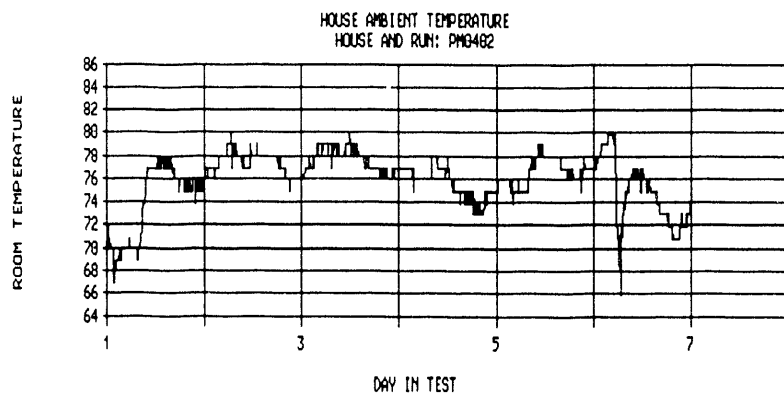
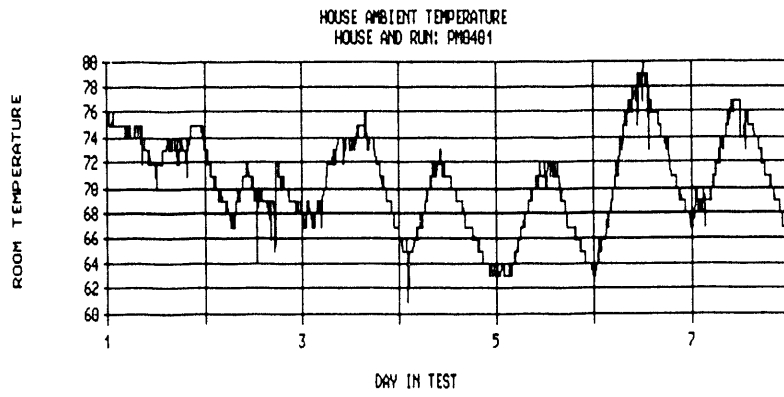
Home 4; Breckwell

Stack Oxygen



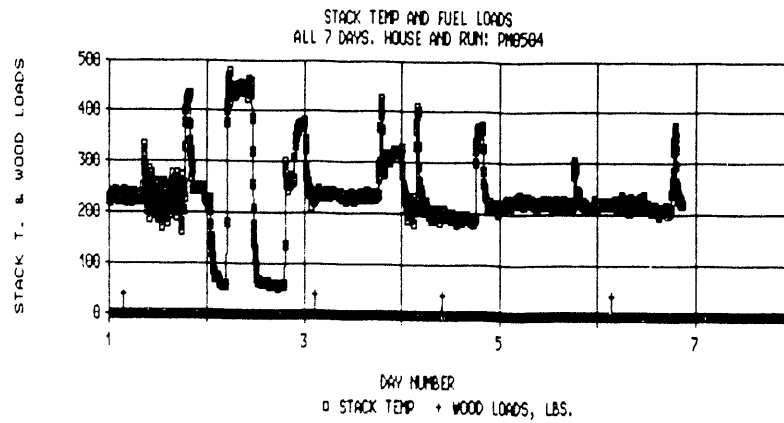
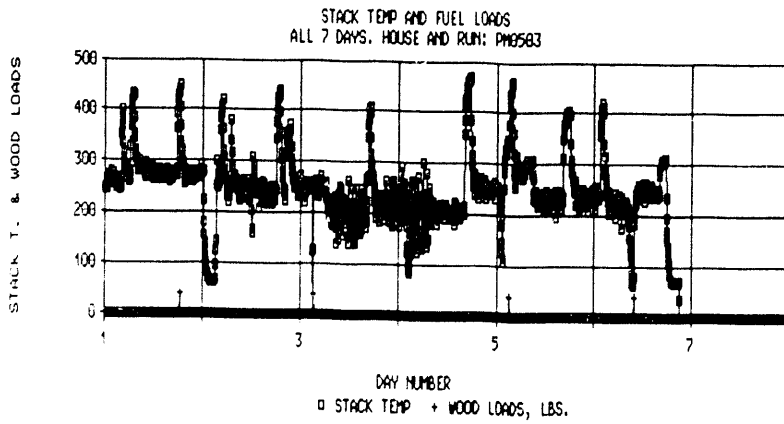
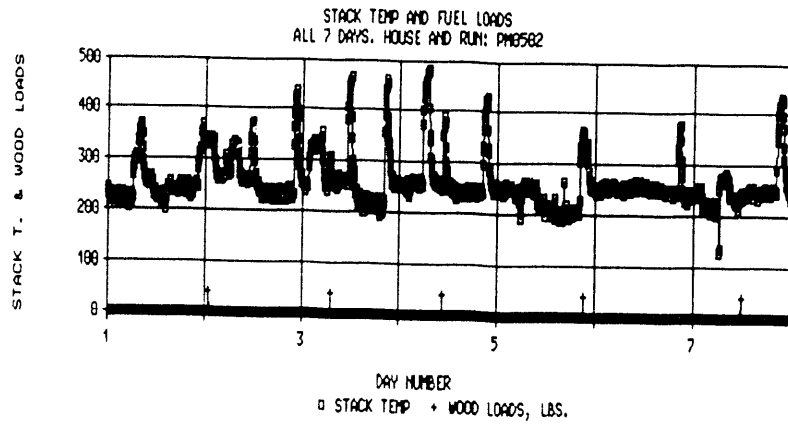
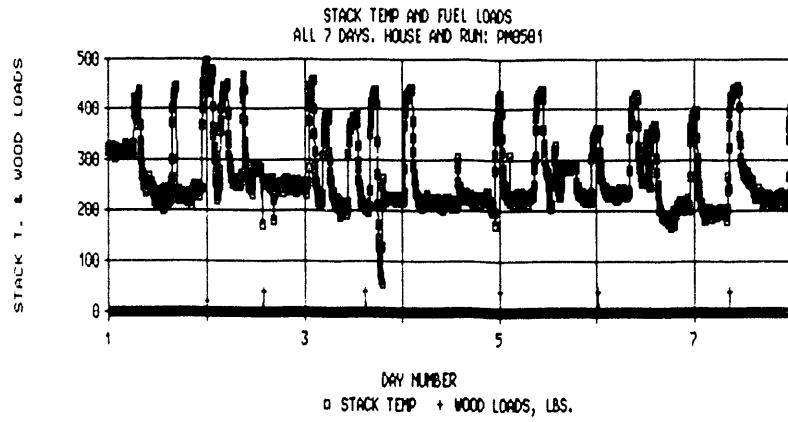
Home 4; Breckwell

House Ambient Temperature

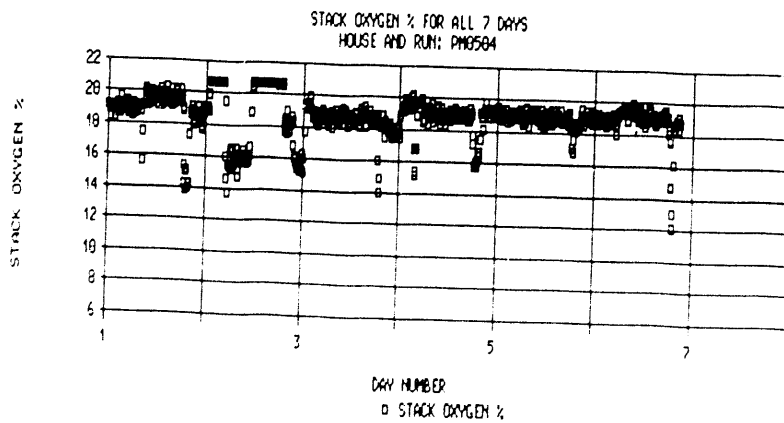
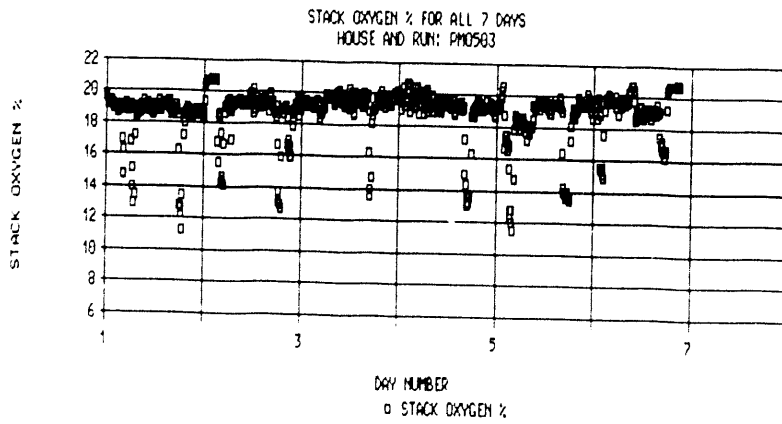
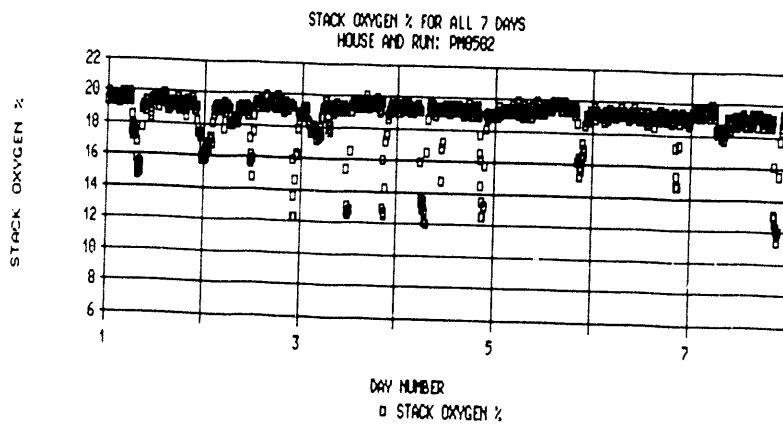
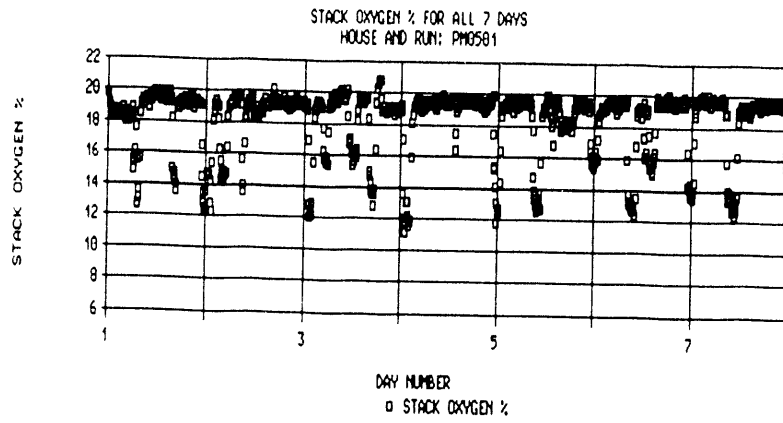


Home 5; Horizon

Stack Temperature and Fuel Loads

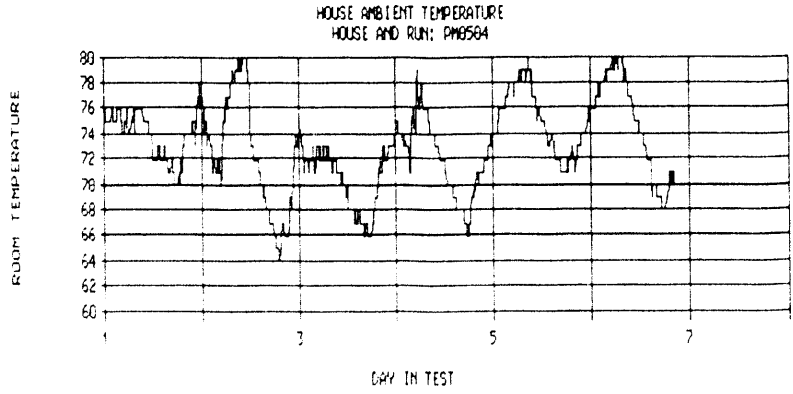
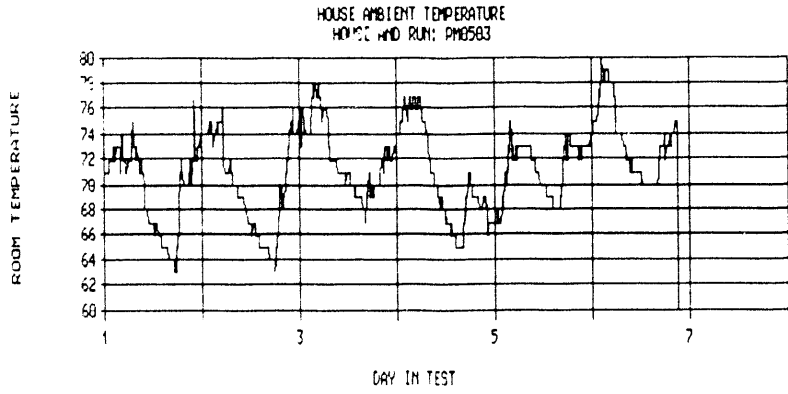
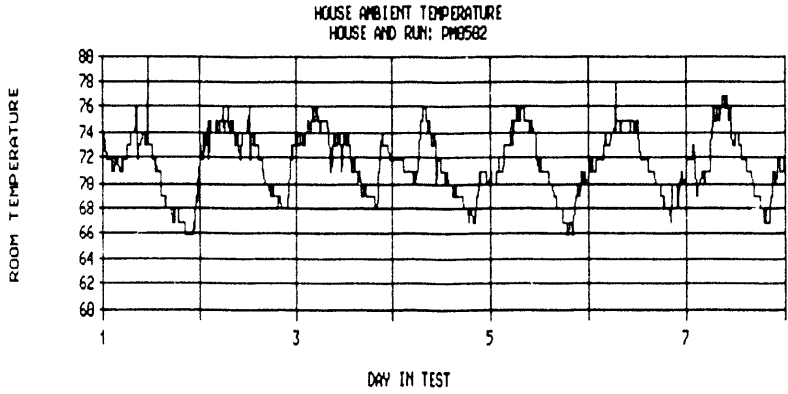
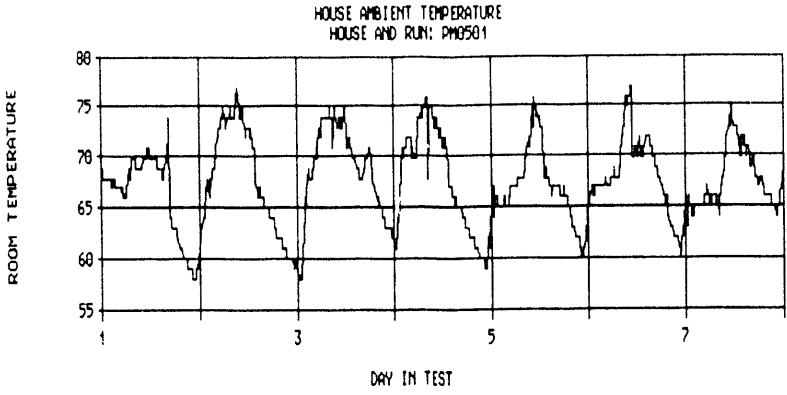


Home 5; Horizon Stack Oxygen



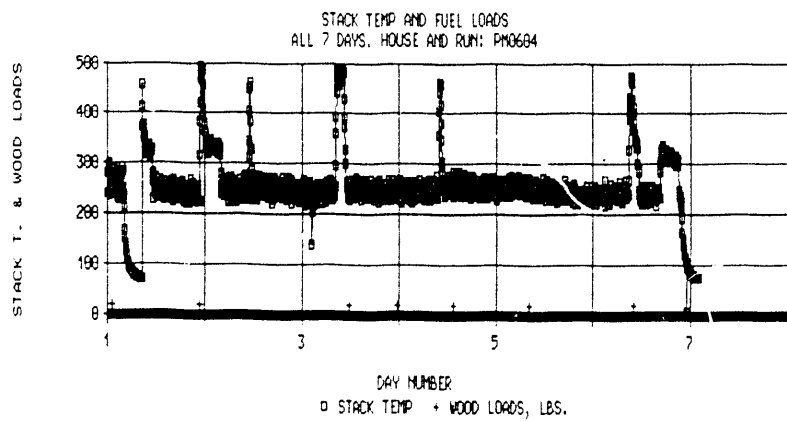
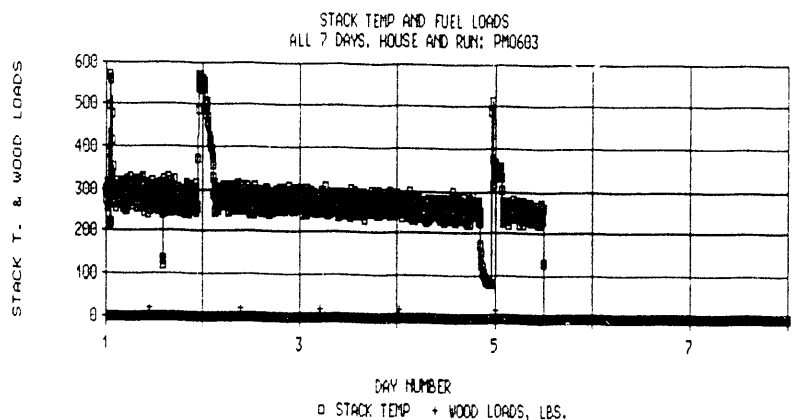
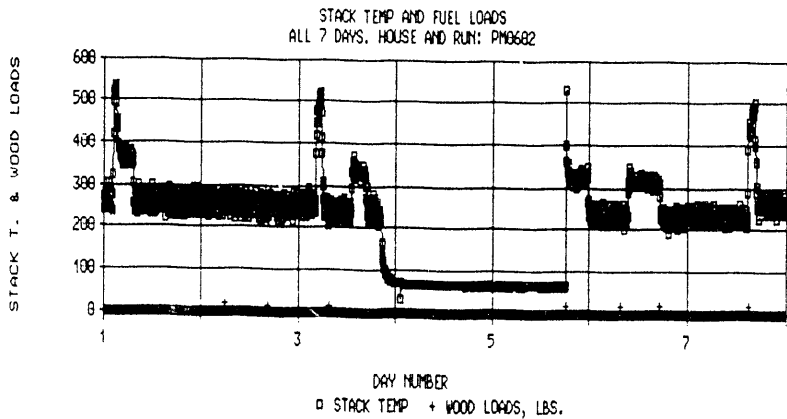
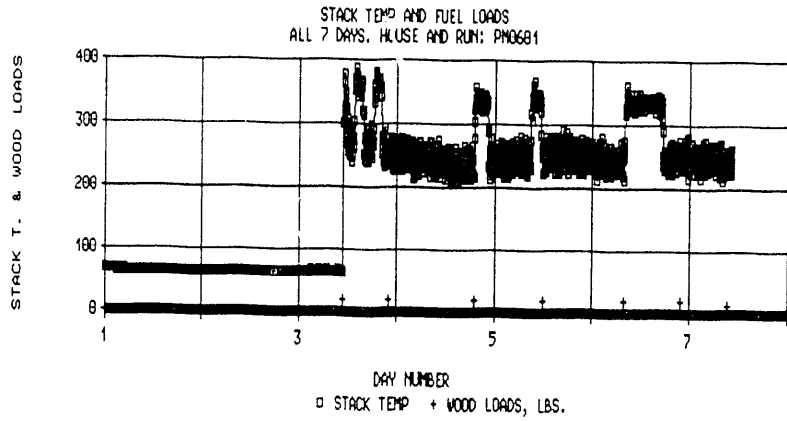
Home 5; Horizon

House Ambient Temperature

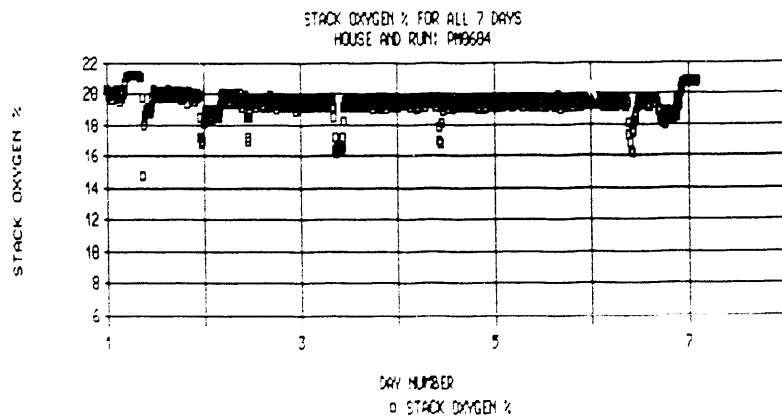
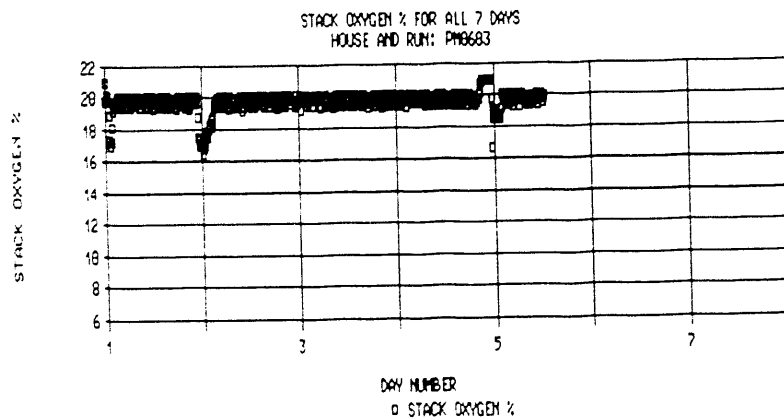
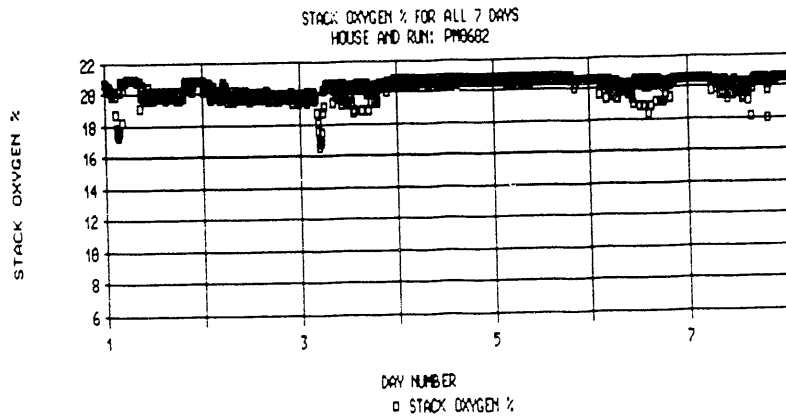
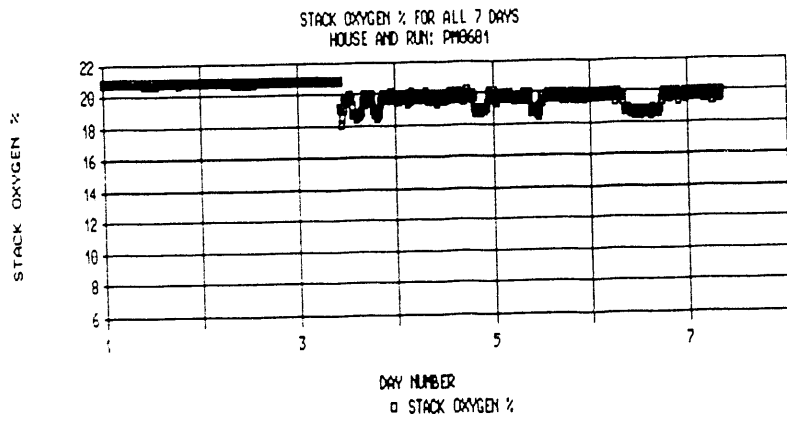


Home 6; Earth Stove

Stack Temperature and Fuel Loads

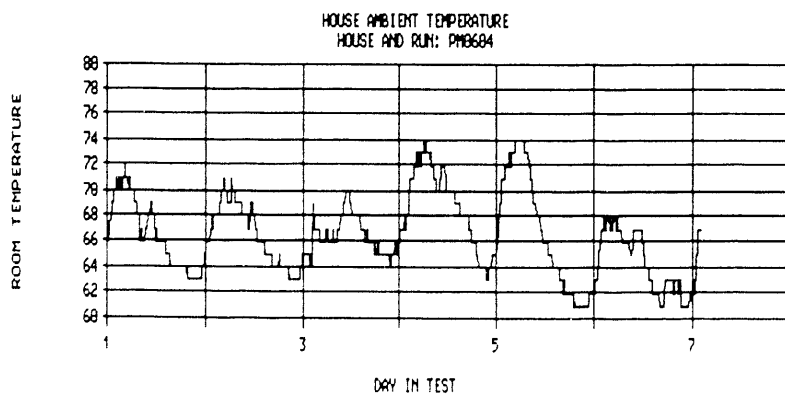
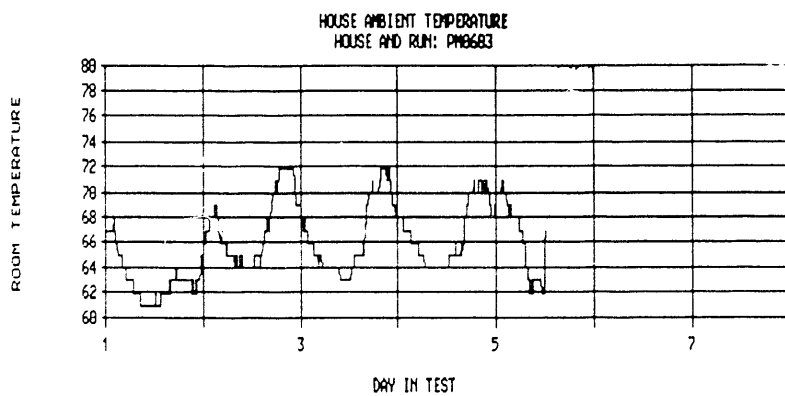
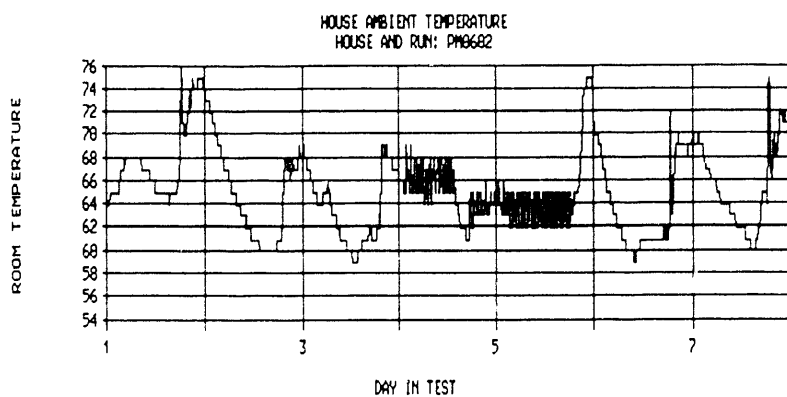
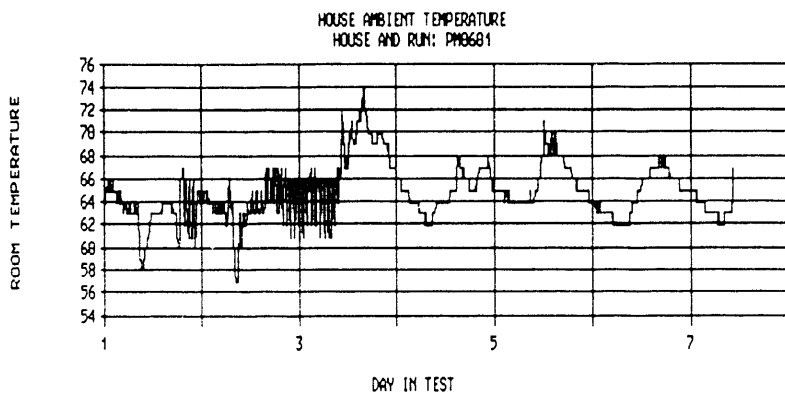


Home 6; Earth Stove Stack Oxygen



Home 6; Earth Stove

House Ambient Temperature



Home 1; Breckwell

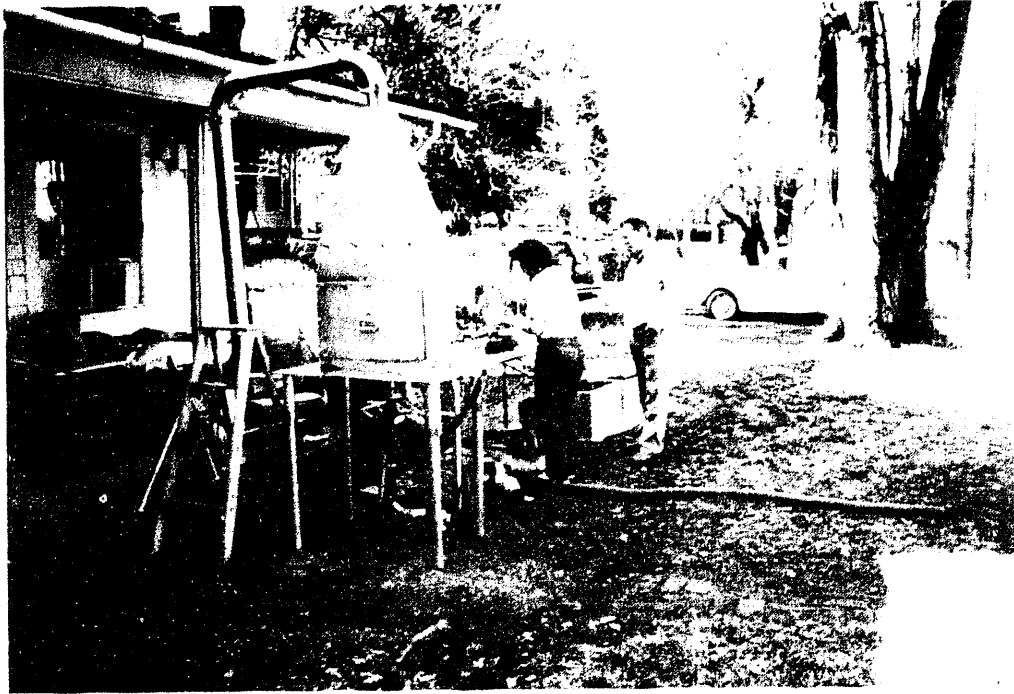


Photo 1. Exterior of home 1 with Dilution Source Sampler unit (DSS).



Photo 2. Stove installation.

Home 2; Horizon



Photo 3. Exterior of home 2.



Photo 4. Stove installation and AWES sampling system.

Home 3; Breckwell



Photo 5. Exterior of home 3.

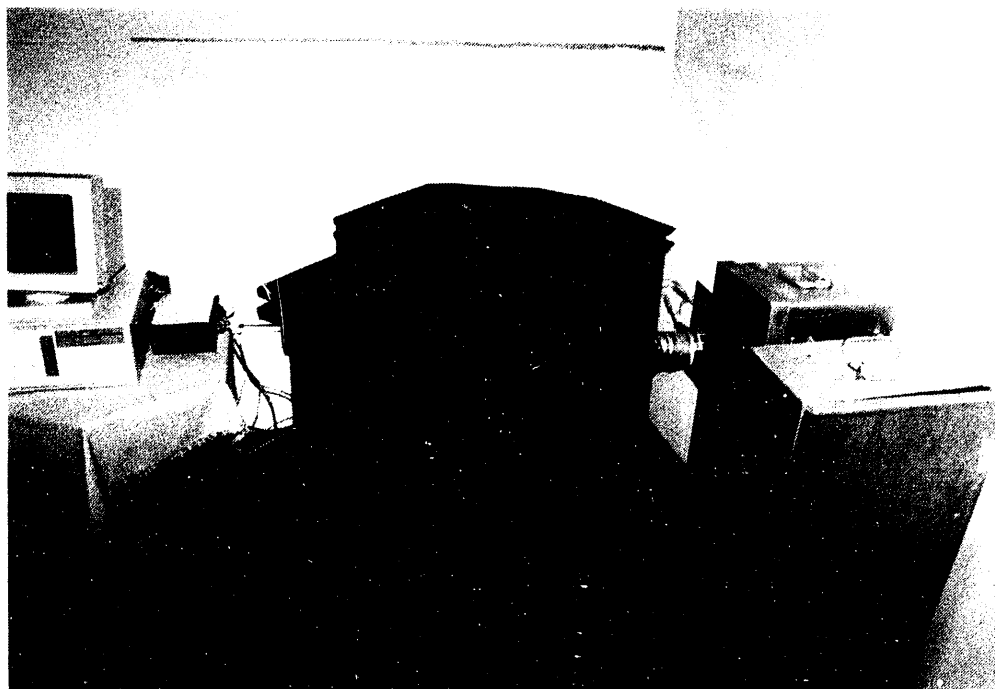


Photo 6. Stove installation and AWES sampling system.

Home 4; Breckwell



Photo 7. Exterior of home 4.

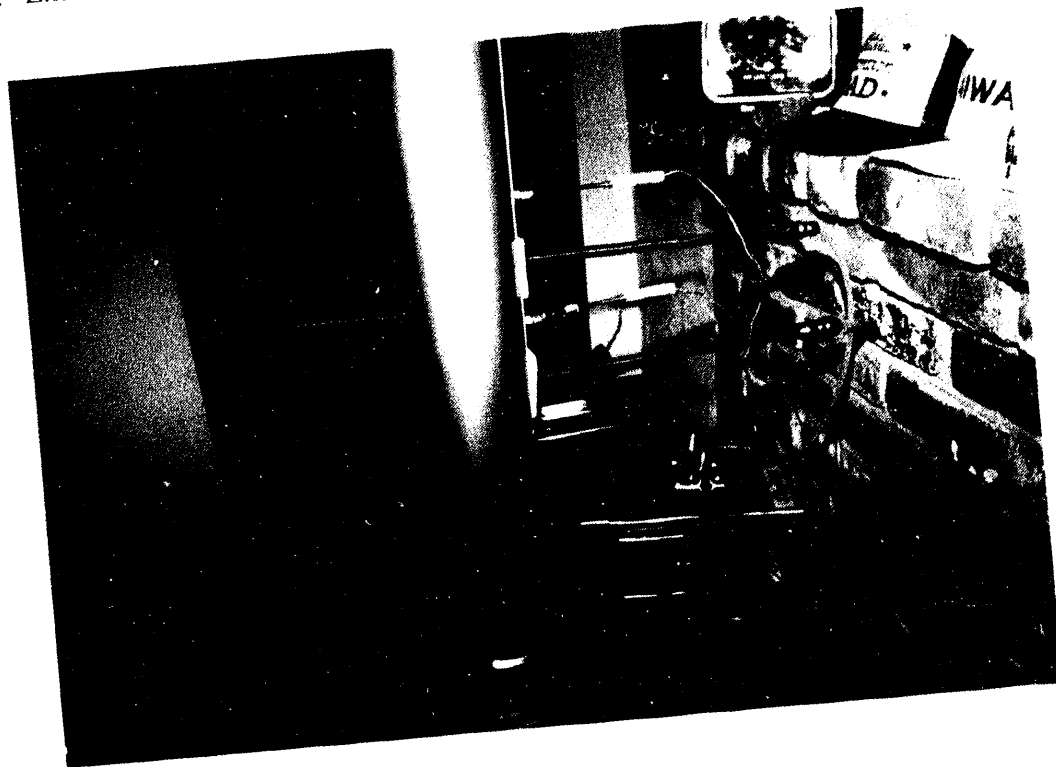


Photo 8. Stove installation and AWES sampling system.

Home 5; Horizon

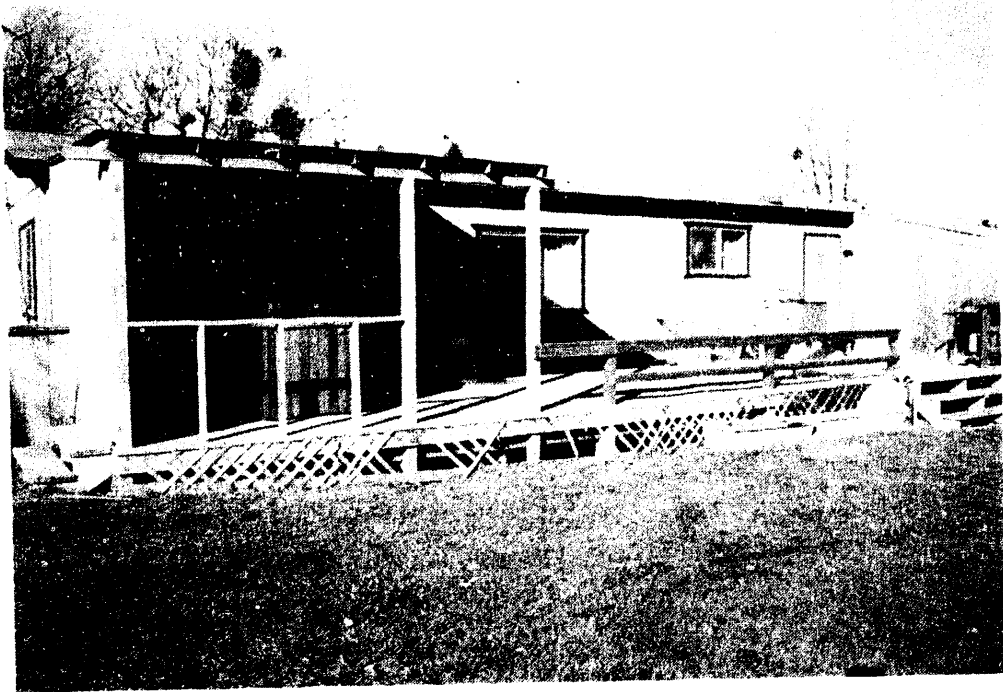


Photo 9. Exterior of home 5.



Photo 10. Stove installation and AWES sampling system.

Home 6; Earth Stove



Photo 11. Exterior of home 6.



Photo 12. Stove installation and AWES sampling system.

Appendix B

**Description of home installations.
Operator practices and opinions.
Proximate-Ultimate analysis of fuel.
Flue gas calculations**

Contents

	<u>Section</u>	<u>Page</u>
0.	Contents	B-i
1.	Description of home installations, operator practices and opinions	B-1
2.	Proximate-Ultimate analysis of pellet fire	B-7
3.	Flue gas calculations for pellet stoves	B-8

1991 BPA Pellet Stove Study Homes

House No.: PM01
Owner's Name: Byron Brown
Address: 1204 2nd Avenue, Gold Hill, OR 97525 (PO Box 411)
Phone #: 855-1342

House square footage and number of stories: 950 sq ft, 2 stories

Describe portion of house heated by woodstove and estimated square footage:

dining, living, kitchen, dinette (~ 750 sq ft)

Type of conventional heat:

Two baseboard heaters that heat oil

Percentage of heat owner believes pellet stove provides:

95%

Type of stove used in this study: Breckwell

Installation type: specify pipe diameter, elbows, chimney height, etc.:

4" OD ~ 3 1/2" ID; 1 45° elbow, inside height 30", stack length ~ 3' long

Previous stove type: Fireview woodstove

Participated in previous study and what one?

None

Owner reactions and opinions of new stove (compare with old stoves):

Cleaner to operate, heats better, "handier"

Daily burning habits (include details on how owner starts the stove):

Stove runs 24 hours a day except for afternoon cleaning (every 1 to 2 days). One flake of paraffin with firestarter in middle to start stove.

1991 BPA Pellet Stove Study Homes

House No.: PM02
Owner's Name: Robert Lester (Carolyn)
Address: 650 Upper River Road, Gold Hill, OR 97525
Phone #: 855-7240

House square footage and number of stories: 1500 sq ft, 1 story

Describe portion of house heated by woodstove and estimated square footage:

Entire house: living room, dining room, kitchen, hallway, 2 bedrooms, 1 bath

Type of conventional heat: Electric baseboard

Percentage of heat owner believes pellet stove provides:

75 - 80% (25% electric used because stove was not working properly)

Type of stove used in this study: Horizon HR2 Destiny

Installation type: specify pipe diameter, elbows, chimney height, etc.:

4" OD, 3 1/2" ID, 1 45° elbow, 3 1/2' stack length

Previous stove type: None

Participated in previous study and what one?

No

Owner reactions and opinions of new stove (compare with old stoves):

Problems with fuel - pellet source had been in salt water - caused extreme corrosion. Supplier changed stove. New stove - overheated and combustion fan would stop - total shutdown of system resulted. Replaced fan and changed door to one with vent.

Daily burning habits (include details on how owner starts the stove):

Evening/night - feed rate - 1 1/2; 5 a.m. - feed rate to 4 if cold outside; use all day and night

1991 BPA Pellet Stove Study Homes

House No.: PM03

Owner's Name: Ivan Hayes

Address: 218 Sierra Drive, Eagle Point, OR 97524

Phone #: 826-5664

House square footage and number of stories: 900 sq ft, 1 story

Describe portion of house heated by woodstove and estimated square footage:

Entire house: dining room, living room, bedroom, bathroom

Type of conventional heat: None

Percentage of heat owner believes pellet stove provides:

100%

Type of stove used in this study: Breckwell P24FS

Installation type: specify pipe diameter, elbows, chimney height, etc.:

45° elbow, two pipes 7" and 8", outside 3 1/4", 18 1/4" total

Previous stove type: None

Participated in previous study and what one?

None

Owner reactions and opinions of new stove (compare with old stoves):

They like it, have had no problems

Daily burning habits (include details on how owner starts the stove):

Clean every one to two days. Keep stove on 1 most of the time, turn up to 2 in a.m.

1991 BPA Pellet Stove Study Homes

House No.: PM04
Owner's Name: Jim Alcorn
Address: 3057 Delta Waters, Medford, 97504
Phone #: 779-5965

House square footage and number of stories: 1200 sq ft, 1 story

Describe portion of house heated by woodstove and estimated square footage:

Entire house: 3 bedrooms, 2 bath

Type of conventional heat: Electric furnace

Percentage of heat owner believes pellet stove provides:

99%

Type of stove used in this study: Breckwell

Installation type: specify pipe diameter, elbows, chimney height, etc.:

4" pipe vents vertically from top of stove. Pipe length = 4'.

Previous stove type: Thelin-Thompson woodstove

Participated in previous study and what one?

None

Owner reactions and opinions of new stove (compare with old stoves):

Operation - a lot nicer; Convenient; Feels better by burning pellets instead of wood - cleaner.
Heats house as well, but not as quickly as a woodstove.

Daily burning habits (include details on how owner starts the stove):

Burns at 1 1/2 nearly 24 hours a day in winter.

1991 BPA Pellet Stove Study Homes

House No.: PM05

Owner's Name: Jerry Asher

Address: 760 Neil Creek Road, Ashland, Oregon, 97520

Phone #: 482-3102

House square footage and number of stories: 1150 sq ft, 1 story (double wide mobile home)

Describe portion of house heated by woodstove and estimated square footage:

entire house: 3 bedrooms, 2 bathrooms

Type of conventional heat: Electric furnace

Percentage of heat owner believes pellet stove provides:

99%

Type of stove used in this study: Horizon Eclipse

Installation type: specify pipe diameter, elbows, chimney height, etc.:

3" diameter pipe is in two lengths of 6" and 2' with one 45° elbow.

Previous stove type: None

Participated in previous study and what one?

None

Owner reactions and opinions of new stove (compare with old stoves):

Likes it, heats house well, warmer than electricity.

Daily burning habits (include details on how owner starts the stove):

a.m. F.R. ~ 5, turn down at 8 a.m. to 1; evenings - F.R. ~ 3

1991 BPA Pellet Stove Study Homes

House No.: PM06
Owner's Name: Brad Miller
Address: 2944 Aldersgate, Medford, OR 97504
Phone #: 779-3660

House square footage and number of stories: 1520 sq ft.

Describe portion of house heated by woodstove and estimated square footage:

1220 (doesn't heat one bedroom)

Type of conventional heat: Electric heat pump

Percentage of heat owner believes pellet stove provides:

90%

Type of stove used in this study: Earth Stove

Installation type: specify pipe diameter, elbows, chimney height, etc.:

4" pipe vents out top of stove for 1', makes 45° angle to rear, and then vents out existing chimney (~4').

Previous stove type: Thelin-Thompson

Participated in previous study and what one?

No

Owner reactions and opinions of new stove (compare with old stoves):

Pellet provides heat to greater portion of house, has fan

Daily burning habits (include details on how owner starts the stove):

M - F (a.m.): load up and put on low

M - F (p.m.): high for one hour, keep on medium or low

Sat - Sun: doesn't burn much, but tries not to let it go out

**ANALYSIS OF GOLDEN FIRE PELLET FUEL CONDUCTED BY
COMMERCIAL TESTING AND ENGINEERING CO.**

ANALYSIS TYPE	PROJECT YEAR		PROJECT YEAR	
	1989 - 1990 (Certified Stoves)		1990 - 1991 (Exempt Stoves)	
	As Received	Dry Basis	As Received	Dry Basis
Proximate Analysis:				
% Moisture	3.62		4.89	
% Ash	0.32	0.33	0.27	0.28
% Volatile	80.44	83.46	80.72	84.87
% Fixed Carbon	15.62	16.21	14.12	14.85
(Total %)	100.00	100.00	100.00	100.00
BTU/lb.	8092	8396	8178	8598
% Sulfur	.02	.02	0.18	0.19
Ultimate Analysis:				
% Moisture	3.62		4.89	
% Carbon	49.55	51.41	49.00	51.52
% Hydrogen	5.87	6.09	5.72	6.01
% Nitrogen	0.29	0.30	0.07	0.07
% Sulfur	0.02	0.02	0.18	0.19
% Ash	0.32	0.33	0.27	0.28
% Oxygen	40.33	41.85	39.87	41.93
(Total %)	100.00	100.00	100.00	100.00

Appendix C

Quality Assurance and Propagation of Uncertainty Analysis

Contents

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Preamble: This QA plan was written for the 1988-1989 NCWS Project. This particular section was amended and updated during that project (see section 9). The amended QA plan passed the EPA audit in 1989 and is included on the following pages. This plan has been followed in all subsequent projects.

1.0 QA Objectives For Measurement Data In Terms of Precision, Accuracy, Completeness, Representativeness, and Comparability

Precision, Accuracy, and Completeness

Precision and accuracy goals for this program are presented in Tables 1-1 and 1-2. Table 1-1 presents precision, accuracy and completeness goals for key reported parameters. Table 1-2 lists the comparable objectives for those primary measurements necessary for calculating the key reported parameters.

Precision is defined as the degree of mutual agreement among individual measurements made under prescribed conditions. Accuracy is the degree of agreement of a measurement with an accepted reference or true value. Completeness is defined as the percent of the total number of samples judged to be valid. Every attempt will be made to have all data generated be valid data. However, realistically, some samples may be lost in laboratory accidents, and some results may be deemed questionable based on internal QC procedures. The objective will be to have 90 percent of the data valid.

Precision will be estimated based on previously-conducted paired sampling. The AWES II units to be used in this study have been modified to eliminate or reduce potential sources of sampling error. The effect of these changes, which are described in Section 4, will be improved overall sampling precision. However, no paired sampling will be conducted during this study due to budget constraints and precision estimates will be based on the prior precision estimates.

Overall accuracy of the AWES particulate sampling system cannot be determined within the scope of this project. Accuracy estimates are based on:

- Accuracy estimates for similar particulate sampler systems;
- Comparability testing with standard sampling systems;
- Analysis of standards and recovery data for analytical procedures.

Fuel wood through-put accuracy and precision are based on data previously collected for this purpose. No modifications have been made to the fuel weighing system.

Fuel wood characteristics will be analyzed using ASTM methods and subjected to each method's requirements for precision and accuracy.

Table 1.1 Quality Assurance Objectives—Key Reported Parameters ^a

Parameter	Units	Method of Determination	Precision	Accuracy
1. Mass particles/volume of flue gas	grams/cubic meter	AWES Data Logger System/lab support	±8 ^b	±5%
2. Mass particles/mass dry wood burned	grams/kilogram(dry)	AWES Data Logger System/lab support	±16%	±17%
3. Mass particles/time of stove operation	grams/hour	AWES Data Logger System/lab support	±20%	±18%
4. Mean dry mass of wood burned per heating degree day	kilograms(dry)/heating degree day	Electronic Scale/Data logger/ National Weather Service records	±2.5%	±2.5%
5. Percent of time catalyst in operation	percent	Type k thermocouple/data logger	±1%	±2%
6. Percent of time stove in operation	percent	Type k thermocouple/data logger	±3%	±3%
7. Percent of time alternate heat source used	percent	Solid state temperature	±1%	±2%
8. Mean fuel moisture by species	percent (dry basis)	< 30% -Delmhorst Moisture Meter	< ±2% absolute	< ±2% absolute
		> 30% -Mass loss on drying	±4%	±2%

^a Precision and Accuracy value are reported for one standard deviation of the propagated error assuming fully dependent errors.

^b All percentage values are relative unless noted as absolute.

Table 1.1 Quality Assurance Objectives-- Key Reported Parameters (continued)

Parameter	Units	Method of Determination	Precision	Accuracy
9. Mean wood burn rate	kilogram (dry)/hour	Electronic scale/data logger	±0.1	±0.1
10. Mean flue gas oxygen content	volume percent	Electrochemical sensor/data logger	0.3% abs.	±0.69% abs. uncorrected ±0.2% abs. corrected
11. Mean flue gas temperature	degrees centigrade	Type k thermocouple/data logger	3°C	8°C
12. Mean catalyst temperature	degrees centigrade	Type k thermocouple/data logger	3°C	8°C
13. Maximum catalyst temperature	degrees centigrade	Type k thermocouple/data logger	±0.75%	±0.75%
14. Temperature difference before and after catalyst	degrees centigrade	Type k thermocouple/data logger	±1.5%	±1.5%
15. Total time catalyst bypass damper open	minutes	Switch/pulse recorder	±60 sec.	±60 sec.
16. Percent time catalyst bypass damper open	percent	Switch/pulse recorder	±2% absolute	±2% absolute
17. Mean number of catalyst bypass damper openings per day	unitless count per day	Switch/pulse recorder	±1/day	±1/day
18. Mean duration of catalyst bypass damper openings	seconds	Switch/pulse recorder	±2 sec.	±2 sec.

Table 1.2 Quality Assurance Objectives--Primary Measurements

Parameter	Units	Method of Determination	Precision	Accuracy
1. Wood fuel weight	kilograms	Electronic scale	±0.1 kg	±0.1 kg
2. Wood fuel moisture	weight percent dry basis	ASTM D2016 (for Delmhorst readings > 30%)	±10%	±5%
		Delmhorst Model RC Moisture Meter	±1% (absolute)	±2% (absolute)
3. C,O,N,H composition of wood	% by weight	ASTM D3178	±1% (absolute)	±1% (absolute)
		Laboratory experience	±25%	±25%
4. Fuel carbon conversion to CO	% of C to CO			
5. Mass of particles collected on filter	milligrams	Analytical balance	±0.3 mg	±0.3 mg
7. Mass of particles collected in probe and connecting tubing	milligrams	Analytical balance	±0.3 mg	±0.3 mg
8. Mass of semi-volatiles collected on XAD-2	milligrams	Analytical balance	±0.3 mg	±0.3 mg
9. Sample flow rate	liter/min	Critical flow orifice meter	3%	3%
10. Flue gas O ₂	percent by volume	Commercial electrochemical analyzer	±0.8% (absolute)	±1.5% abs. uncorrected 0.8% abs., corrected
11. Mean barometric pressure (for flow rate calibrations)	inches mercury	Mercurial barometer	±0.5 mm Hg	±0.5mm Hg

Table 1.2 Quality Assurance Objectives--Primary Measurements (continued)

Parameter	Units	Method of Determination	Precision	Accuracy
12. Duration of sampling	minutes	Data logger internal clock	±1%	±1%
13. Temperature (stack, filters, ambient, catalyst, flue)	degrees Fahrenheit	Type K thermocouple	±4°F or ±0.75% (whichever is greater)	±4°F or ±0.75% (whichever is greater)
14. Sampling period	minutes	Data logger internal clock	±0.1%	±0.1%
15. Heating degrees days	degree (°F) days	National Weather Service calculation	±0.5/day	±1.0/day
16. Bypass damper switch counts	unitless number	Event recorder	±1 event	±1 event

Representativeness and Comparability

It is recognized that the usefulness of the data is also contingent upon meeting the criteria for representativeness and comparability. The corresponding QA objective is that all data resulting from sampling and analysis be comparable with other representative measurements made by OMNI or other organizations for the processes operating under similar conditions. The use of (1) U.S. EPA and ASTM reference methods where possible; (2) widely accepted published sampling and analytical techniques for measurements that have no reference methods; and (3) standard reporting units will aid in ensuring the comparability of the data. Data will be reported both in standard and metric units.

2.0 Sampling and Monitoring Procedures

In order to accomplish the objectives of the proposed study sampling or monitoring of the following must be conducted:

- Fuel wood: mass burn rate; moisture content; elemental composition;
- Flue gas and aerosol stream: Oxygen concentration; particulate matter concentration; temperature
- Woodstove operations: woodstove fueling characteristics; catalyst by-pass operation; catalyst temperature; flue gas temperature
- Heating demand: auxiliary heating system operation; heating degree days; outdoor temperature

The great majority of these data will be measured and recorded by the OMNI AWES/Data Logger system. This system has been used previously in similar studies (OMNI, 1987a; OMNI, 1987b; Simons, et al., 1987, Simons, et al., 1988.) This experience demonstrates that the system can reliably sample and record key data pertinent to determining woodstove performance. Both the AWES and the Data Logger have been subject to revision to improve their overall precision, accuracy, and reliability. These improved and updated units will be used throughout this study. The specific changes to the units are discussed in the standard operating procedures for the AWES/Data Logger system which are located in Section 10. The effects of the changes on precision, accuracy, and reliability are discussed in Sections 5 and 7.

Residential woodstove sampling will be conducted at 3 homes with each appliance being sampled four times. Each sample is taken with actual sampling time being one minute out of thirty minutes. The AWES sampler collects particulate matter on a filter and semi-volatile compounds on sorbent resin. Some particulate material is also recovered from the sampling probe and Teflon inlet line when it condenses out of the gas/aerosol stream. A schematic of the AWES unit is shown in Figure 2-1. AWES sampler operations are controlled by the Data Logger, which also records temperature data for selected locations in the woodburning appliances, outside the residence and at an auxiliary heat outlet. In addition, the Data Logger system records the weight and time of fueling operations and the flue gas oxygen content. Weights are determined using a load cell with a digital output. A description of the Data Logger system control logic and data-recording capabilities is presented in Section 10.

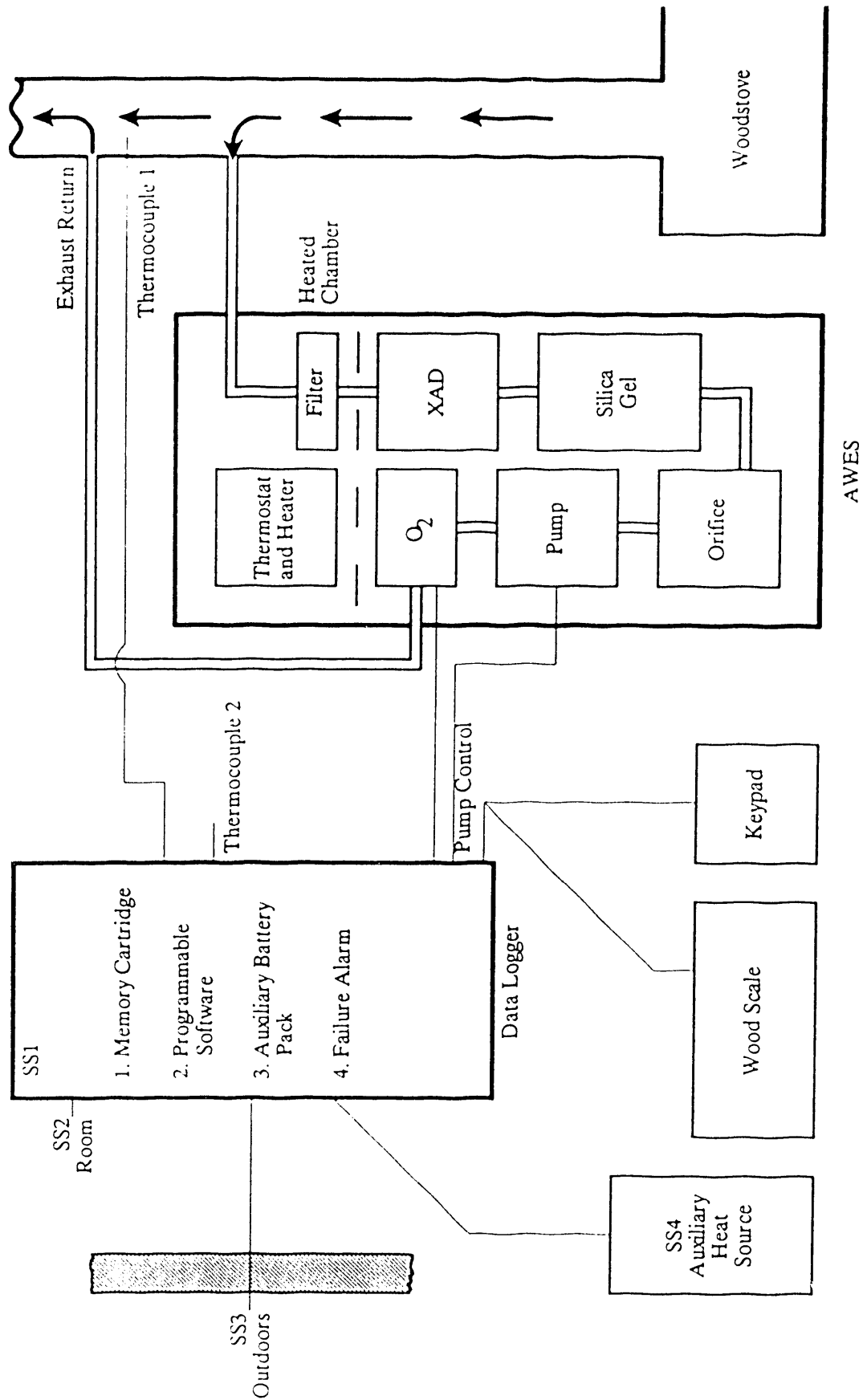


Figure 2-1. Schematic of the Automatic Woodstove Emission Sampler (AWES).

3.0 CALIBRATION PROCEDURES AND FREQUENCY

This section addresses the calibration procedures for the sampling equipment. A schedule and frequency of calibrations for each piece of equipment is presented in Table 3-1. Results of the calibrations will be reviewed and retained by the project manager in a project file. Calibrations to the extent applicable will be performed in conformance with the EPA publication "Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III, Stationary Source Specific Methods" (EPA document 600/4-77-027b).

Vacuum Gauge Calibration

Bourdon tube gauges will be used during this project to measure the static pressures at two locations in the AWES. The purpose is to identify that the pressure drop across the critical flow orifice is sufficient to assure choked flow and to ensure that the filter is not overloaded. Because any pressure drop greater than approximately 36 cm Hg assures such flow, great accuracy is not required. Commercial grade B vacuum gauges will be used providing an accuracy of $\pm 3\%$ of full scale (ANSI B40.1). Since the upstream gauge will run at near zero and the downstream near 60 cm Hg of vacuum choked flow can be assured without calibrating individual units.

Temperature Measuring Device Calibration

During source sampling, accurate temperature measurements are required. Individual type k thermocouple temperature sensors will not be calibrated due to their well-documented performance. The thermocouple read-out meter will be calibrated every two weeks with an electronic thermocouple simulator (OMEGA Engineering, Inc., Model CL-300-2100F).

Dry Gas Meter Calibration

A dry gas meter (DGM) will be used as a transfer standard to calibrate individual AWES unit flow rates. The dry gas meter will be calibrated (documented correction factor at standard conditions) just prior to AWES calibration.

The dry gas meter to be used for measuring orifice flow will be calibrated using the system illustrated in Figure 3-1. Using the procedure outlined in Section 3.3.2 of EPA document 600/4-77-027b, a positive pressure leak-check of the system will be performed prior to calibration. To perform the leak-check, the system is placed under approximately 25 cm of water pressure and an oil gauge manometer is used to determine if a pressure decrease can be detected over a one-minute period. If leaks are detected, they will be eliminated before actual calibrations are performed. A laboratory mercurial barometer and mercurial thermometers will be used during the calibration procedures for barometric and temperature values, respectively.

To calibrate a dry gas meter, the pump will be allowed to run for 15 minutes after the sampling console is assembled and leak-checked. Once the pump and dry gas meter are warmed up, the valve on the console is adjusted to obtain the desired flow rate. After 10 minutes, the valve is closed, and a final set of data is recorded. A duplicate calibration is then performed at the same flow rate. If necessary, additional calibrations are conducted until the calibration results (Y_i) vary by no more than 2 percent. The average Y_i is then calculated and recorded on the face of the DGM console. An example DGM calibration data sheet is presented in Figure 3-2.

Analytical Balance Calibration

The analytical balances will be calibrated over the expected range of use with standard weights (NBS Class S) prior to use each day. Measured values must be within ± 0.1 milligram.

AWES/Data Logger System Calibration

Calibration procedures for those measurement elements of the AWES/Data Logger system are presented in Appendix D.

Wood Moisture Meter

The Delmhorst moisture meter is calibrated through adjustment to its internal circuitry. This calibration may be gauged by applying known resistances to the contact pins of the meter. Readings which deviate from the values associated with the known resistance standards by more than one percent (absolute) require factory overhaul and/or adjustment.

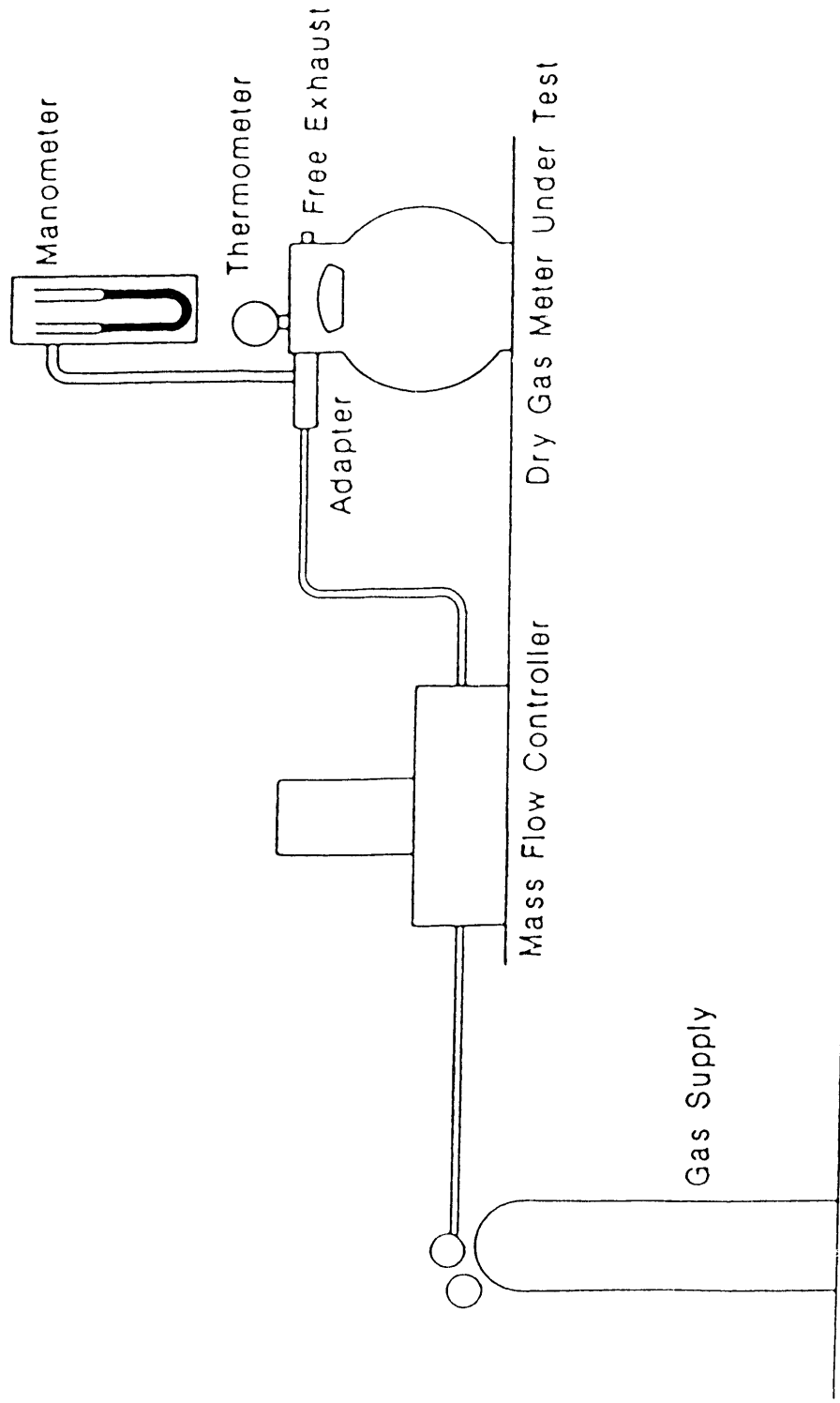


Figure 3-1. Dry Gas Meter Calibration System

Table 3-1. Calibration Frequency of Field Sampling Equipment

Sampling Equipment	Calibration Frequency			
	Before Sampling ^a	After Sampling ^b	Weekly	Daily
Dry Gas Meter	*	*	N/A	N/A
Laboratory Analytical Balance	N/A	N/A	N/A	*
Wood Moisture Meter (Delmhorst)	*	*	N/A	N/A
Vacuum Gauges (AWES)	*	*	N/A	N/A
Critical Orifice (AWES)	*	*	N/A	N/A
Oxygen Sensor (AWES) ^d	*	*	N/A	N/A
Data Logger Clock/Calendar	*	*	N/A	N/A
Electronic Scale (Data Logger)	*	N/A	* ^c	N/A
Temperature Measuring Devices (Data Logger)	*	N/A	N/A	N/A

^a Within 30 days prior to sampling.

^b Within 30 days after testing.

^c Biweekly.

^d Calibrated before and after each weekly sample.

* Calibration required.

N/A Not applicable. Calibration not required.

Dry Gas Meter Calibration Data Sheet

Date: _____

Calibration Meter Identification: _____

Barometric Pressure: _____

Meter Box Identification: _____

Calibrated By: _____

Y _{ds}	(Q)		ΔH in. H ₂ O	Cal. Meter V _{ds} ft ³	Box Meter V _d ft ³	Temperature (°F)						Time (θ)	Meter Box Coefficient (Y _d)		Comments
	Ave	Actual				Calibration Meter (t _{ds})			Box Meter (t _d)				Y _d	ave	
						in	out	ave	in	out	ave	min	ave	ave	

Where: $\Delta H(\bar{Q})$ = orifice pressure differential that gives 0.75 cfm of air at 70°F and 29.92 inches of mercury, in. H₂O

$$Y_d = Y_{ds} \times \frac{V_{ds}}{V_d} \times \frac{\bar{t}_d + 460}{\bar{t}_{ds} + 460} \times \frac{P_b}{P_b + \frac{\Delta H}{13.6}}$$

$$Q = 17.65 \times \frac{P_b}{\bar{t}_{ds} + 460} \times \frac{V_{ds}}{\theta}$$

$$\Delta H(\bar{Q}) = \frac{0.0317 \Delta H}{P_b(\bar{t}_d + 460)} \times \left[\frac{(\bar{t}_{ds} + 460) \theta}{V_{ds}} \right]^2$$

• For definition of terms refer to EPA-600/4-77-027b, section 3.7.2.

Figure 3-2. Dry Gas Meter Calibration Data Sheet

4.0 Analytical Procedures

Table 4-1 lists the samples to be collected during the test period, the parameter to be measured, the analytical method and the analytical laboratory.

Table 4-2 lists the total number of individual samples, duplicate samples, sample blanks, and sample splits to be analyzed for each parameter. Where necessary, precision will be demonstrated by using duplicate samples or by sample splits. Since precision values for the AWES/Data Logger system have been demonstrated in previous studies, no duplicate sampling is proposed. (See Section 5.) Similarly, spiked sample studies (for polycyclic aromatic hydrocarbons) completed previously showed high recovery rates for extraction procedures. This spiking is not proposed for this study since the procedure has not been modified. (OMNI, 1987a)

Figure 4-1 is a schematic of the AWES procedures for gravimetric analysis of particles and condensibles. The probe rinse, tubing, and filter will be brought to dryness and measured for particulate matter. The XAD-2 sorbent resin will be extracted with analytical reagent grade methylene chloride in a Soxhlet extraction device. The dried extracts will be weighed and their value added to probe and filter masses to give a total mass. This procedure is detailed in Appendix D.

Table 4-1. Analysis Summary

Sample Description	Parameters Quantified	Procedure	Method	Laboratory ^a
Fuel	Moisture	Heat/gravimetric	ASTM D3173 ^b	OMNI
	Elemental Composition	Ultimate	ASTM 3176	CT&E
Gas stream particles and condensible compounds	Particles (filter)	Gravimetric	AWES SOP ^c	OMNI
	Particles & condensible organics (probe and connecting tubing rinse)	Gravimetric	AWES SOP	OMNI
	Condensible organic compounds (XAD-2 resin extract)	Extraction/ Gravimetric	AWES SOP	OMNI

^a Laboratory: OMNI - OMNI Environmental Services, Inc. (Beaverton, Oregon)
 CT&E - Commercial Testing and Engineering Laboratories (Denver, Colorado)

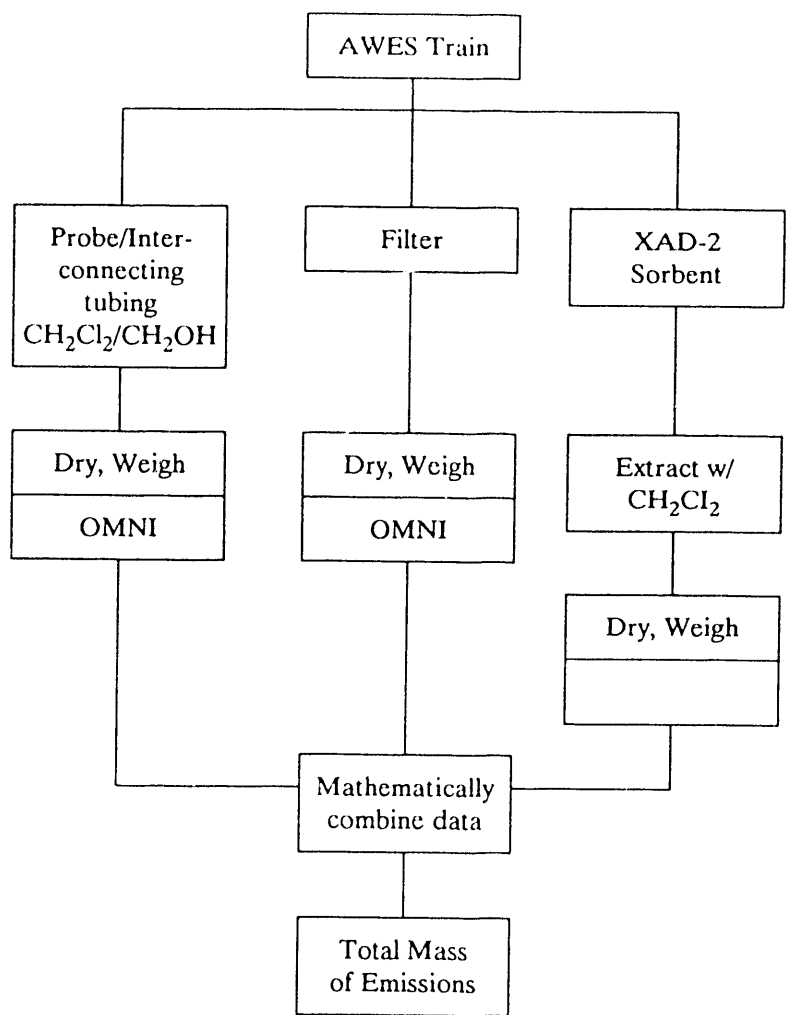
^b Only for samples with moisture content greater than 30% DWB as determined by Delmhorst moisture meter.

^c AWES Standard Operating Procedures

Table 4-2. Sample Inventory

Sample Description	Number of Samples	Sample Blanks	Duplicate Samples	Splits	Total Samples Analyzed Per Parameter
Fuel Moisture (> 30% DWB)	30	0	3	1	34
AWES/Data Logger Part/condensibles	125	10	0	0	135
Fuel Elemental Composition (C,O,H,N)	6	0	0	0	6

Figure 4-1. AWES Analysis Procedures



5.0 Data Analysis, Validation, and Reporting

The overall data reduction, validation, and reporting process is illustrated in Figure 5-1. Table 1-1 lists the principal project parameters which will be produced by the analysis of field and laboratory data. The following formulas will be used in their calculation:

- (1) Mass of Particles/Volume of Flue Gas

$$\text{Mass of Particles/Volume of Flue Gas} = \frac{MP}{(FR)(SD)}$$

where MP = Mass of particles collected by AWES sampler;
 FR = Flow rate of AWES sampler
 SD = Sampling duration of AWES sampler.

- (2) Mass of Particles/Mass Dry Wood Burned

$$(a) \text{ Mass Particulate Emissions} = (MP) \times \frac{(TF)}{(FR) \times (SD)}$$

where TF = Total flue gas volume during sampling.

$$(b) \text{ Total Flue Gas Volume (TF)} = \frac{(SV) \times (MDW)}{\left(1 - \frac{\%O_2}{20.9\%}\right)}$$

where SV = Volume of flue gas per unit mass of dry wood from the stoichiometric combustion of wood, obtained from literature wood analysis data (a small correction is made for carbon monoxide levels characteristic of conventional and catalytic woodstove emissions;

MDW= Mass of dry wood burned during sampling (see (4)); and

%O₂ = Percent of oxygen in flue gas measured with AWES/Logger system.

Combining 2a and 2b and dividing by the mass of dry wood burned during sampling (MDW), yields:

(c) Mass Particulate Emissions/Mass Dry Wood Burned =

$$\frac{(MP) \times (SV)}{(FR) \times (SD)} \times \frac{1}{(1 - [\%O_2/20.9\%])}$$

(3) Mass Particulate Emissions/Time of Stove Operation

$$\frac{(MP) \times (SV) \times (MDW) \times 100}{(FR) \times (SD) \times (SP) \times (WO)} \times \frac{1}{(1 - [\%O_2/20.9\%])}$$

where MDW = Mass of dry wood burned. See (4).

SP = Sampling period (usually one week)

WO = Percent of time stove in operation. See (6).

(4) Mean Dry Mass of Wood Burned per Heating Degree Day

(a) Mass of wet wood burned

Wood use is determined from direct measurement of individual fuel load weights with an electronic balance and recorded by the Logger system. The data are summed over the time periods of interest.

$$MWW = \sum_{i=1}^n (W_i - W_{i+1})$$

W_i = Weight of wood in Data Logger basket. Two measurements i and $i+1$ (before and after wood is removed) comprise each measurement.

(b) Mass of dry wood burned

$$MDW = \sum_{i=1}^n x_i \left(\frac{MWW}{1 + MDC_i} \right)$$

where i = the wood species

x_i = the fraction of the total wood of species used.

MDC_i = the mean moisture content (dry basis) of species; see (8).

(c) Mean Dry Mass of Fuel Burned per Heating Degree Day

$$= \frac{MDW}{\sum_{i=1}^7 HDD_i}$$

HDD_i = Heating Degree Days for day i (as reported by the National Weather Service) of the seven-day sampling period.

(5) Percent of Time Catalyst in Operation and Percentage of Time Above Specified Threshold Temperatures.

Ignition temperature of catalysts is between 200°C and 300°C. Discrete thermocouple measurements recorded every 10 minutes by the Data Logger system will be used to determine the fraction of time the catalyst is operating. Some catalysts operate only poorly at near the ignition temperature and high temperatures can damage catalysts. For this reason, the percentage time above other threshold temperatures will be calculated.

$$\text{Percent of Time Catalyst Operating} = \frac{\text{No. of Reading } T_c > 260^\circ\text{C}}{\text{Total No. of Readings } T_f > 38^\circ\text{C}} \times 100$$

Determination will be made for a one-week sampling period. One reading will be recorded every ten minutes, which yields 1008 readings when all measurements are valid. Analogous calculation of percentage of time the catalyst is above specified threshold temperatures is:

$$\text{Percent of time above threshold temperatures} = \frac{\text{No. of readings } T_c > \text{threshold temp.}}{\text{Total No. of readings } T_f > 38^\circ\text{C}} \times 100\%$$

The threshold temperatures will be 600°F (315°C), 200°F (371°C), 800°F (427°C), 1600°F (871°C), 1700°F (927°C), and 1800°F (982°C).

(6) Fraction of Time Stove in Operation

The woodstove will be determined to be operating whenever flue gas temperature exceeds 38°C (100°F). Temperature will be determined continuously by thermocouple and the value recorded every ten minutes for catalyst stoves and every five minutes for non-catalyst stoves. The fraction of time the stove is operating will be calculated as follows:

$$\text{Percent of Time Woodstove Operates (WO)} = \frac{\text{No. of Readings where } T_f > 38^\circ\text{C}}{\text{Total No. of Readings}} \times 100\%$$

(7) Percent of Time Alternate Heat Source Used

The signal from the solid state temperature sensor adjacent to the auxiliary heat source is recorded every five minutes by the Data Logger system. Temperature values above a pre-set threshold level (e.g. 35° C) are being recorded as an “on” status.

$$\text{Percent of Time Alternate Heat Source Used} = \frac{\text{No. of Readings where } T > 35^\circ\text{C}}{\text{Total No. of Readings}}$$

Determination will be made for a one-week sampling period (nominally 1008 readings).

(8) Mean Fuel Moisture by Species

Mean fuel moisture will be determined each week by successive measurements of fuel destined for immediate burning. The average moisture for each species of fuel wood will be determined from at least three individual measurements at the start and at the end of each weekly sampling period, i.e., at least six measurements will be made for each species of wood for each sampling period.

$$\text{MDC}_i = \frac{1}{n} \sum_{j=1}^n \text{MC}_j$$

MDC_i = Average weekly fuel moisture (dry basis) for species i

MC_j = Moisture value of the j^{th} Delmhorst measurement
 $n \geq 6$.

When a Delmhorst reading exceeds 30 percent moisture, a sample containing the location of the Delmhorst measurement will be taken and moisture determined by standard oven drying techniques. In these cases:

$$MDC_i = \frac{W_{BD} - W_{AD}}{W_{AD}}$$

MDC_i = Moisture content for species i
 W_{BD} = Weight of the sample before drying
 W_{AD} = Weight of the sample after oven drying

Average weekly fuel moisture content will be calculated as above after substituting moisture values determined for the oven-dried samples for the associated Delmhorst readings.

(9) Mean Wood Burn Rate

$$= \frac{(MDW) \times 100}{(SP)(WO)}$$

(10) Mean Flue Gas Oxygen Content

$$O_2\% = \frac{1}{n} \sum_{i=1}^n O_{2i}$$

$O_2\%$ = mean flue oxygen concentration (%)
 O_{2i} = oxygen concentration of the flue gas of the i^{th} reading (%)
 n = total number of valid readings

Chimney oxygen will be recorded every five minutes and averaged over each sampling period or fraction of sampling period of interest.

(11) Mean Flue Gas Temperature

$$T_f = \frac{1}{n} \sum_i^n (T_f)_i$$

- T_f = Mean flue gas temperature
 $(T_f)_i$ = Mean flue gas temperature for the i^{th} valid reading
 n = Number of valid readings in the sampling period

(12) Mean Catalyst Temperatures

$$T_c = \frac{1}{n} \sum_i^n (T_c)_i \quad \text{where}$$

- T_c = Mean catalyst temperature
 $(T_c)_i$ = Catalyst temperature for the i^{th} valid reading
 n = number of valid readings

(13) Maximum Catalyst Temperature

All $(T_c)_i$ will be reviewed to determine the maximum value.

(14) Temperature Difference Before and After Catalyst

The means of the differences between two thermocouples in the flue after the catalyst and before the catalyst when the temperature recorded in the catalyst is above 260°C will be calculated.

$$TD = \frac{1}{n} \sum_i^n (T_f)_i - (T_b)_i \quad \text{where}$$

- $(T_b)_i$ = Temperature of combustion products before the catalyst.
 n = Number of measurements when $(T_c)_i > 260^\circ\text{C}$.

(15) Total Time Catalyst Bypass Damper Open

The position of the catalyst bypass damper will be determined by microswitch and recorder as either: (1) fully closed, or (2) not fully closed. The date and time of the opening and closing of the

bypass damper will be recorded electronically. The differences in the time of the events will be determined and summed over the weekly sampling period. Only periods when the stove is in operation will be considered in this calculation. This will be defined as $(T_f)_i > 38^\circ\text{C}$ for the ten-minute reading immediately preceding the door opening or if there was a wood addition in the preceding 10 minutes (start-up).

(16) Percent of Time the Catalyst Bypass Damper is Open

The summation of time periods when the bypass damper is open will be calculated by the following equation:

$$\text{Percent of Time Bypass Damper Open} = \frac{\text{Total Time Bypass Open When Stove Operating}}{(\text{WO}/100\%) \times \text{SP}} \times 100$$

(17) Mean Number of Catalyst Bypass Damper Openings per Day

The number of opening events will be totalled for each day. An arithmetic mean of these values will be determined for periods of interest.

(18) Mean Duration of Catalyst Bypass Damper Openings

The duration of each opening event will be determined by subtracting the time of opening from the time of closing. A mean duration will be calculated for home and time period combinations of interest.

$$\text{DBO} = \frac{1}{n} \sum_{i=1}^n (t_{ci} - t_{oi})$$

DBO = Mean duration of catalyst bypass damper open periods.

t_c = Time of the i^{th} closing event during the averaging period.

t_o = Time of the i^{th} opening event during the average period.

n = Number of paired opening and closing events during the averaging period.

Data validation and integrity will be accomplished by two techniques. During sample collection, monitoring, laboratory preparation and analyses, complete log book records will be kept (see Appendix D). The impact on data that any unusual event may produce can thus be evaluated. Secondly, the Logger records will be reviewed to ensure that only valid data is being used. For example, the continual operation of a woodstove during the sampling period can be confirmed (or data corrected for intermittent operation) by examining flue gas temperature and oxygen records. Similarly, the operation of the AWES sampler during the sampling period can be evaluated by examining the Logger records and the operating time totalizer of the AWES units. In addition, the entry of wood use data by the homeowner into the Logger system can be confirmed by comparing the wood weight records and flue gas temperatures. If, for example, in any of these cases an unexplained consistency is noted the data will not be included for subsequent reduction and reporting.

There is no standard protocol for dealing with outliers. Due to the anticipated wide range of values generated from various stoves and from numerous environmental and operating parameters it is difficult, if not impossible, to define at this time the acceptable range for most parameters. Data that are clearly outside the normal range, will, of course, be reviewed on a case-by-case basis to determine the cause.

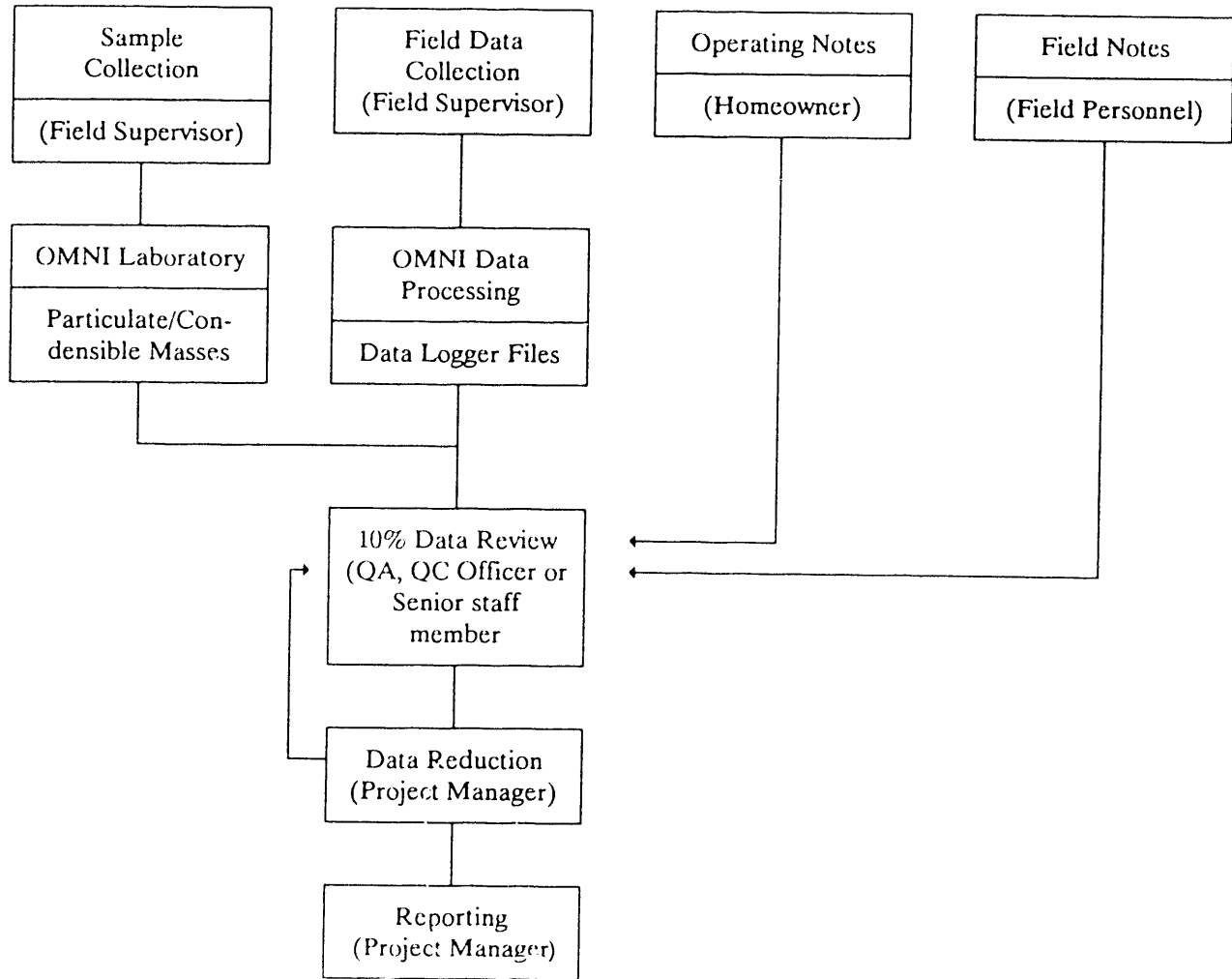
All records of instrument calibrations, sample collection, monitoring, laboratory preparatory work, analyses, and computerized and manual calculations will be stored by OMNI for a minimum of two years after completion of the final report.

The project manager will be responsible for maintaining a centralized inventory of all field, laboratory and data reduction records. The project manager, quality assurance officer, or other senior staff member will check 10% of the final calculations performed by field and laboratory personnel. The responsible individuals for each step in the data analysis, quality assurance and reporting process are listed in Table 5-1.

**Table 5-1. Summary of Data Reduction, Review, and Validation
of Reporting Responsibilities**

Task	Personnel Responsibilities		
	Data Reduction	Data Review and Validation	Reporting
Quality Assurance	J.Houck	J. Houck	J. Houck
Site-specific Data Summaries	Field and Lab Team Members	J. Fesperman	S. Barnett
Final Report Outline		J. Houck	S. Barnett
Draft Final Report	S. Barnett	J. Houck	S. Barnett
Final Report		J. Houck	S. Barnett

Figure 5-1. Data Reduction, Validations, and Reporting Flow Scheme



6.0 Internal Quality Control Checks

Specific QC procedures will be followed to ensure the continuous production of useful and valid data throughout the course of the test program. The QC checks and procedures described in this section represent an integral part of the overall sampling and analytical scheme. Strict adherence to prescribed procedures is quite often the most applicable QC check. A discussion of both the sampling and analytical QC checks that will be utilized during this program is presented below.

Prior to actual sampling on the site, all of the applicable sampling equipment will be thoroughly checked to ensure that each component is clean and operable. Each of the equipment calibration data forms will be reviewed to ensure the QC objectives have been met. Each component of the various sampling systems will be carefully packaged for shipment. Upon arrival on site, the equipment will be unloaded, inspected for possible damage and then assembled for use. Method-specific QC procedures follow.

Sampling Quality Control Procedures for AWES/Data Logger System

Total particulate mass concentrations in the stack gas will be determined using AWES methods described in Appendix D. Quality control measures are summarized in the following discussion:

1. AWES/Data Logger system improvements¹

Since the basic AWES design has been used to collect hundreds of individual and numerous paired samples, much is known of its overall performance and limitations. Certain weaknesses in the original design were identified which adversely affected precision and accuracy of results, overall reliability, or field serviceability. Efforts have been made to correct these weaknesses either through changes to the basic design or to data collection and handling procedures. In each case, the changes made will improve accuracy, reduce uncertainty, or improve reliability and serviceability. These changes are summarized below:

- a. The glass filter holder which was subject to excessive breakage after a week-long "soak" at 120°C was replaced with a stainless steel holder.
- b. All glass tubing with ball joint connections, which was subject to breakage and required the use of joint sealing grease, has been completely replaced by Teflon tubing and stainless steel fittings.
- c. The oxygen concentration measurement system was modified to improve accuracy and precision.

¹ The effect of AWES/Data Logger system revisions on precision and accuracy of results is discussed in Section 12.

- Temperature indicating strips have been applied to the oxygen (O₂) cells. These will identify the temperature of the cell during calibration and ensure calibrations will be done after the samples have equilibrated to near-room temperature.
 - Data Log's circuitry changes which caused O₂ cell readings to be biased have been corrected to remove the bias.
- d. Vacuum gauges have been installed before and after the critical orifice to allow verification that sufficient pressure drops existed to maintain constant flow and that excess filter loading or system plugging has not occurred.
 - e. A rotometer has been installed to allow flows to be quantified at the beginning and end of each sampling period.
 - f. All AWES probe assemblies have been redesigned to assure smooth internal surfaces, allowing more efficient cleaning.
 - g. A time totalizer was added for comparison with the sampling duration recorded by the Logger.

2. Revised Sampling Procedures

- a. Oxygen cell bias or drift will be assessed by performing a three-point calibration (~8% ~15%, and 20.9% O₂) before and after each sampling period.
- b. Vacuum gauge readings before and after the critical orifice will be recorded before and after a sampling period.
- c. Rotameter readings will be recorded before and after a sampling period.
- d. Sampling probes will be cleaned and rinsed once with a nylon brush for sample recovery. A second cleaning with a copper brush and rinsing will be performed to assure all recalcitrant residues are removed prior to re-use.
- e. Fuel moisture will be determined by Delmhorst moisture meters for moisture contents of 30% or less. Fuel demonstrating higher levels will be sampled for moisture determination using oven-drying procedures.

3. Revised Data Processing Procedures
 - a. Correction factors based on oxygen cell calibration data will be used to calculate overall oxygen concentration data. Sampling results with calibration data showing the O₂ cell readings mid-range to be biased by more than 1.0% absolute or any value to have drifted by more than 1% absolute after the weekly sampling period will be flagged for possible exclusion from data summaries.
 - b. AWES unit flow rates will be based on the individual mean values, accuracy, and precision established during orifice calibration.
 - c. A change in flow rate of 10 percent or greater between pre- and post-sampling rotameter checks will cause sampling results to be flagged for possible exclusion from data summaries.
4. In addition to these revised procedures, the following routine quality assurance measures will be taken.
 - a. Prior to sampling, each AWES filter will be placed in a labeled, individual precleaned glass or plastic petri dish.
 - b. Assembly of the AWES and sample recovery will be performed in an environment free from uncontrolled dust. AWES filter recovery and handling will be performed over a clean plastic drop cloth to allow recovery of fragments which may separate from filter edges.
 - c. Each AWES will be visually inspected for proper assembly before use.
 - d. All sampling data and calculations will be recorded on pre-formatted data sheets.
 - e. The temperature measurement systems will be visually checked for damage and checked for operability. Early in the sampling program, the system will be checked for integrity by submersing thermocouple leads in boiling water and an ice bath and noting Data Logger readouts.
 - f. The entire sampling train will be leak-checked before and after each run.
 - g. The filter, orifice, and sorbent trap will be maintained at the proper temperature throughout the test run.

- h. In weighing the filters, both prior to and after sampling, repeat weighing will be performed at least six hours after the initial weighing. Repeat weighing must agree within ± 0.5 mg to be considered acceptable.
- i. Mass blank determinations (for particulate matter determinations) will be performed on each lot of methylene chloride/methanol rinse solution. Blank residues must be ≤ 0.01 mg/g or 0.001% of the solvent weight.
- j. Any unusual conditions or occurrences will be noted after each run in the appropriate field notebook or data form.
- k. The field supervisor will review sampling data sheets daily during field testing and communicate problems to the project manager.
- l. Except for fuel samples, all sampling equipment will expose the sample material to only glass, Teflon or stainless steel surfaces.
- m. Amber or opaque containers will be used for all samples taken from gas streams.
- n. The methods of sample collection will be documented.
- o. One field blank will be collected for each of ten AWES samples. Blank filters and blank probe rinses will be processed in the same fashion as samples. Filters will be placed into filter holders, the AWES "train" will be assembled, and the filters will be removed for weight determinations. XAD-2 cartridge will be placed in the AWES system and treated during shipping, extraction, and evaporation periods in the same manner as sample XAD-2 cartridges. The probes will be cleaned, and the solvent rinse will be processed for the determination of mass. A blank "catch" value will be calculated.
- p. Certified span gases will be used to calibrate the O₂ cell. (stated precision and accuracy).
- q. Wood moisture values determined by the ASTM D2016 on blocks of wood will be compared with the mean of three Delmhorst moisture meter determinations on the same blocks of wood.
- r. A certified weight will be used to document the AWES scales performance.

- s. The recording of data collected during the sampling program will in the same consistent sequence for all field and laboratory work.

7.0 SPECIFIC PROCEDURES TO ASSESS DATA PRECISION, ACCURACY AND COMPLETENESS

The precision of the fundamental measurement parameters has been (or will be) estimated from: (1) instrument manufacturers' specifications; (2) field and laboratory experience; and (3) repetitive measurements on a single sample. The accuracy of the fundamental measurement parameters has been (or will be) estimated from: (1) instrument manufacturers' specifications; (2) field and laboratory experience; and (3) measurement of standards. The precision estimates are either in terms of standard deviation, i.e.,

$$\sigma = \frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2, \quad (12.1)$$

where: σ = standard deviation,
 n = the number of measurements,
 x_i = the value of measurement i , and
 \bar{x} = the mean of the measurement values;

or in terms of limit of error, i.e.,

$$\lambda = 2.6 \sigma \text{ (normal distribution),} \quad (12.2)$$

where: λ = limit of error.

Limits of error are determined in many cases, as it is easier to estimate the error associated with a 1 percent confidence limit for most measurement parameters than it is to estimate a σ value. Once a λ is determined it is converted to a σ by equation 12.2 for propagation of error calculations. The accuracy estimates are in terms of bias, i.e.,

$$B = \bar{x} - T, \quad (12.3)$$

where: B = bias;
 \bar{x} = the mean of the measurement values; and
 T = the true value.

Completeness is simply a ratio between the number of acceptable data points and the planned number of data points. Data points may be rejected or unavailable due to failure to collect samples; spilled, lost, or broken samples; improper samples; or analytical procedures or rejection of data based on final data review.

The estimated precision (some to be determined), accuracy, and completeness for the fundamental

measurement parameters are provided in Table 1.2. It is assumed that the U.S. EPA and ASTM have developed accuracy and precision estimates for their analytical procedures.

From the accuracy and precision estimates of the individual measurement parameters the accuracy and precision for the emission and energy parameters of interest can be calculated. The standard partial derivative approach will be used, i.e., if

$$F = f(x_1, x_2, \dots, x_n), \quad (12.4)$$

$$\text{then } dF = \frac{\partial F}{\partial x_1} dx_1 + \frac{\partial F}{\partial x_2} dx_2 + \dots + \frac{\partial F}{\partial x_n} dx_n, \quad (12.5)$$

where: $dx_n \equiv$ uncertainty in individual measurement, and
 $dF \equiv$ uncertainty in final value, if absolute values are used; i.e.

$$\text{Uncertainty Final Value} = \left| \frac{\partial F}{\partial x_1} \right| (\text{uncertainty } x_1) + \left| \frac{\partial F}{\partial x_2} \right| (\text{uncertainty } x_2) + \dots + \left| \frac{\partial F}{\partial x_n} \right| (\text{uncertainty } x_n) \quad (12.6)$$

Equation 12.6 can be used for calculating both the propagated accuracy and precision; however, it should be noted that the values obtained represent the maximum probable propagated uncertainties (i.e., assuming totally dependent variables additive uncertainties) rather than the most probable propagated uncertainties (which would require a root mean square analysis with a covariance term expansion). When variables are independent of each other, the uncertainties will, to some extent, cancel each other out. Because the degree of dependence and corresponding covariance terms between many of the variables are difficult to estimate, a conservative (maximum probable uncertainty) approach has been taken in this study.

As has been stated previously in this QAPP, the AWES/Data Logger sampling system that will be used for sampling of residential woodstoves in this study is a modification of an earlier system. The earlier design has been extensively reviewed and characterized as to performance and validity of results. (Evans and Yeager, 1987; Simons, et al., 1988; OMNI Environmental Services, 1987; Houck, et al., 1986) The theoretical performance analysis of the precision and accuracy of AWES/Data Logger system reported in these references provide a baseline against which performance of the latest system can be compared. The remainder of this discussion focuses on this comparison rather than detailing error propagation methods presented in the references.

Changes made to the original AWES/Data Logger samplers were aimed at more reliable performance and reducing the uncertainty of sampling results. Error propagation analyses performed by Evans and Yeager (1987) indicated the contributions to bias and precision of particulate emission rate estimates for a selected near worst-case shown in Table 7-1 example. The individual errors were assumed to be dependent, thus resulting in an estimate of maximum error. Calculations (root mean square) were also made assuming totally independent variables where randomers allow positive and negative deviations to off-set one another to some extent reduce

overall uncertainty. Since some of the variables are not independent of each other, the actual value lies between the two estimates (Evans and Yeager, 1987).

Table 7-1
Analysis of Component Contribution
to Bias and Precision of Example AWES Measurements

Measured Parameter	Estimates of Relative Bias and Precision, P = 0.01	
	Bias (%)	Precision (%)
Mass of particles	7.83	79.71
Stoichiometric volume	16.57	0.00
Flow rate	26.32	17.54
Sampling time	1.67	1.67
Oxygen concentration	58.82	29.41
Maximum error (dependent variables with additive error)	105.31 (40.5) ^a	128.33 (49.4)
Root Mean Square (independent variables)	65.81 (25.3)	86.68 (33.3)

^a Values in parentheses are for one standard deviation, (P = 0.32).

Though these estimates are for an individual case, the magnitudes are indicative of the relative importance of the individual parameters to overall precision and accuracy.

7.1 Actual Measurement of Accuracy and Precision

Accuracy of the AWES system was evaluated in comparison to other test methods promulgated by regulatory agencies for use on woodstoves. One series of comparability tests was conducted by EPA to establish the relationships between the Oregon Method 7, both in-stack (a single train) and in a dilution tunnel (paired trains), and the AWES unit used in-stack. In these relatively short duration tests, the AWES were operated so that sampling occurred on a one minute on, five minute off cycle. Six runs were completed. Table 7-2 presents the means and standard deviations of the ratios of sampling results for the different sampling systems. Similar data also are presented for week-long AWES/Method 5H comparisons conducted for the Department of Energy, Bonneville Power Administration. (1987)

Table 7-2. Mean Comparability Data (McCrillis, 1986; OMNI 1987b)

Units	R/Q	AWES/OM-7	AWES/5H	AWES \bar{x}	OM-7 \bar{x}
g/hr	1.39, 0.38	1.09, 0.57	1.35, 0.41	0.75, 0.25	0.86, 0.46
g/kg	1.39, 0.38	0.86, 0.52	1.34, 0.39	0.70, 0.23	0.85, 0.46
g/mJ	1.39, 0.38	1.42, 0.71	- -	0.98, 0.30	0.87, 0.50

R/Q = Mean ratio of two OM-7 trains sampling from a dilution tunnel, n=6
 AWES/OM-7 = Mean ratio of AWES results to OM-7 results with both systems in stack, n=6
 AWES/5H = Mean ratio of AWES results to Method 5H, both in stack, n=4
 AWES \bar{x} = Mean ratio of the AWES results to the mean of the results of the two dilution tunnel OM-7 trains, n=6
 AOM-7 \bar{x} = Ratio of the in-stack OM-7 train results to the mean of the results of the two dilution tunnel OM-7 trains, n=6

Examination of the data in Column 1 shows that considerable bias in measurement can result even using identical sampling systems (in this case paired OM-7 trains). Comparison of in-stack sampling using the AWES paired with OM-7 and paired with Method 5H trains show mean ratios closer to one than those ratios developed using paired OM-7 systems. The ratios developed from paired AWES and OM-7 systems, illustrated in Column 2 of Table 7-2, do show greater variability, which is probably due in part to the short sampling period (60 minutes) of these tests.

Comparison of the ratio of the AWES-measured values with those of EPA Method 5H over a week-long sampling period typical of AWES sampling of woodstoves (Column 3) shows the means and standard deviations comparable with those of the paired OM-7 trains. Table 7-2 also displays the mean ratios of the in-stack AWES and the in-stack OM-7 to the average of the dilution tunnel OM-7 trains. Both in-stack systems report lower mass values with the ratio of the AWES to the average of the OM-7 trains showing the least variability. These data indicate the AWES unit to be comparable in accuracy to promulgated methods.

The results of numerous paired samples taken using AWES units have been reported previously (OMNI, 1987b). Evaluation of the differences in the twenty-nine paired measurements, made using the first generation AWES systems show a mean of the absolute value of the differences of 3.2 g/hr and a standard deviation of about 4.1 g/hr. The absolute differences are not particularly correlated with the mean values. For the samples collected in this study, the mean of the ratios of the absolute difference to the average value is about 0.184. This overall value compares favorably with the precision values resulting from paired sampling using OM-7 as shown previously.

7.2 AWES Modifications to Reduce Propagated Error

As stated previously, several modifications to the original AWES have been made to reduce the overall propagated error. The effects of the changes on the elements of the propagated error are discussed in the following sections.

Mass of Particulate Matter

Previous difficulties in measurement of total mass values stemmed from the high blank values associated with probe rinses and dissolved joint sealant (halocarbon stopcock grease). New probes with smooth interior wall and a new cleaning procedure assuring a full cleaning of used probes will eliminate high blank values for the probe rinse component of the mass. All second generation AWES units are constructed with Teflon sample lines and stainless steel compression fittings. No joint sealant is required. Experience with these modified units (Simons, et al., 1987) but using the original probe design and cleaning procedures has resulted in average blank values of 26.0 mg (Simons, 1987). The additional use of enhanced probe cleaning, as now planned for this study,

resulted in field blank values of 12.0 mg in a limited field study. (Simons, 1988) These changes will have no effect on the accuracy of the particle mass determination but will significantly improve the precision of results.

Stoichiometric Volume

The uncertainty in the determination of the stoichiometric volume (SV) is dependent upon the uncertainties of the estimates of the elemental (H,O,N,C) composition of the wood and estimates of the relative efficiency of combustion. The latter is principally related to the percentage of carbon converted to carbon monoxide rather than carbon dioxide. It should be noted that due to the incomplete combustion of woodstoves, i.e., some CO is produced, the volume is not truly a stoichiometric volume in the exact sense of the term. Perhaps modified stoichiometric volume would be more appropriate terminology. Evaluation of published chemical composition data and allowing significant variability (± 25) for the CO/CO₂ conversion factor resulted in an estimated relative uncertainty in the SV of approximately 11%.

Uncertainty in species composition accounts for about 90% of total uncertainty in the SV. To reduce this uncertainty, samples of each significant species will be obtained from wood piles of homes in the study. These will be composited by species and analyzed for C, H, O, and N composition. These values will serve as a check on literature values. The results for each composite sample will be applied to SV calculations for the relevant species.

Variability of composition within a species will be obtained from test data. It is difficult to predict the benefit from this level of analysis to overall accuracy and precision until sample results are obtained. However, since previous estimates were based on the full range of published composition values, improvement in the accuracy and uncertainty of the mean composition is expected. The relative overall uncertainty in the SV is expected to be reduced to less than 10%.

Flow Rates

No changes have been made to the AWES system which would improve the quantification of sample flow. However, two changes will be made procedurally that reduce the estimated uncertainty and minimize the potential for the inclusion of faulty data.

In previous error propagation analyses, the uncertainty in flow rates was based on the manufacturer's reported range of flow for their nominal 1 lpm orifice. This value was used even though the flow rate of each orifice was determined by separate calibration. To improve the flow rate estimate, accuracy and precision values for the calibration flow rate will be used in calculation of propagated error. Flows for individual AWES units are

determined by measuring flow with a dry gas meter which has been calibrated against an NBS-traceable mass flow controller, the latter having an accuracy of $\pm 0.5\%$. Flows for individual units will be determined with an estimated accuracy of $\pm 3.0\%$ after calibration with this transfer standard. Analysis of the variability of consecutive calibration runs indicate precision to be approximately $\pm 2\%$.

Flow rates in each sampler will also be measured by a fixed rotometer. Readings will be taken before and after the sampling period. The rotometer manufacturer guarantees accuracy to 4% of full scale, which corresponds to $\pm 100\text{cc/min}$ or approximately 10% of the nominal 1 lpm flow. Changes of more than 10% between the before and after rotometer values will serve as cause for review with the possible assignment of higher uncertainty or rejection of the data.

Sample Duration

Sample duration is established by the Data Logger control systems and is nominally 336 minutes in a one-week sampling period. Power failures or control system anomalies have the potential to affect this value without necessarily invalidating the sample. To verify sampling time, a time totalizing clock has been incorporated in all AWES units which will indicate pump operating time independently from the Data Logger operation record. The clocks have a published accuracy $\pm 1\%$. Measured accuracies are 0.4% or less. Precision values are estimated as equivalent to the accuracy.

Stack Flow Correction

Stack flow rate is determined from stack gas oxygen concentration data. The performance of the oxygen cell used to make these determinations was found to be temperature-sensitive. Calibration at a temperature below actual operating temperature could result in a biasing of reported data. In addition, a modification to the AWES/Data Logger circuitry to correct RF interference problems was also subsequently found to induce a bias to results.

To correct these problems, AWES units oxygen cells will be equipped with a temperature indicating tape. Calibration will not be performed until five minutes after the temperature of the cell is within 5°C of room temperature. Though the magnitude of the net effect of erroneous calibration procedures used in previous seasons is difficult to judge due to its believed random occurrence, cold temperature calibration has been shown to cause a biasing of results. This source of bias will be reduced to a minimum by the required temperature equilibration.

In addition, the electronic circuitry of a Data Logger modification which induced a voltage bias in the O₂ cell output has been corrected, eliminating this source of error.

To further verify O₂ cell output, a three-point calibration will be performed immediately before and after each sampling period. Calibrations will be performed using portable gas cylinders containing oxygen-nitrogen mixture with oxygen concentrations in the ranges of 6 to 10 percent and 13 to 17 percent. The uncertainty of the gas concentration will be ±2% relative.

Calibration values will be used to establish:

1. Whether the O₂ cell is functioning properly;
2. Drift in the O₂ cell over the one-week sampling period; and
3. Correction values to account for non-linearity and drift on a case-by-case basis.

Table 7-3 summarizes the criteria for data review for each factor.

The oxygen equation for determining stack flows is an asymptotic function resulting in high uncertainty in the factor as the mean sample O₂ concentration approaches that of the atmosphere. Even with the improvement in the precision and accuracy of the O₂ cell output, uncertainty in the correction factor will be high at mean sample O₂ concentrations greater than 18% O₂. All samples with O₂ levels exceeding this value will be closely reviewed to establish whether they should be excluded from data summaries.

Bias values determined from the pre- and post-sample calibrations will be used to reduce the uncertainty in overall results by reducing the uncertainty in the O₂ values. Calibration values will be used to calculate correction values for O₂ concentration data collected by the Data Logger. An average correction factor for each calibration point will be developed from the average of the two bias values so that

$$\%O_{2c} = \%O_{2M} + 1/2 (B_{i,f} + B_{i,o}) \text{ where}$$

$$\%O_{2c} = \text{Corrected O}_2 \text{ level during sampling}$$

$$\%O_{2m} = \text{Measured O}_2 \text{ level during sampling}$$

Table 7-3
O₂ Cell Calibration Results
Evaluation Criteria

Parameter	Maximum Allowable Value ^a	Corrective Action if Max. Allowable Value Exceeded
Initial Bias ^b	1.0	Flag data for special review/evaluation
Initial Bias ^b	2.0	Replace O ₂ cell
Drift from Span ^c	1.0	Flag data for special review/evaluation
Drift from calibration ^d	2.0	Flag data for special review/evaluation
Final Bias ^b	2.0	Flag data for special review/evaluation

^a Equivalent O₂ percent (absolute)

^b = Bias from linear response for calibration gas i, $B_i = 20.9 (V_{c,i}/V_o) - C_i$

^c = Drift of the span value, $D_s = 20.9 (V_f - V_o)/V_o$

^d D_i = Drift of calibration value for calibration gas i,

$$D_i = B_{i,f} - B_{i,o}$$

where

$V_{c,i}$ = O₂ cell voltage for calibration gas i

V_o = O₂ cell voltage for air prior to sampling

V_f = O₂ cell voltage for air after sampling

C_i = concentration of O₂ in calibration gas i

$B_{i,f}$ = B_i as determined after sampling

$B_{i,o}$ = B_i as determined prior to sampling

$$\begin{aligned} B_{i,f} &= \text{Bias of O}_2 \text{ calibration for cal. gas i measured after sampling} \\ &= \text{actual concentration} - \text{measured concentration} \end{aligned}$$

$$\begin{aligned} B_{i,o} &= \text{Bias of O}_2 \text{ calibration for cal. gas i mean before sampling} \\ &= \text{actual concentration} - \text{measured concentration} \end{aligned}$$

The approach assumes a bias equivalent to that which results from a linear drift with time and that the arithmetic value is an accurate indicator of the mean bias.

Corrected O₂ concentration values will be calculated for all measured O₂ values using a second order interpolating polynomial (Lagrange's form). Functional values used in preparing the polynomial will be the right-hand side of the preceding equation evaluated at the three points of calibration. Error due to the interpolating polynomial is difficult to evaluate; however, it is a function of the third derivative of the response curve of the cell and is expected to be very small. Error of the polynomial will be zero for each calibration point and will be maximum at low O₂ concentrations where such error will have minimum effect on overall uncertainty.

The effect of O₂ correction factors will be to reduce bias to one-half the measured drift, assuming such drift to be uniform. Using the criteria of Table 7-2, which limit drift to 1.0%, maximum bias would be 0.5% O₂ absolute. The uncertainty in the accuracy and precision of the calibration gases which has been specified as 2% relative must be added to this estimate, however.

7.3 Estimates of Overall Uncertainties

The remainder of this section discusses the effect of the revisions to the AWES/Data Logger system on propagated error in the context of the example case drawn from Evans and Yeager discussed earlier. This example is from real sampling data and represents a near-worst case due to the high average oxygen concentration. However, it serves well to demonstrate the significance of the revisions on overall uncertainty.

For convenience in reviewing the subsequent equations, Table 7-4 summarizes the estimated accuracy and precision of the components of the mass emission rate equation after incorporation of the revisions to the AWES/Data Logger system and incorporation of methods of data screening described in the preceding subsections.

By far the greatest uncertainty is associated with the accuracy and precision limitations of the O₂ cell. A precision value of 0.8% absolute has been assigned based on data collected and reported by OMNI (August 27, 1987.) An accuracy value of 1.5% is based upon the averaging of an initial calibration bias of 1.0% absolute and a post-sampling calibration bias of 2.0% absolute allowed by the calibration results evaluation criteria of Table 12-3. The accuracy estimate should represent the extreme case since the initial calibration will set bias to 0% at 20.9% O₂. The bias of the mean O₂ measurements in the critical 15%–18% range should have considerably less than 1.0% initial bias unless the cell is extremely non-linear. At lower O₂ concentrations, where an initial bias of 1% absolute would be more probable, the effect of such bias on results is far less important to accuracy due to the asymptotic nature of the stack flow term.

As described by Evans and Yeager, the calculations for the example case illustrating the effect of the system changes on ratio accuracy and precision are shown below.

$$\frac{d(\text{g/kg})}{\text{g/kg}} = \frac{d\text{MP}}{\text{MP}} + \frac{d\text{SV}}{\text{SV}} + \frac{d\text{FR}}{\text{FR}} + \frac{d\text{SD}}{\text{SD}} + \frac{d\%O_2}{(20.9-\%O_2)}$$

where the numerators are the precision or bias for that parameter, as reported in OMNI (1987a) Table C-1 and the denominators are the measured values used to calculate the emissions rate. In this equation

- MP = Mass of particulate from the combined masses of the filter, probe rinse, and XAD-2 resin extraction, minus the appropriate field blank value.
- SV = Stoichiometric volume.
- FR = Sample flow rate.
- SD = Sample duration.
- %O₂ = Mean percent oxygen (absolute) in the sample gas.

Again referring to the data from rotation 4 at house 4 in Vermont, the emissions rate in g/kg is

$$\text{g/kg} = \frac{(0.1635)(4686)(20.9)}{(1.14)(225)(20.9-17.5)} = 18.36 \text{ g/kg.}$$

The bias in the calculated emissions in gm/kg is estimated as

$$\begin{aligned} \frac{d(\text{g/kg})}{\text{g/kg}} &= \frac{1.1+(0.5)(20.6)+1.4}{163.5} + \frac{500}{4686} + \frac{0.3}{1.14} + \frac{1}{60} + \frac{2.0}{(20.9-17.5)} \\ &= 7.83\% + 10.67\% + 26.3\% + 1.67\% + 58.82\% = 105.31\% \text{ or } 19.33 \text{ g/kg} \end{aligned}$$

However, the values shown in Table C-1 represent the 99% confidence interval. They must be divided by 2.6 to find one standard deviation (SD).

$$105.31\%/2.6 = 40.50\% \text{ or } 7.5 \text{ g/kg}$$

Incorporating changes proposed in this plan and the bias and precision estimates of the preceding sections the new bias estimate would be:

$$\frac{d(\text{g/kg})}{\text{g/kg}} = \frac{1.1+(0.5)(20.6)+1.4}{163.5} + \frac{468}{4686} + \frac{0.034}{1.14} + \frac{3.36}{336} + \frac{(0.5 + 0.02(15))}{(20.9-17.5)}$$

$$= 7.83\% + 10\% + 3\% + 1\% + 23.5 = 45.33$$

$$\text{SD} = 38.0/2.6 = 17.4\% \text{ or } 3.20 \text{ g/kg.}$$

The precision of the original emissions rate estimate is

$$\frac{5.0+(0.2)(20.6)+121.2}{163.5} + \frac{0}{4686} + \frac{0.2}{1.14} + \frac{1}{60} + \frac{1.0}{(20.9-17.5)} =$$

$$79.71\% + 0.0\% + 17.54\% + 1.67\% + 29.41\% = 128.33\%.$$

$$128.33\%/2.6 = 49.36\% \text{ or } 9.1 \text{ g/kg.}$$

The revised precision estimate is

$$\frac{5.0+(0.2)(20.6)+15.0}{163.5} + \frac{0}{4686} + \frac{0.034}{1.14} + \frac{3.36}{336} + \frac{0.8}{(20.9-17.5)} =$$

$$14.7\% + 0\% + 3.0\% + 1.0\% + 23.5\% = 42.2\%.$$

$$\text{SD} = 44.2\%/2.6 = 16.2\% \text{ or } 2.98 \text{ g/kg.}$$

**Comparison of Accuracy, Precision, and Propagated Error Estimate
for Calculating Specific Emission Rates
Using the Original and Proposed AWES/Data Logger Systems (Example Case)**

Data Logger System		Equation Components ^a						Propagation of Errors ^b			
		Mass of Particles (MP)	Stoichio- metric Volume (SV)	Flow Rate (FR)	Sample Duration (SD)	Oxygen Con- centration (%O ₂)	Dependent Additive		Independent		
							P = 0.01	P = 0.32	P = 0.01	P = 0.32	
Original (AWES I) System	Accuracy	7.83	0.67	26.3	1.67	58.8	105.3	40.5	65.8	25.3	
	Precision	7.97	0.0	17.54	1.67	29.4	128.3	49.3	86.8	33.7	
Proposed (AWES II) System	Accuracy	7.83	10.0	3.0	1.0	16.2	45.3	17.4	26.9	10.3	
	Precision	14.7	0.0	3.0	1.0	23.5	42.2	16.2	27.9	10.7	

This analysis assumes dependent errors which are totally additive and represents worst case errors for the example case. In addition, the mean O₂ levels (which dominate overall error estimate) for this example are very near the 18% O₂ value proposed as a criterion level for data review. Consequently, this example illustrates nearly the absolute worst case error that would not be subject to detailed evaluation. A value of 18% O₂ would increase the bias error estimate to approximately 41% and the precision error estimate to approximately 53%.

Assuming independent, uncorrelated measurements, the revised error may be estimated by using the root mean square of the parameter errors:

$$\text{Bias error} = (7.83^2 + 10^2 + 3^2 + 1^2 + 23.5^2)^{1/2} = 26.9\%$$

$$\text{SD} = 10.3\% \text{ or } 1.9 \text{ g/kg}$$

$$\text{Precision error} = (14.7^2 + 0^2 + 3^2 + 1^2 + 23.5^2)^{1/2} = 27.9\%$$

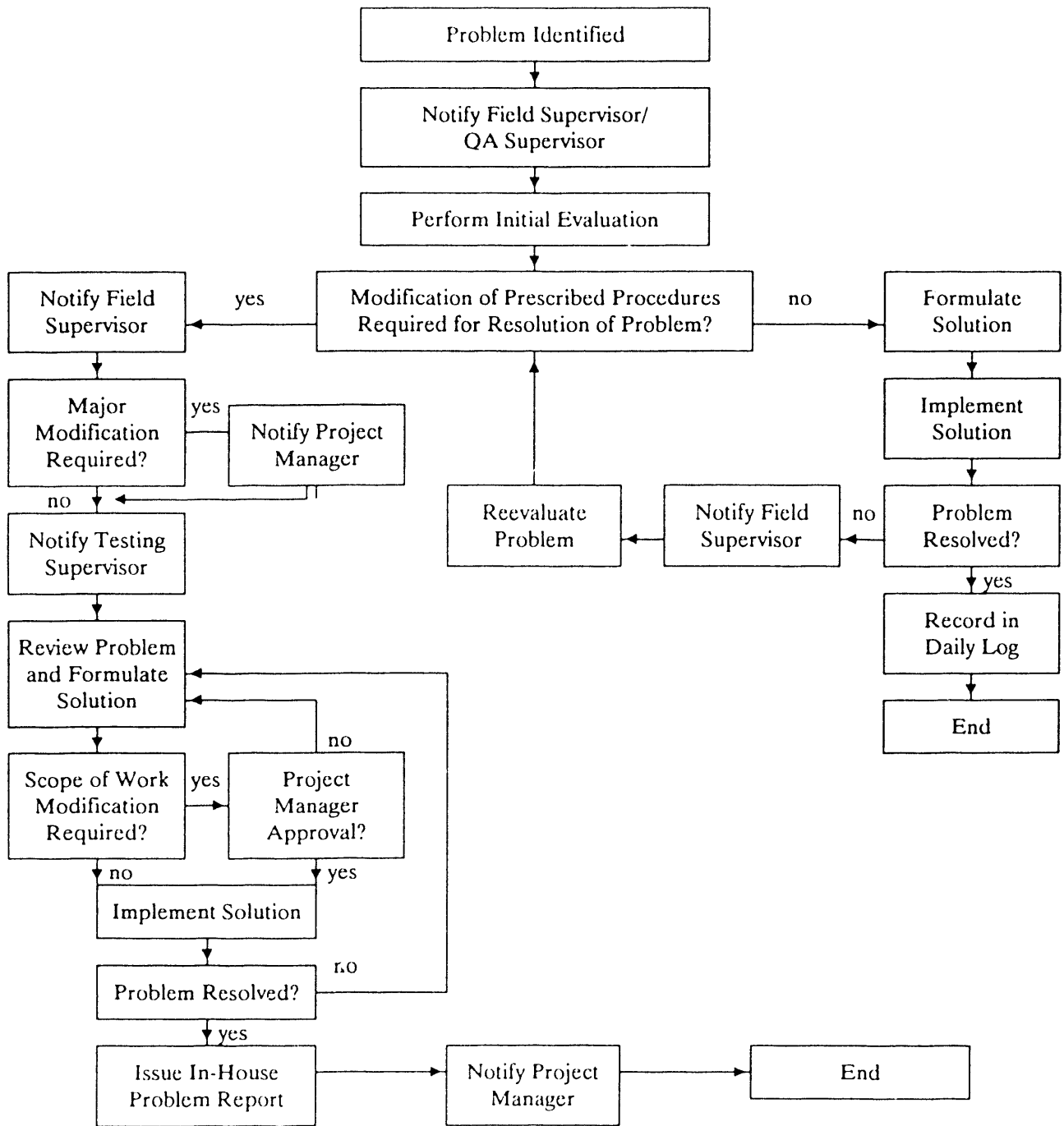
$$\text{SD} = 10.7\% \text{ or } 1.96 \text{ g/kg}$$

Since there is some degree of dependence between some of the variables the best estimate of accuracy and precision lies between the values for independent and dependent errors.

8.0 CORRECTIVE ACTION

During the course of the testing program, it will be the responsibility of the field supervisor and the sampling team members to see that all measurement procedures are followed as specified, and that measurement data meet the prescribed acceptance criteria. In the event a problem arises, it is imperative that prompt action be taken to correct the problem(s). Spare AWES and Data Logger systems will be maintained on site for emergency deployment in the event of a sampler malfunction. The field team supervisor will initiate corrective action in the event of QC results which exceed acceptability limits. Corrective action may be initiated by the QA officer based upon QC data or audit results. The corrective action scheme is shown in the form of a flow chart in Figure 8-1.

Figure 8-1. Corrective Action Flow Scheme



9.0 AMENDED ANALYSIS OF UNCERTAINTY IN RESULTS, 1988-89 NCWS

As a result of some problems encountered in the process of field sampling in the 1988-89 NCWS project and the solutions that were developed and implemented during that same sampling period, the level of error changed considerably. The analyses of error which will be discussed below are all based on empirical treatment of large databases of field data. In the process of conducting these analyses it was discovered that while most error is non-systematic precision in nature, it is not possible to assign a relative amount of error to precision or accuracy. Therefore error will be treated here in the more general context of "level of uncertainty". Error will be presented in both Standard Deviation and 95% Confidence Level (1.96 S.D.) form.

The following sections of the Appendix treat each error source separately and in detail. The table below lists these sources and indicates when they were in effect in the field test sequence.

Error type	Run 1	Run 2	Run 3	Run 4	Run 5
Sample Blank Error	Y	Y	Y	Y	Y
Broken Filters	Y	N	N	N	N
Catalytic Res. Cell	Y	Y	Y	N	N
Lynn Oxygen Cell	N	N	N	Y	Y

Thus, the table shows that there were three distinct test "situations", each with its own characteristic error level: Test Run 1, Test Runs 2-3 and Test Runs 4-5.

The magnitude of each type of uncertainty as empirically determined herein is shown in the following table. In addition, values for the two other variables contributing to uncertainty, stoichiometric volume and sample duration, obtained from the Quality Assurance Plan, are included at the bottom of the table for completeness.

Error type	1.0 Standard Deviation	1.96 Standard Deviations
Sample Blank Error	2.0%	4.0%
Broken Filters	10.1%	19.8%
Catalytic Res. Cell	9.2%	18.0%
Lynn Oxygen Cell	3.6%	7.2%
Stoichiometric Vol.	3.9%	7.5%
AWES Flow Rate	1.1%	2.1%
Sample Duration	0.3%	0.7%

The table below contains estimates of overall uncertainties (propagation of error) for each of the three error “situations” throughout the project. Uncertainty is shown as 1 S.D. (P=0.32), and 1.96 S.D. (P=0.05) for both the independent and dependent variable condition. For the current project, variables can be considered either independent or nearly independent of one another.

Propagation of Uncertainty, 1988-89 NCWS

Situation	Variables Independent		Variables Dependent	
	P = 0.32	P = 0.05	P = 0.32	P = 0.05
Run 1	14.4%	28.2%	26.6%	52.1%
Runs 2 & 3	10.3%	20.1%	16.5%	32.3%
Runs 4 & 5	5.8%	11.3%	10.9%	21.4%

The best estimate of average uncertainty at the 95% confidence level for Run 1 is 28.2%, for Runs 2 and 3 it is 20.1% and for Runs 4 and 5 it is 11.3%. For comparison, the Quality Assurance Plan originally estimated this project would have a precision uncertainty of 21% and an accuracy uncertainty of 20.2% at the 95% confidence level. Run 1 fell somewhat short of expectations, runs 2 and 3 were in close agreement, and Runs 4 and 5 essentially halved the expected uncertainty.

The conditions used for runs 4 and 5 have been present for all subsequent field sampling projects.

9.1 THE MAGNITUDE OF SAMPLE BLANK ERROR; 1988-89 NCWS

Analysis of blank values: Historically the error caused by sample blanks associated with AWES studies has been high. The average blank value was 101.5 mg in the first NCWS study primarily do to the use of ball joints and sealing grease. The standard deviation was 46.6 mg with the probable error at the 95% confidence level being ±91 mg. With experience, blank-induced error has more recently decreased to much lower levels as evidenced by the Whitehorse Study.

Because of this historical situation, extra attention was paid to the blank situation in the 1988-89 project. Ten blanks were required, but a total of 23 were analyzed. A policy of blind blanks was also instituted where the lab thought the blank samples had actually been run in the field. It was hypothesized that this might cause a lab to attempt to obtain higher recovery in probe washes and XAD traps. Table 9.1 shows all of the blank values in

milligrams. Blanks Y2-3 and 9-4 were blind to both labs and the other 12 blind blanks were blind only to the OMNI lab (where XAD_s were extracted).

Analysis of the 23 blanks indicates that the average blank value is a very low 3.9 mg. Values for blind blanks show no elevation compared to the non-blind group. Analysis of variance indicates that the standard deviation of blank values is 2.49 mg and the probable error at the 95% confidence level (1.96 S.D.) is ±4.88 mg. Figure 9.1 shows the distribution of blank values. As a result of this analysis, an average blank value of 3.9 mg was subtracted from all particulate catches.

Determination of blank-induced error: The probable error of ±4.88 mg has a differential effect on the error of the eventual emissions value. In general, emissions values of dirty burning stoves with large particulate catches are little-affected by such a small blank error but clean-burning stoves where catches are often less than 50 mg clearly are. This phenomenon is exhibited in figures 9.2 and 9.3 which contain all 114 NCWS emissions results.

Figure 9.2 shows the moderately highly correlated relationship between total particulate catch and emissions (gm/hr). It demonstrates that catches for clean-burning stoves are low (“average” for a 4 gm/hr stove is about 80 mg). Catches of less than 50 mg are typical. These occur when the stove burned significantly less than a full week and/or stack dilution was high (high average oxygen).

Figure 9.3 shows the magnitude of the “blank-induced error effect” on the NCWS emissions results (using the same ±4.88 mg blank error). Note that the “average” error for 4 gm/hr stoves is about 8% with some values in the teens. In retrospect, it would be preferable if this error had been lower. In addition, in future studies it is anticipated that a higher percentage of cleaner burning stoves will be studied so efforts should be made to reduce this form of error. Since blank-induced error has probably been reduced to its practical minimum, the logical solution is to double the sample volume from the current 336 liters/week to 672 liters/week. This empirical analysis of a large field sample is probably our first opportunity to develop a comprehensive understanding of the contribution blank error makes to total emissions error.

Summary: The average blank value of 23 1988-89 NCWS blanks is 3.9 mg., significantly reduced from earlier NCWS studies. The standard deviation is 2.49 mg and the probable error at the 95% confidence level is ±4.88 mg. This error contributes little to emissions uncertainty for dirty-burning stoves, but is approximately 8% for 4 gm/hr stoves. The average magnitude of this error to emissions values (at 9.6 gm/hr emissions) is about 4%. Future sampling should increase sample volume to further reduce the magnitude of this error.

Table 9-1. New York Woodstove Study Analysis of All Blanks

ID	Rinse	Filter	XAD	Total	Notes
Blank; Run 1	1.5	-5.1	6.7	3.1	
Y23 Blank; Run 1	1.7	0.1	3.7	5.5	
Blank; Run 2	5.4	-2.6	-0.9	1.9	
Blank; Run 3	-0.7	-1.8	1.7	-0.8	
Y2 Blind; Run 3	23.9	-19.8	4.6	8.7	Broken filter
Blank; Run 4	0.2	0.4	-0.6	0.0	
Blind Blank; 9-4	0.6	-0.5	4.6	4.7	Blind
Blank; Run 5	3.5	-0.5	1.6	4.6	
Elank; 9-58	3.0	-0.3	5.2	7.9	
Blank; 12-681	-0.5	-0.4	3.9	3.0	
Blank; 12-682	-0.3	-0.2	1.9	1.4	
Y13	-0.4	-0.1	3.4	2.9	Blind
Y14	-0.2	0.4	3.9	4.1	Blind
Y15	0.1	0.0	3.7	3.8	Blind
Y16	-0.1	-0.4	5.3	4.8	Blind
Y17	0.5	-0.1	8.0	8.4	Blind
Y19	-0.2	-0.7	5.7	4.8	Blind
Y20	-0.2	0.0	6.5	6.3	Blind
Y21	0.2	0.3	4.5	5.0	Blind
Y22	0.1	0.1	1.8	2.0	Blind
Y23	-0.1	-0.4	5.7	5.2	Blind
Y24	0.1	0.2	1.5	1.8	Blind
Y25	-0.2	-0.2	1.1	0.6	Blind
Averages	0.63 ^a	-0.54 ^a	3.63	3.90	
S.D.	1.49 ^a	1.20 ^a	2.25	2.49	

a. Y23 Blank excluded.

N = 23; Ave. = 3.90 mg; S.D. = 2.8 mg.
 Maximum probable error @ 95% conf. level = ±4.88 mg

Figure 9.1

DISTRIBUTION OF '89 N.Y. WOODSTOVE STUDY
 BLANK VALUES; N=23, AVG.=3.9 MG.

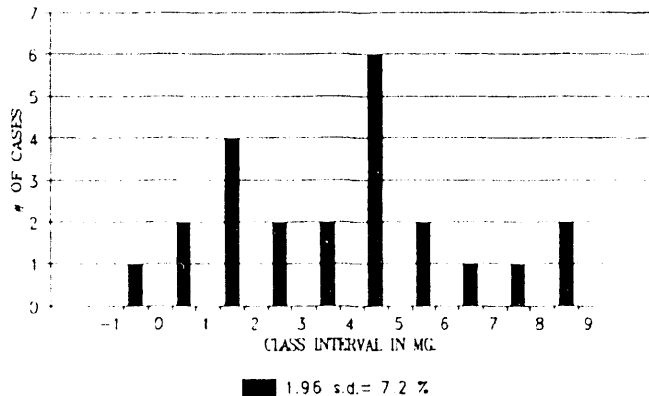


Figure 9.2

GM/HR EMISSIONS VS. TOTAL PARTICULATES NCWS 1988-89

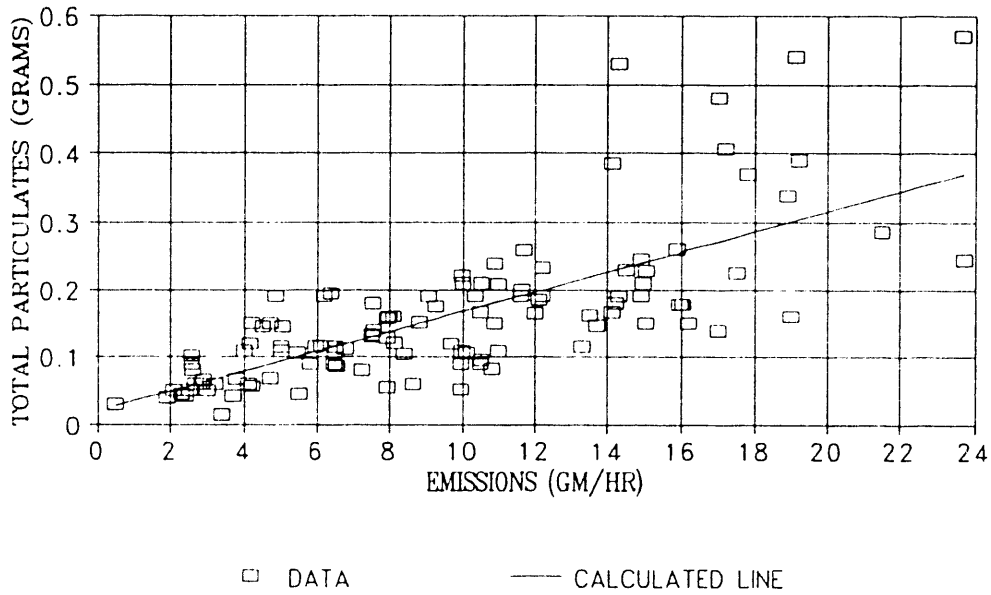
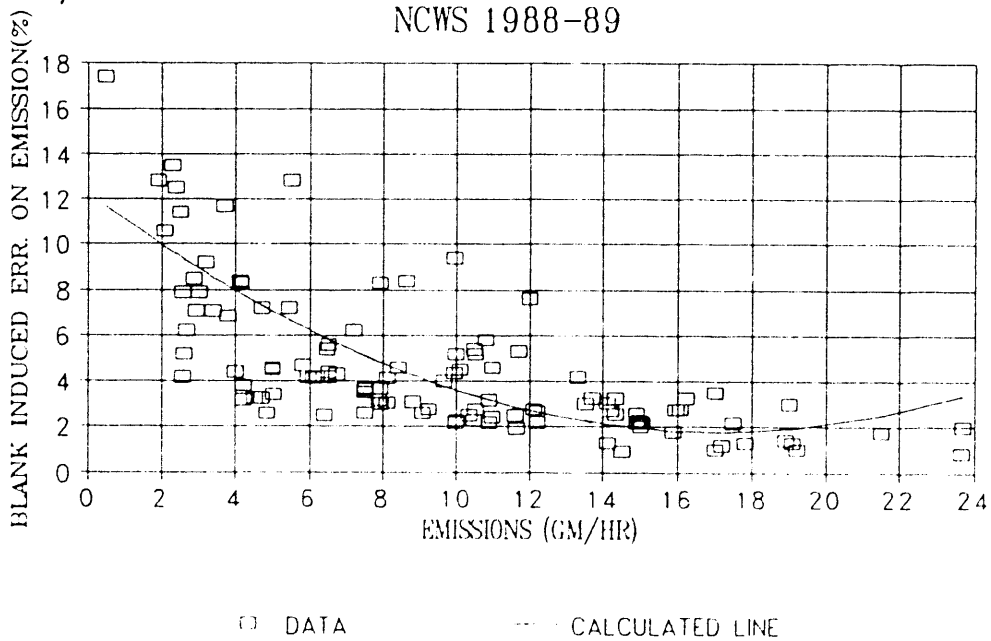


Figure 9.3

GM/HR EMISSIONS VS. BLANK INDUCED ERROR NCWS 1988-89



9.2 MAGNITUDE OF ERROR FOR THE LYNN OXYGEN CELL

The Lynn oxygen cell replaced the Catalytic Research cell in the final two test runs of the 1988-89 NCWS. Of a total of 114 tests, 40 (or 35%) were conducted using the new cell. This sample size was large enough to optimize field use patterns, evaluate its performance and analyze for error effectively.

Basic precision of the cell: During the last test run the weather warmed significantly. In response, five of the homeowners burned infrequently enough that significant downtimes resulted. During such times the AWES sampled room temperature ambient air which the cell should read as 20.9 percentage points. During the new data reduction computer program's regression analysis, data is sorted according to stack temperature. This scrambles the readings with respect to time during the week. If a drift in cell output took place, the scatter in readings would be visibly and quantitatively high. The 732 oxygen readings made when the stack temperature was less than 75°F were analyzed for variance. The results are shown below.

Test	N	Ave.Amb.Ox reading	S.D.	Probable error @ 95% conf.
Y04-5	131	20.88%	0.037%	0.072%
Y06-5	236	20.96%	0.107%	0.210%
Y08-5	50	20.87%	0.045%	0.089%
Y15-5	195	20.94%	0.047%	0.093%
Y20-5	120	20.92%	0.082%	0.160%

This empirical analysis of the Lynn cell's performance under field conditions indicates that the precision (at the 95% conf. level) for any single oxygen reading is equal to or better than ± 0.2 percentage points. The 95% confidence limit for the mean for a sample population of measurements (the situation for AWES sampling where 336 measurements are involved) is much lower. For example such a limit for the most variable test, Y06-5, is only ± 0.014 percentage points.

It is concluded that the repeatability for Lynn cell measurements is excellent, and for determining means from large AWES sample populations measurement repeatability contributes essentially no error.

Other sources of possible error: Experience with the Lynn and the Catalytic Research cells indicates that an oxygen cell can cause error in the emissions results in several ways in addition to the cell's inherent precision. They include 1) the cell wasn't calibrated well at setup (cell wasn't thermally stabilized etc.), 2) the cell drifted

during the time between setup and takedown, 3) the takedown calibration wasn't correct and 4) the calibration curve was not mathematically "smooth".

The new computer program was designed primarily to establish the best calibration for the oxygen cell during the test period and has done so effectively. With the Lynn cell, differences between setup and takedown ambient readings greater than 0.2 percentage points occur only about 25% of the time (see table 1 and figure 1). In this minority of cases the program allowed for adjustment of calibration to within ± 0.1 percentage points when more than about 25 cool-temperature downtime measurements were present. In the worst of cases, when the stack temperatures did not fall below 200°F, calibration uncertainty is at about ± 0.2 percentage points.

The computer program's analysis showed that in those cases where a discrepancy between setup and takedown calibrations differed by more than 0.2 percentage points the takedown calibration agreed best with the test period calibration. No drift of the cell's output during the week-long sample period has been detected.

In the 1988-89 field testing the oxygen cell was calibrated to three calibration gases, 20.9% (as well as ambient), 15% and 8%. A calibration curve over this range of values was calculated to allow for correction of all raw values. Both cells were slightly non-linear and a quadratic best fit regression was to be used to develop calibration curves. However, quadratic fits to only three points produce poor, highly artificially curved fits. Linear regression has been used instead. Trying to fit a straight line to a curved set of points causes residuals, but observation showed that largest observed residuals were only 0.2 percentage points with one residual tending to offset another. The resulting error from calibration curve fitting is very small. If higher precision is desired, a fourth calibration point, 0% oxygen should be used. This was done for some cell calibrations to evaluate the procedure. The four point quadratic regressions produced the desired minimal residuals. The necessity of using a 0% calibration gas is not great since only 0.25% of the study's oxygen readings were lower than the 8% calibration point.

Determination of maximum possible error: In light of the above discussion, the worst possible error that could be produced would be to assume that no correction and/or reconciliation could be made for the difference between setup and takedown calibrations of ambient air. The error would then consist of a propagation of the setup minus takedown difference through the emissions equation. Table 9.2 shows the setup and takedown ambient oxygen values as well as their differences for all 40 tests. Figure 9.4 shows the distribution of the differences. The standard deviation is 0.19 percentage points and the probable error at the 95% level is ± 0.37 percentage points.

The most significant aspect of this error is how much it affects the final emissions value, since the emissions equation uses oxygen in the form $(20.9-X)$. The right column of table 9.2 shows these error values. They are

graphically depicted in figure 9.5. The standard deviation of these error values is 3.56% and the probable error at the 95% confidence level is $\pm 7.17\%$.

Summary: The inherent precision of the Lynn oxygen cell as analyzed from 732 in-home ambient readings involving 5 cells is very good; a maximum of ± 0.2 percentage points (at ambient) at the 95% confidence level for an individual reading and 0.015 percentage points or less for an average of several hundred points.

After extensive field experience with the Lynn cell, the maximum error situation that can be envisioned is to assume that no correction can be made to reconcile the differences between the setup and takedown calibrations. Since the new computer program can reconcile these differences to a large degree such an error calculation is considered a "worst case situation".

The probable error at the 95% confidence level for ambient setup-takedown differences is ± 0.37 percentage points, far less than that required by the QA plan. The effect of this error on the final emissions value is greater due to the (20.9-X) effect. That error is $\pm 7.17\%$ at the 95% confidence level.

It can be concluded that the error contributed by use of the Lynn oxygen cell to emissions values has been reduced to a very low and acceptable level; less than $\pm 7.17\%$.

Table 9-2. New York Woodstove Study Analysis of Performance of the Lynn Oxygen Cell

House & Run	Setup Ambient Ox. Reading	Takedown Ambient Ox. Reading	Setup Minus Takedown Ox. Readings; Direct Readings	Setup Minus Takedown Ox. Shown as % Difference	Test's Average Stack Oxygen	Emissions % Error Using Test's Ox. & Setup Takedown Difference
1-5	21.00	20.7	0.3	1.45	13.3	2.54
1-6	20.90	20.8	0.1	0.48	13.02	0.79
2-5	21.00	20.9	0.1	0.48	15.75	1.46
2-6	20.90	20.9	0	0.00	14.75	0.00
3-5	20.90	20.6	0.3	1.46	14.24	3.11
3-6	21.10	21.1	0	0.00	15.1	0
4-5	20.90	20.8	0.1	0.48	17.24	2.26
4-6	20.90	20.7	0.2	0.97	16.95	4.15
5-5	20.90	20.9	0	0	16.56	0
5-6	20.90	20.9	0	0	16.48	0
6-5	20.90	21.1	-0.2	-0.95	17.32	-4.59
6-6	20.90	20.8	0.1	0.48	17.89	2.86
7-5	20.9	20.8	0.1	0.48	15.47	1.37
7-6	20.9	20.1	0.8	3.98	15.85	12.49
8-5	20.8	20.6	0.2	0.97	17.07	4.33
8-6	20.8	20.7	0.1	0.48	17.41	2.41
9-5	20.7	20.6	0.1	0.49	15.81	1.51
9-6	20.90	20.7	0.2	0.97	16.24	3.37
10-5	20.9	20.9	0	0	15.15	0
10-6	20.8	20.8	0	0	16.67	0
11-5	20.9	20.4	0.5	2.45	17.82	14.18
11-6	21	21.1	-0.1	-0.47	17.2	-2.20
12-5	20.9	20.9	0	0	14.58	0
12-6	20.9	20.8	0.1	0.34		
13-5	20.9	20.8	0.1	0.48	14.31	1.04
14-4 ^a	20.8	20.70	0.1	0.44	14.44	0.98
14-5	21.0	21.1	-0.1	-0.47		
15-4 ^a	21.0	20.8	0.2	0.89	17.42	4.51
15-5	20.9	21	-0.1	-0.48	17.85	-2.79
16-5	20.9	20.7	0.2	0.97	17.19	4.48
17-4 ^a	20.9	20.8	0.1	0.45	16.17	1.54
17-5	20.9	20.7	0.2	0.97	16.66	3.80
19-4	21.1	20.9	0.2	0.80		
19-5	20.9	20.8	0.1	0.48	15.52	1.39
20-4	21	20.9	0.1	0.48	16.23	1.66
20-5	20.9	20.7	0.2	0.97	17.33	4.69
21-5	20.9	21.2	-0.3	-1.42	17.26	-6.71
22-5	21	20.7	0.3	1.45	16.46	5.37
23-5	20.9	20.8	0.1	0.48	14.03	0.98
24-4	21	20.8	0.2	0.96	15.21	2.57
24-5	20.9	20.6	0.3	1.46	15.26	3.94
25-4	20.9	20.8	0.1	0.48	15.16	1.27
25-5	21	21.3	-0.3	-1.41	14.82	-3.43
Average	20.916	20.808	0.107	0.523		1.883
S.D.	0.075	0.204	0.186	0.907		3.656
95% Conf.	0.146	0.400	0.365	1.777		7.165
N	43	43	43	43		40

Figure 9.4

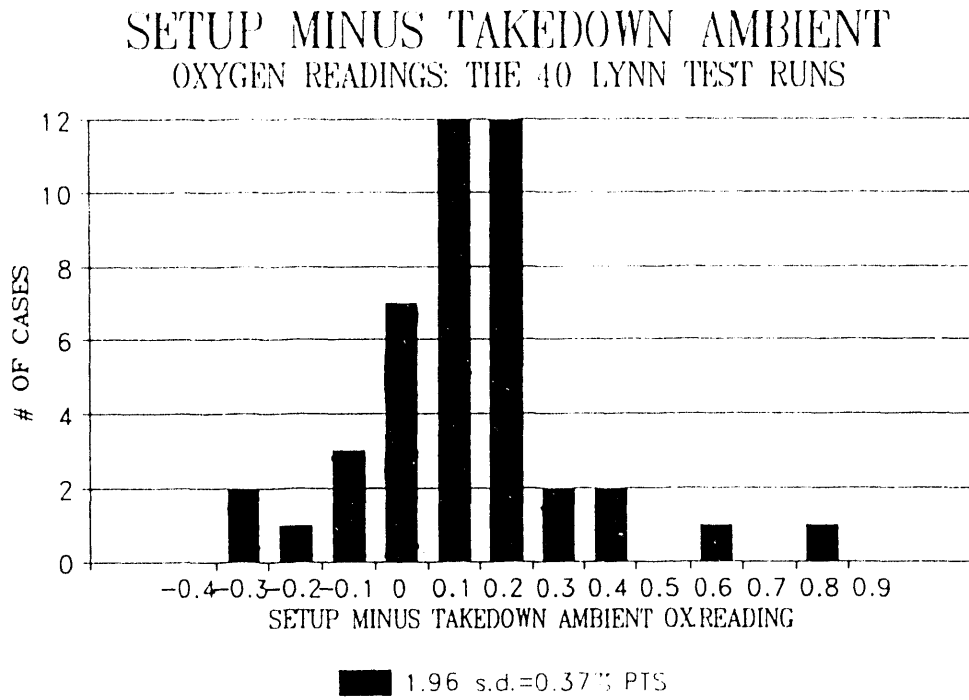
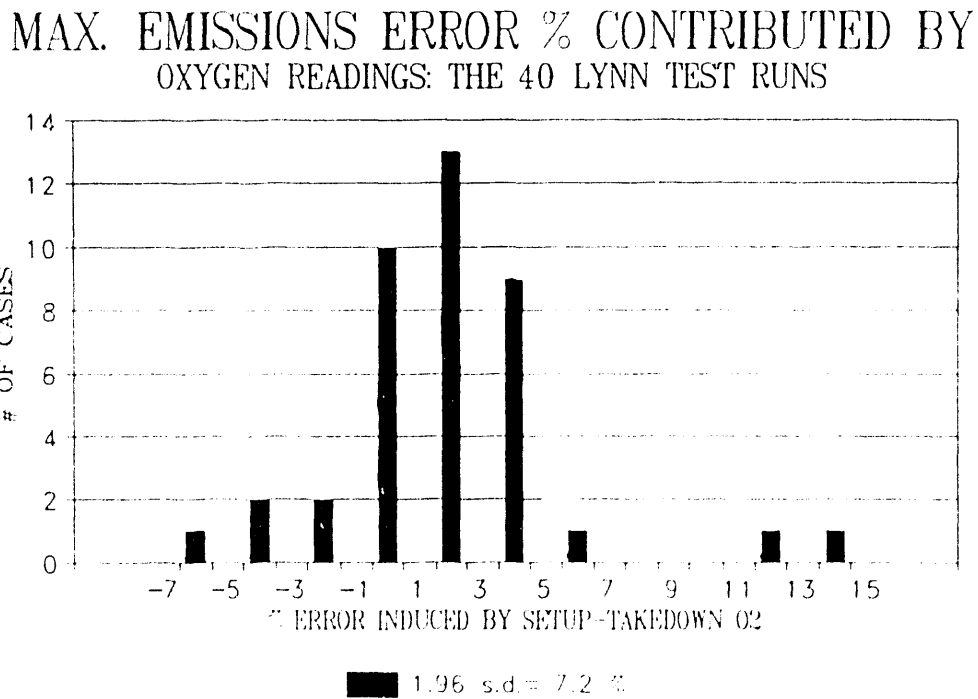


Figure 9.5



9.3 EVALUATION OF THE UNCERTAINTY IN CRITICAL ORIFICE FLOW RATES

Two possible sources of error could be present in critical orifice flow measurements. The first is non-systematic error caused by lack of precision in the calibrating instrument. The second is a systematic error that could develop as the result of partial clogging of the orifice with hydrocarbons during field use of the AWES.

These sources of error were evaluated in the following manner. All orifices were calibrated using a bubble meter before the field season. They were again calibrated at the end of the season; after all sample runs. The results shown in table 9.3, indicate that there was no change in average orifice flow during field use. Therefore no orifice clogging had developed.

Analysis of the individual pre-season vs. post-season flow rates indicates a high level of consistency. The standard deviation is only 0.0098 liter/minute. The magnitude of uncertainty at the 95% confidence level (1.96 S.D.) is $\pm 2.14\%$. This is very close to the $\pm 2.3\%$ used in the original Quality Assurance Plan.

In summary, empirical documentation of all pre and post field season critical orifice flows using a bubble meter indicates that no loss of flow took place. Partial orifice clogging did not develop. Analysis of variance indicates that the level of uncertainty emanating from non-systematic error is $\pm 2.14\%$. This verifies that the $\pm 2.3\%$ used in the Quality Assurance Plan is valid.

Table 9-3. AWES Critical Orifice Calibrations 9/8/1989

AWES Unit Number	Pre-Field Calibration (l/minute)	Post-Field Mean Calibration (l/minute)	Standard Dev. (l/minute)	Pre- Minus Post-Field Calibration (l/minute)	% Error (Post-Pre * 100/Pre)
1	1.037	1.043	0.005	0.006	0.58
2	0.972	0.979	0.002	0.007	0.72
4	1.220	1.216	0.003	-0.004	-0.33
5	0.962	0.969	0.002	0.007	0.73
6	1.004	1.009	0.003	0.005	0.50
7	1.142	1.138	0.001	-0.004	-0.35
8	1.006	1.001	0.002	-0.005	-0.50
9	1.037	1.025	0.002	-0.012	-1.17
10	1.179	1.189	0.005	0.010	0.84
11	1.198	1.178	0.001	-0.020	-1.67
12	1.071	1.091	0.001	0.020	1.87
13	1.000	1.008	0.001	0.008	0.80
14	1.090	1.097	0.002	0.007	0.64
15	1.219	1.211	0.002	-0.008	-0.66
17	1.198	1.186	0.003	-0.12	-1.01
18	1.232	1.233	0.005	0.001	0.08
19	1.220	1.216	0.004	-0.004	-0.33
20	1.159	1.170	0.005	0.011	0.95
21	1.071	1.061	0.002	-0.010	-0.93
23	1.133	1.131	0.003	-0.002	-0.018
25	1.199	1.184	0.002	-0.015	-1.25
27	1.181	1.176	0.002	-0.005	-0.42
28	1.160	1.182	0.001	0.022	1.90
29	1.248	1.246	0	-0.002	-0.16
31	1.096	1.097	0.003	0.001	0.09
32	1.130	1.123	0.002	-0.007	-0.62
33	1.229	1.225	0.007	-0.004	-0.33
34	0.881	0.873	0.001	-0.008	-0.91
Average	1.11693	1.11632		-0.00061	
			S.D.	0.00978	
			1.96 S.D.	0.01918	
			95% Conf.	2.14%	

10.0 Standard Operating Procedures

10.1 Standard Operating Procedure

Automated Woodstove Emission Sampler (AWES) Field Operating Instructions

rev.1/89

(Use Only Black Ink in Log Books)

A. Installation

1. Prior to transport to study home, load AWES sampler with filter, XAD-2 cartridge, and silica gel. Use fresh or regenerated silica gel (blue color). **Cap both inlet and outlet fittings with compression plugs.** Use only Teflon inlet lines, stainless steel sampling probes, filter housings, associated compression fittings that have been previously cleaned with methylene chloride and methanol. Record AWES number, XAD-2 cartridge number, and filter number (note that this is the filter number written in pencil on the side of the filter, not the filter holder number) in Data Log Book.
2. Transport AWES units in an upright position to study home in a heated vehicle. Minimize exposure to low temperatures. The sampler line must be connected to itself. The probe must be capped on one end and sealed with foil on the open end. Both the Teflon lines and the probes should be transported in plastic bags.
3. Allow sampling system to equilibrate to room temperature before calibrations or leak checks. Accelerate "warm-up" with hot air blower if necessary. Apply only warm, gentle heat to the unit. The temperature indicator strip beside the oxygen cell will indicate when the sampler is at ambient temperature. The temperature indicator strip attached to the O₂ cell block must be approximately $\pm 10^{\circ}\text{F}$ of the room temperature and it must maintain its temperature reading for five minutes before calibration and leak checks can be started. (This is especially important if an air blower is used to heat the sampler.)
4. Record home code, sampling rotation, date sample is installed, and your initials in log book. Be sure the correct AWES number and corresponding XAD cartridge and filter number are installed for that home. The **sample i.d. number** is the **home code** followed by the **sampling rotation**. For example, Y12-2 is home Y12, and sampling rotation 2. "Y" is the code used by OMNI to distinguish New York samples from samples collected for other projects from other regions of the country.
5. Visually inspect AWES for handling and shipping damage. Check heater and pump operation by flipping on switches (note switch lights, heat output and pump motor operation).
6. If not already done, install Data Logger, wood basket, scale, thermocouples, and solid state temperature sensors as described in Data Logger instructions. Record Data Logger, thermocouple, and solid state temperature information in the log book entitled "Data Logger Systems Log". Attach the AWES/Data Logger communication cable.
7. Set up AWES/Data Logger system approximately three feet from woodstove. Attempt to put AWES unit in a location such that radiant heat from the woodstove or heat from other auxiliary sources (i.e., hot air vents, wallboard heaters, etc.) is minimized. Make sure there are no sags in the sampling line where water can accumulate. Record the **date and time sampling is programmed to start**, not the time start-up checks are performed. Also record date and time sampling is programmed to stop.

8. **Without** the inlet line attached, perform start-up tests. Operate pump for one minute for “warm-up”. Plug filter holder inlet with a compression plug. With pump running, wait at least one and one-half minutes. Record maximum vacuum obtained in right and left vacuum gauges. Shut toggle valve slowly. Turn off pump. Record vacuum reading on right and left vacuum gauges after exactly 30 seconds. **Slowly unplug inlet.** The open toggle valve. Turn on pump. Wait 30 seconds. Record vacuum on right and left vacuum gauges and flow from rotameter. Read rotameter value at center of ball. (Note that rotameter scale is cc/min \times 100, i.e., 10 on scale is equal to 1.0 lpm.) Record rotameter value in notebook in units of lpm.
9. Check the temperature monitor strip inside the AWES. **Before proceeding with the oxygen calibration, the temperature monitor strip must read approximately $\pm 10^{\circ}\text{F}$ of ambient temperature and have held its temperature for at least five minutes.** Follow the O₂ calibration instructions as described in the Data Logger SOP. Verify and record in log books that the heating bar is hot. Turn off pump. Record cumulative time recorder reading. **DO NOT turn pump on again after this entry!** Leave heaters on. Initial calibration section in log book.
10. Install the sample line, probe line, and exhaust lines. Install exhaust line one foot **above** sample line in woodstove chimney. Record inlet probe and sample line i.d. number in log book.
11. Record wood species, moisture content, and room temperature in the log book entitled “Wood Characterization”. Carefully follow the instruction manual for the Delmhorst moisture meter. Select several representative logs from the wood basket for measurement. Measure the moisture at three random points in each log. Drive the pins in at least one inch along the grain. Record values in the log book. Record average values if necessary. Also record ambient temperature and relative percentage of each wood species in woodpile. Select wood species to match, as closely as possible, the species listed at the front of the log book.

If a moisture reading is greater than 30%, cut a 1" slice of the test log for oven-drying. The slice must include both pinholes. Label the wood slice with the house code and rotation number. Place the sample in a Ziploc bag. Add the moisture meter reading, ambient temperature and species, plus the sample code, to the bag. Then double-bag. Note on the log sheet that a wood sample has been taken.

12. Place a cable tie through a latch on the AWES to seal the sampler.

B. Removal

1. Upon completion of a sampling week, the AWES units should be picked up as soon as possible. Record the date sampler was removed and initial in log book. If the instrument malfunctioned prior to the programmed stop time, record actual stop time and date and comments describing situation.
2. Turn heater off. Carefully loosen both ends of the Teflon sample line. If there is water in the Teflon inlet line, carefully raise both ends and couple the line upon itself, **being careful not to spill any liquid.** (A spill would ruin the entire weekly sample.) Note in the comment section if liquid was present in the sample line.
3. Cap the probe end, loosen the compression nut holding the probe in the stack and remove. Immediately cover the open (stack) end of the probe with foil. Place the probe and the sample line in a plastic bag. Label the bag with the house code. Treat the bag containing the inlet line and probe carefully to avoid loss of material during transport to laboratory. (Any loss of material would ruin the entire sample.)
4. **Record the time accumulator value first.** Next, complete span gas check and end-of-file oxygen calibration (refer to the Data Logger SOP). Then perform leak, vacuum, and flow tests. Operate pump for one minute. Plug filter holder inlet with a stainless steel compression fitting while the pump is running. Wait at least one minute. Record maximum vacuum obtained in right and left vacuum gauges.

Shut toggle valve slowly. Turn off pump. Record vacuum reading on right and left vacuum gauges after exactly 30 seconds. Slowly unplug inlet. Open toggle valve. Turn on pump. Wait 30 seconds. Record vacuum on right and left vacuum gauges and flow from rotameter.

5. Plug filter holder inlet and outlet lines with compression caps prior to transport. Unplug AWES from AC power, and disconnect the AWES/Data Logger communication cable.
6. Record wood species, moisture content, and room temperature in the log book entitled "Wood Characterization". As before, obtain a woodblock if necessary.

AWES PREPARATION AND CLEAN UP

rev. 1/89

Overview:

The following SOP describes the procedures for preparing the OMNI Automated Woodstove Emissions Sampler (AWES) units for sampling in the field and for cleaning the AWES and shipping the recovered samples to the OMNI lab after sampling. Note that the functions performed by the field lab and the main OMNI lab are different: the field lab will prepare samplers by loading fresh filters, silica gel, and XAD cartridges and will clean the samplers after sampling by removing the exposed filters and XAD cartridges, replacing the expended silica gel, and rinsing various components of the sampler with a 50/50 mixture of dichloromethane and methanol; the OMNI Oregon lab will receive the filters, XAD cartridges, and the rinse and further process those samples for residue determinations.

Note: methylene chloride is an alternative name for dichloromethane; it may be abbreviated DCM on the log sheets and on sample labels. Methanol may be abbreviated MeOH.

NOTE: THE ACCURACY OF THE AWES SAMPLES DEPENDS ON THE FIELD TECHNICIANS DOING CAREFUL, ACCURATE WORK AND PROPERLY DOCUMENTING ALL SAMPLES.

Procedure:

A. Preparation for Sampling

1. Load the blue plastic container in the bottom of the AWES unit with fresh or regenerated silica gel (it should be deep blue in color). Use a funnel to load 450 ml of silica gel carefully into the container (450 ml of silica gel brings the level of the silica gel to about 2 cm below the rubber O-ring). Avoid getting the silica gel granules into the O-ring gasket seat. Carefully remove any granules that do get into the track with a brush. Carefully screw the cap on the blue container. Do not force the cap on; if the silica gel packs around the center tube connected to the cap to the extent that twisting becomes difficult, loosen the cap 1/3 turn, gently vibrate canister, and try again.
2. Used silica gel (identified by the blue indicator turning white or clear) may be regenerated by spreading a thin layer (2 cm) of silica gel in a flat metal container (such as a cookie sheet) and placing in an oven at 100-110 degrees C for **30-45 minutes**. At the end of that time the silica gel should have regained its deep blue color. A thicker layer of silica gel may be baked at one time provided the technician stirs the gel at some point during the baking to insure that all the moisture is driven off. Silica gel which is **over-baked** will turn **brown** or **black**. If this happens the silica gel must be **discarded**.
3. Use only tubing, filter holders, compression fittings, and probes which have been previously thoroughly cleaned with the dichloromethane (methylene chloride) and methanol solution. Insure that all tubing, glassware, and fittings are completely dry; place the parts in the hood if necessary to hasten drying.
4. Remove the aluminum foil from a fresh XAD cartridge. Record the XAD cartridge number on the log sheet corresponding to the house and rotation for which the XAD cartridge will be used. Screw on the **clean** white end cap; one will have a straight brass fitting and one will have a 45° stainless steel fitting. **The stainless steel fitting will always be the inlet to the cartridge and will always be on top when the cartridge is fitted into the AWES unit.** Place cartridge in the holder on the outside of the AWES unit and attach the lower tubing to the brass fitting. Note: When reconnecting the compression fittings, they should only be tightened 1/8 to 1/4 turn past finger-tight. Because the compression fittings are on soft

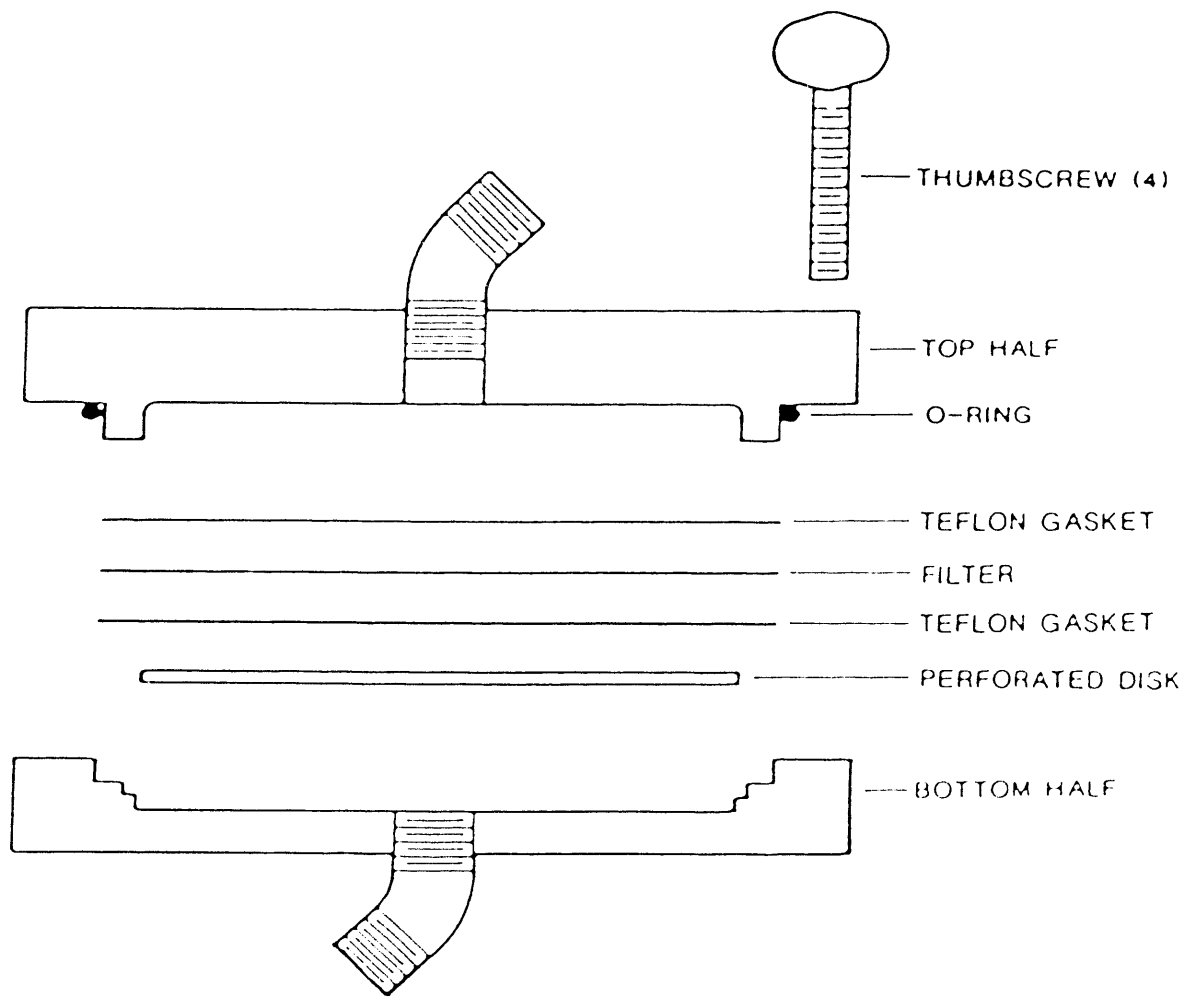
Teflon tubing, it is extremely easy to continue tightening the fitting until the tubing is completely pinched off. **Do not over-tighten the compression fittings.**

5. Thread the two-inch section of 1/4" Teflon tubing, with its compression fitting, into the bottom of the heated filter chamber. Attach the tubing to the 45 degree stainless steel fitting on the white end cap of the XAD cartridge.
6. Remove a fresh glass fiber filter from its petri dish. Note: these filters have been pre-weighed so the amount of deposit collected can be determined; **handling of the filters should be with tweezers only at all times.** Before putting the filter in the filter holder, **record the filter number directly in the log book.** This is necessary because the filter ID number will be covered when the filter is placed in the holder. Assemble the filter holder as shown in Figure 1. Note: the rough side of the filter should be facing up (the number will be facing **down**). Note: the four bolts holding the assembly together should be tightened to a **gentle** finger-tight fit. It is recommended that the bolts be gently tightened in sequence.
7. Place the filter holder assembly in the "hot" chamber of the AWES unit. Attach the XAD tubing to the bottom of the filter holder, taking care not to over-tighten the compression fitting.
8. Complete the assembly by connecting the filter holder to the bulkhead fitting using the short length of Teflon tubing and the attached compression fittings.
9. Test the AWES unit for leaks. Place a compression fitting cap over the sampler inlet. Turn on the pump (unlighted toggle switch) and let it run for one minute. Close the toggle valve and turn off the pump with the toggle switch. If either vacuum gauge changes more than one inch in a 30-second period, check the cap, compression fittings, and filter holder. If necessary **gently** tighten loose connections. Repeat procedure until successful leak test is made. Cap AWES inlet with a stainless steel cap and the outlet with a brass cap.
10. Place probe (with foil on sampling end and cap on other end) and sampling line (coupled to itself) in plastic bags with sampler.

B. Post-sample Cleaning and Sample Recovery

1. Wear proper safety gear: solvent-proof heavy gloves, eye protection, and a lab apron or coat. Work only under a hood or with adequate ventilation. Dichloromethane is a suspected carcinogen, and methanol is flammable and toxic; be aware of this and take proper precautions. Refer to the attached Material Safety Data Sheets for these two solvents.
2. Find the appropriate AWES data sheet to match the sampler. Locate the matching probe and Teflon tubing. **Check** that the AWES unit number, XAD cartridge number, probe number, tubing number, and filter number all match the data entered on the data sheet.
3. Label a bottle using a pencil to mark labels. Place the same data on lab tape and place the lab tape on the bottle lid.
4. After locating the proper probe, rinse and brush the probe with a 50/50 (volume) mixture of DCM and MeOH into the labelled, wide-mouth amber bottle using a funnel supported in a ringstand. Take care that all solvent and particulate **inside** the probe is collected in the sample jar. Avoid knocking or washing the impacted material on the outside of the probe into the rinse. Carefully wiping the outside of the probe before starting will help prevent this. Note: If the brush has aged to the point that bristles are being lost, replace it; bristles in the rinse jars will make residue determinations difficult. Continue brushing and rinsing with solvent until the inside of the probe appears clean or until no more material can be removed. Set probe aside.

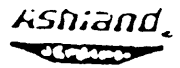
5. **Carefully** disconnect one end of the fitting on the sampling line. Hold the line with the fitting at the top, making a “u” shape as the fitting is loosened. Pour away condensate into the sample jar, taking care not to spill any sample. Place one end of the sample line in the funnel and rinse/brush the line and compression fitting into the sample bottle. Continue until the line is clear. Set sampling line aside.
6. Disconnect the compression fittings on the filter holder and remove the filter assembly from the AWES unit. Place the assembly in a coffee can for support and remove the bolts from the assembly.
7. Remove the filter from the filter holder carefully using tweezers and prying with a small spatula (if necessary). Take time to remove the filter intact as much as possible. After verifying the filter number on the back side of the filter, place the filter into its original petri dish. If small pieces of filter stick to the filter holder, scrape the pieces on top of the filter in the petri dish.
8. Rinse and brush the two Teflon gaskets and the two filter holder halves into the sample jars using the DCM/MeOH solvent.
9. Place the filter support disk in the funnel and thoroughly saturate with solvent and allow to drain into the sample jar.
10. **The sample jar should now be tightly capped.** Wrap joint between lid and jar with Teflon tape. Verify that labels are on the jar and the lid and that data are correct. The level of solvent should be marked on the jar using a Sharpie permanent marker or a strip of marking tape turned sideways, with the straight upper edge of the tape at meniscus (the level of the solvent).
11. The petri dish containing the filter should be sealed with Teflon tape around the gap, then taped shut with masking tape. Place a date label on the petri dish. Double-check to verify the data are correct.
12. Remove the XAD cartridge from the AWES unit. Verify the cartridge number against the log sheet. Cap both ends of the cartridge with Teflon tape. Wrap the entire cartridge in foil, and place a data label on the outside. Verify that all data are correct. Place cartridge in a Ziploc bag, remove excess air, and seal tightly.
13. Solvent jars, filters, and XAD cartridges will be shipped immediately after all samples for a rotation have been cleaned. Make sure that Chain of Custody Forms are completed for each shipment and that a copy of the form accompanies each shipment. Make sure that all samples, particularly the glass jars and the petri dishes, are well-padded. Deliver samples and the Chain of Custody Form to Ship Shaper (the packing company).
14. Insure that cleaning and shipping is recorded in the log book, including the dates and the technician's initials.



NOTE:
 COMPRESSION FITTINGS ARE POSITIONED TO
 FACE OPPOSITE DIRECTIONS FROM EACH OTHER

**MATERIAL SAFETY
DATA SHEET**

24-HOUR EMERGENCY TELEPHONE (606) 324-1133



004200

METHYLENE CHLORIDE (EMI CONTROL)

PAGE 1

ACCEPTED BY O. E. M. A. AS ESSENTIALLY SIMILAR TO O. E. M. A. FORM 20

ASHLAND PRODUCT NAME: METHYLENE CHLORIDE (EMI CONTROL)
CAS NUMBER: 75-09-2

CHEMONICS
P. O. BOX 17376
PORTLAND, OH 43217
ATTN: JEFF NICOU

OS 170
DATA SHEET NO. 017047-001
LATEST REVISION DATE: 03/84-ME081
PRODUCT: 7340170
INVOICE: ACCLOC
INVOICE DATE: 03/11/84
TO:

**** INTERCOMPANY MAIL ****

SECTION I - PRODUCT IDENTIFICATION

GENERAL OR GENERIC ID: CHLORINATED HYDROCARBON

HAZARD CLASSIFICATION: (17) NOT APPLICABLE

SECTION II - HAZARDOUS COMPONENTS

INGREDIENT	PERCENT	PEL	TLV	
METHYLENE CHLORIDE	100	500	100 PPM	(1)

(1): NIOSH RECOMMENDS A LIMIT OF 75 PPM - 8 HOUR TIME WEIGHTED AVERAGE.

SECTION III - PHYSICAL DATA

PROPERTY	REFINEMENT	MEASUREMENT
INITIAL BOILING POINT	FOR PRODUCT	104.00 DEG F (40.00 DEG C) 0 760.00 MMHG
VAPOR PRESSURE	FOR PRODUCT	370.00 MMHG 0 68.00 DEG F (20.00 DEG C)
VAPOR DENSITY	AIR = 1	2.9
SPECIFIC GRAVITY		1.318 0 77.00 DEG F (25.00 DEG C)
PERCENT VOLATILES		100.00%
EVAPORATION RATE	(ETHYL ETHER = 1)	1.80

SECTION IV - FIRE AND EXPLOSION DATA

FLASH POINT: NOT APPLICABLE

EXPLOSIVE LIMIT: NOT APPLICABLE

EXTINGUISHING MEDIA: WATER FOG OR CARBON DIOXIDE OR DRY CHEMICAL

HAZARDOUS DECOMPOSITION PRODUCTS: MAY FORM TOXIC MATERIALS: CARBON DIOXIDE AND CARBON MONOXIDE, HYDROGEN CHLORIDE, PHOSGENE

SPECIAL FIRE FIGHTING PROCEDURES: WEAR SELF-CONTAINED BREATHING APPARATUS WITH A FULL FACEPIECE OPERATED IN PRESSURE-DEMAND OR OTHER POSITIVE PRESSURE MODE WHEN FIGHTING FIRES.

NEURAL FIRE & EXPLOSION HAZARDS: NOT APPLICABLE

SECTION V - HEALTH HAZARD DATA

PERMISSIBLE EXPOSURE LEVEL: 100 PPM

THRESHOLD LIMIT VALUE: 100 PPM

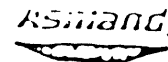
SEE SECTION IX

EFFECTS OF OVEREXPOSURE: FOR PRODUCT

- I - CAN CAUSE IRRITATION
- N - CAN CAUSE IRRITATION
- ATM - EXCESSIVE INHALATION OF VAPORS CAN CAUSE NASAL AND RESPIRATORY IRRITATION, DIZZINESS, HEADACHES, FATIGUE, NAUSEA, HEADACHE, POSSIBLE UNCONSCIOUSNESS, AND EVEN ASPHYXIATION
- BL - CAN CAUSE GASTROINTESTINAL IRRITATION, NAUSEA, VOMITING, AND DIARRHEA

MATERIAL SAFETY
DATA SHEET

24 HOUR EMERGENCY TELEPHONE (606) 374 1133



002100

METHYLENE CHLORIDE GASE CONDENS

PAGE 2

SECTION V-SPECIAL HAZARD DATA (CONTINUED)

OCCASIONALLY, GET MEDICAL ATTENTION

IF SWALLOWED, DO NOT INDUCE VOMITING. CALL PHYSICIAN OR TRANSPORT TO AN EMERGENCY FACILITY.

IF BREATHED: IF AFFECTED, REMOVE INDIVIDUAL TO FRESH AIR. IF BREATHING IS DIFFICULT, ADMINISTER OXYGEN. IF BREATHING HAS STOPPED, GIVE ARTIFICIAL RESPIRATION. KEEP PERSON WARM, QUIET AND GET MEDICAL ATTENTION. DO NOT GIVE STIMULANTS. (EPINEPHRINE OR EPHEDRINE MAY ADVERSELY AFFECT THE HEART WITH FATAL RESULTS.)

SECTION VI-REACTIVITY DATA

HAZARDOUS POLYMERIZATION: CANNOT OCCUR

STABILITY: STABLE

INCOMPATIBILITY: AVOID CONTACT WITH ALUMINUM

SECTION VII-SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED

SMALL SPILL: ABSORB LIQUID ON PAPER, VERMICULITE, FLOOR ABSORBENT, OR OTHER ABSORBENT MATERIAL AND TRANSFER TO HOOD

LARGE SPILL: PERSONS NOT WEARING PROTECTIVE EQUIPMENT SHOULD BE EXCLUDED FROM AREA OF SPILL UNTIL CLEAN-UP HAS BEEN COMPLETED. STOP SPILL AT SOURCE, DIKE AREA OF SPILL TO PREVENT SPREADING, PUMP LIQUID TO GALVANE TANK. REMAINING LIQUID MAY BE TAKEN UP ON SAND, CLAY, EARTH, FLOOR ABSORBENT, OR OTHER ABSORBENT MATERIAL AND SHOVELED INTO CONTAINERS.

WASTE DISPOSAL METHOD:

SMALL SPILL: ALLOW VOLATILE PORTION TO EVAPORATE IN HOOD. ALLOW SUFFICIENT TIME FOR VAPORS TO COMPLETELY CLEAN HOOD DUCT WORK. DISPOSE OF REMAINING MATERIAL IN ACCORDANCE WITH APPLICABLE REGULATIONS.

LARGE SPILL: DESTROY BY LIQUID INCINERATION WITH OFF-GAS SCRUBBER. CONTAMINATED ABSORBENT MAY BE DEPOSITED IN A LANDFILL IN ACCORDANCE WITH LOCAL, STATE AND FEDERAL REGULATIONS.

SECTION VIII-PROTECTIVE EQUIPMENT TO BE USED

RESPIRATORY PROTECTION: IF TLV OF THE PRODUCT OR ANY COMPONENT IS EXCEEDED, A NIOSH/MSHA JOINTLY APPROVED AIR SUPPLIED RESPIRATOR IS ADVISED IN ABSENCE OF PROPER ENVIRONMENTAL CONTROL. OSHA REGULATIONS ALSO PERMIT OTHER NIOSH/MSHA RESPIRATORS UNDER SPECIFIC CONDITIONS (SEE YOUR SAFETY EQUIPMENT SUPPLIER). ENGINEERING OR ADMINISTRATIVE CONTROLS SHOULD BE IMPLEMENTED TO REDUCE EXPOSURE.

VENTILATION: PROVIDE SUFFICIENT MECHANICAL (GENERAL AND/OR LOCAL EXHAUST) VENTILATION TO MAINTAIN EXPOSURE BELOW TLV(S).

PROTECTIVE GLOVES: WEAR RESISTANT GLOVES SUCH AS POLYVINYL ALCOHOL

EYE PROTECTION: CHEMICAL SPLASH GOGGLES IN COMPLIANCE WITH OSHA REGULATIONS ARE ADVISED; HOWEVER, OSHA REGULATIONS ALSO PERMIT OTHER TYPE SAFETY GLASSES (CONSULT YOUR SAFETY EQUIPMENT SUPPLIER).

OTHER PROTECTIVE EQUIPMENT: TO PREVENT REPEATED OR PROLONGED SKIN CONTACT, WEAR IMPERVIOUS CLOTHING AND BOOTS.

SECTION IX-SPECIAL PRECAUTIONS OR OTHER COMMENTS

REEXPOSURE TO COMPONENT CAN RAISE THE LEVEL OF CARBON MONOXIDE IN THE BLOOD CAUSING CARDIOVASCULAR STRESS.

CONTAINERS OF THIS MATERIAL MAY BE HAZARDOUS WHEN ENTIRE DRAINAGE CONTAINERS RETAIN PRODUCT RESIDUES (VAPOR, LIQUID, AND/OR SOLID). ALL HAZARD PRECAUTIONS GIVEN IN THE DATA SHEET MUST BE OBSERVED.

REEXPOSURE TO MATERIAL HAS APPARENTLY BEEN FOUND TO CAUSE THE FOLLOWING EFFECTS IN LABORATORY ANIMALS: LIVER ABNORMALITIES, LUNG DAMAGE.

INFORMATION ACCUMULATED HEREIN IS BELIEVED TO BE ACCURATE BUT IS NOT WARRANTED TO BE WHETHER ORIGINATING WITH ARLAND OR NOT. RECIPIENTS ARE ADVISED TO CONFIRM IN ADVANCE OF NEED THAT THE INFORMATION IS CURRENT, APPLICABLE, AND SUITABLE TO THEIR CIRCUMSTANCES.



EM SCIENCE

111 Woodcrest Road, P.O. Box 5018, Cherry Hill, N.J. 08034-0396, Phone (609) 354-9200

MATERIAL SAFETY DATA SHEET

Essentially Similar to U.S. Department of Labor Form OSHA-20

SECTION 1

NAME & PRODUCT

Chemical Name:	Catalog Number:
Methanol	MX0475, MX0483, MX0485, MX0487, MX0488, MX0490

Trade Name & Synonyms:	Chemical Family:
Methyl Alcohol, Wood Alcohol	Alcohols

Formula:	Formula Weight:
CH ₃ OH	32.04
CA #67-56-1	

SECTION 2

PHYSICAL DATA

Boiling Point, 760 mm Hg (°C)	64.5°C	Specific Gravity (H ₂ O = 1)	0.79
Melting Point (°C)	-144°F	Solubility in H ₂ O, % by wt. at 20°C	Soluble
Vapor Pressure at 20°C	96 mm Hg	Appearance and Odor	colorless liquid
Vapor Density (air = 1)	1.1		slight alcoholic odor
Percent Volatiles by Volume	100	Evaporation Rate (Butyl Acetate = 1)	5.91

SECTION 3

FIRE AND EXPLOSION HAZARD DATA

Flash Point (test method) 52°F (cc)	Flammable Limits	Lel 6.7%	Uel 35%
Extinguishing Media CO ₂ , dry chemical, foam	Water spray to cool fire-exposed containers Water spray to disperse vapors		

Special Hazards and Procedures Wear self-contained breathing apparatus

Usual Fire and Explosion Hazards Addition of water to burning fuel may reduce intensity of flame

SECTION 4

REACTIVITY DATA

Reactivity	X	Conditions to Avoid
Stability		heat, sparks, open flame

Materials to Avoid
Oxidizers

Stable Decomposition Products CO_x

SECTION 5

SPILL OR LEAK PROCEDURES AND DISPOSAL

Actions to be Taken in Case Material is Released or Spilled	Evacuate non-essential personnel. Absorb with sand.
---	--

SECTION 6

HEALTH HAZARD DATA

Threshold Limit Value

OSHA std-air: TWA 200 ppm

TXDS: orl-lmn LDLo: 340 mg/kg

Effects of Overexposure

Highly toxic by fumes and contact; ingestion may be fatal and daily contact will have cumulative effect. May cause inebriation, nausea, vomiting; central nervous system damage; blindness; defatting, drying and cracking of the skin.

First Aid Procedures

Skin: wash with soap/water; get medical assistance for skin irritation
Eyes: flush with water 15 minutes; get medical assistance
Inhalation: remove to fresh air; get medical assistance
Ingestion: induce vomiting if conscious; get medical assistance

SECTION 7

SPECIAL PROTECTION INFORMATION

Ventilation, Respiratory Protection, Protective Clothing, Eye Protection

Provide adequate general mechanical and local exhaust ventilation
Protect eyes and skin with safety goggles and gloves
Wear air-supplied mask; face shield may be necessary
Do not breathe vapor
Do not get in eyes or on clothing

SECTION 8

SPECIAL HANDLING AND STORING PRECAUTIONS

Keep container tightly closed
No smoking or flares
Store in a well-ventilated area, away from sources of ignition
Avoid prolonged or repeated contact with skin
If ingested, can cause blindness; cannot be made non-poisonous

SECTION 9

HAZARDOUS INGREDIENTS

(refer to section 3 through 8)

1 - FLAMMABLE LIQUID

SECTION 10

OTHER INFORMATION

HA 704: 1 3 0
 Health Flammability Reactivity

Standard Operating Procedures

CONLOG Data Acquisition System/Data Logger Field Operating Instructions

(Use only black ink in log books.)

Background

The OMNI data acquisition system is a programmable data logger and controller. CONLOG is currently being used in several in-home woodstove, pellet stove, and fireplace studies for monitoring stove conditions (e.g., flue temperatures and weight of wood burned) and home conditions (e.g., room temperature, recording use of any auxiliary heat source), as well as controlling the sampling frequency and duration of the OMNI Automated Woodstove Emissions Sampler (AWES) and gas bag box which collects particles and hydrocarbons and a Tedlar bag sample of cleaned flue gases.

CONLOG consists of a small box with removable sensors and control wires and a computer which contains and controls the software. Sampling parameters are entered by the field technician using the computer.

Note that accurate record-keeping on the part of the field technicians is essential to the integrity of the data collected. The full and proper use of the log sheets cannot be emphasized enough.

Installation

1. Use a checklist to make sure you bring all equipment and tools. Have an extra AWES, bag box, two Tedlar bags, computer, keyboard, monitor, and data logger box on hand at all times.
2. Assemble all equipment next to the appliance to be tested.
3. Connect the power to the computer, computer monitor, bag box, and AWES.
4. Connect the two connectors from the data logger box to the back of the computer. One connects to the loose ribbon cable and the other to the data logger board in the back of the computer. Be careful to match up the cables correctly.

5. It is imperative that you ground the data logger box to a good ground.
6. Connect the control cables to the AWES and bag box from the data logger.
7. Connect the sample line from the AWES to the flue pipe. Connect the return line as well to the flue pipe. Connect the bag box gas line to it from the AWES.
8. Connect the TCs. Channel 1 is for the ambient. Just insert a probe in the data logger box. Channels 2, 3, etc. are for stack etc. temperatures. Use yellow-shielded thermocouple wire to reduce signal noise. Ground the shield wires to the data logger box terminal. Use only isolated type K thermocouple probes.
9. Boot up the computer and check that CONLOG comes up. Check the time and date and reset if necessary.
10. Set the CONLOG settings and calibrate the O₂ cell using the following 19 steps.
 - a. Press L to turn off data logging.
 - b. Press P to turn on the pump; let it run about one minute.
 - c. Press A to get an average O₂ reading.
 - d. Press S to change settings; O₂ calibration should be highlighted.
 - e. Read the average O₂ calibration number (in parentheses) and record it in the field log book and on the Settings screen.
 - f. Press Esc to leave the Settings screen.
 - g. With pump running, press A to verify that actual O₂ is 20.9; if it isn't, repeat steps c through g.
 - h. Connect calibration gas to AWES cal port on side of box. Open cal valve. Wait one-half minute with pump running.
 - i. Press A and record average O₂ in the O₂ cell calibration box of the field log.
 - j. Repeat steps h and i with calibration gases 0.0%, 8.5% and 16.7%.
 - k. Disconnect calibration gas and press A to verify that actual ambient O₂ is still 20.9; if it isn't, repeat steps c through k.
 - l. Press P to turn off the pump.
 - m. SHUT THE CAL GAS PORT.
 - n. Press S followed by Return to highlight Pump Cycle Length. Enter the sampling frequency in minutes (three minutes for fireplaces, 10 for pellet stoves, and 15 minutes for woodstoves).
 - o. Enter the TC frequency in minutes (five minutes for everything but 10 minutes for catalytic woodstoves).

- p. Enter the TC frequency in minutes.
 - q. Enter the auxiliary heat trip temperature.
 - r. Enter the sampler start date and time.
 - s. Enter either (a) the sampler stop time or (b) the sampling interval.
 - t. Enter the data file name. If a file of that name already exists, any existing data in that file will be left alone and new data will be appended to the end of the file.
 - u. Verify all of the settings. If any need to be corrected, press S. Press Return until the incorrect setting is highlighted. Type the correct setting; press Return and press Esc to leave the Settings screen.
 - v. Press L to enable data logging.
 - w. Press K to begin data collection and lock program. Any potential problems with the current settings are reported so that you can inspect and adjust them.
 - x. To get back into the program (unlock it), type U and type the password. Make sure you lock the program before you exit the home.
 - y. **MAKE SURE THAT LOGGING IS ON WHEN YOU ARE FINISHED.**
11. Follow the rest of the AWES setup using the field book AWES Setup page. Activities include
- a. Record AWES cumulative time counter.
 - b. Calibrate TCs.
 - c. Conduct AWES leak checks and fill out the form in the log book.
 - d. Check free flow through AWES, reading the rotometer.
 - e. Check that the AWES heater works.
 - f. Check wood moisture (don't do this for pellet fuel).
12. Bag box instructions:
- a. Set the trip point temperature to below room temperature.
 - b. Turn on AWES sampler pump and check that solenoid is switching on and off (repeat several times).
 - c. Check that Tedlar bag has been leak-checked under pressure in water. If not, do so in a bathtub.
 - d. Carefully connect bag to sample line.
 - e. Make sure valve is turned open.
 - f. Using soapy water, check that there are no leaks around valve stem when pump is on and rotometer shows flow.
 - g. Adjust rotometer to about 25-30 cc/min flow.
 - h. **RESET TRIP POINT TO 100 DEGREES.**

13. Instruct homeowner on how to keypunch in fuel weights and fill out the fuel log.
 - a. Keypunching fuel weights:
 - i. Hit the letter F on the keyboard.
 - ii. If you need to edit, do so in the standard edit manner.
 - iii. Hit return to insert the value.
 - iv. The value is stored to disk every five minutes.
 - v. If you want to change your value before the next five-minute storage, hit F and put in numbers (either + or -) to correctly alter the first number.
 - vi. If you make a change after the data has been stored, hit F and make that same change. In this case, the data file will have two values: the first and your correction. This is fine, as the computer program will do the subtraction etc.

Takedown

Follow instructions on the AWES takedown form in the log book.

1. Record AWES cumulative time counter value.
2. Check O₂ calibrations with ambient, 18.7%, 8.5%, and 0% cal gases and record.
3. Check all Setup screen values and record on the takedown form.
4. Conduct leak check and record results.
5. Check TC calibrations and record results.
6. Copy your data file from the B drive to the A drive. A drive becomes your backup.
7. Remove 3.5" B disk, label, and send to lab.
8. Insert a new B disk for the next test.
9. Remove AWES and equipment from house or change filter, XAD, probe, and sample lines if sampling is to continue.

Temperature Sensor and Thermocouple Installation

The following narrative should be used as a guide for solid state temperature sensor and thermocouple installation.

Solid State Sensors

1. Indoor temperature sensor—this sensor (TC #1) is intended to monitor the representative temperatures experienced in the room with the woodstove. The sensor would preferably be located

adjacent to the room's thermostat. If possible, the sensor should be located between 10 and 25 feet from the woodstove and 4.5 to 5 feet from the floor. The sensor should be installed using mounting clips. Be sure to secure the lead wires to baseboards, doorsills, etc. so they cannot be tripped over or pulled off. If something does happen to the sensor, the event should be noted in the log book as to time and what happened.

2. Alternate heat source sensor—this sensor will be positioned to monitor the amount of time any alternative heat source (central heating, space heaters, etc.) is operating. On forced air heating systems, thread the sensor through a heat register into the duct work. In hot water systems consider attaching the sensor to a radiator in the room with the stove. In electrically-heated homes, secure the sensor directly to the baseboard strip in the room with the woodstove. Other heating alternatives will have to be handled as the setting permits, keeping in mind that the sensor and leads should be protected as much as possible from disturbances by the homeowner's normal routine. Do not expose the sensors to temperatures above 200°F. Set trip point at 90° in CONLOG settings.

Thermocouples

1. Stack thermocouple—this thermocouple will measure the temperature of the flue gases. The TC2 probe is inserted into the flue through a bulkhead compression fitting, which fits through the smaller hole of the two-hole reinforcement plate. This plate should be installed with the larger hole 12" from the top of the stove. Insert probe halfway into the flue pipe.

2. Catalyst thermocouple—this thermocouple will only be used in catalyst-equipped woodstoves. The TC3 probe is inserted into a combustor cell in the middle of the combustor and is positioned so that the tip is one inch below the top of the combustor. Access through the stove wall is obtained by drilling and tapping a hole for a one-quarter inch NPT compression fitting. TC probes may be bent **gently** as needed.

3. Pre-catalyst thermocouple—this TC4 probe is positioned one inch in front of the inlet face of the combustor. It should be directly in line with TC #3 and should always be exactly one inch from the combustor. Photograph all TC installations.

Figure 1

Homeowner: _____

Filename: _____

Configuration: _____

AWES Setup

Run Number _____

Location Code _____ Page _____

OMNI Data Logger Rotation

Maintenance Log Form

1. AES Box # _____	2. Data Logger # _____	3. Computer # _____	4. Scale # _____
Service Call Information			
1. Check one: <input type="checkbox"/> Initial <input type="checkbox"/> Planned <input type="checkbox"/> Unplanned (if unplanned, state reasons in Field Notes.)			
2. Service Call Date: ____ / ____ / ____		Military Time: ____ : ____	Technician's Name: _____
Calibrations			
1. O ₂ sensor span reading in "cal" units (with ambient readings ¹ / ₂ min. apart, using the "A" key)			
1 = _____ units	2 = _____ units	3 = _____ units	
2. O ₂ cell calibration Ambient = _____%		_____ O ₂ Tank = _____%	
_____ % O ₂ Tank = _____%		_____ O ₂ Tank = _____%	
3. Scale calibration with 10 lb wt: CBS 1 = __ 2 = __ 3 = __ 4 = __ ave. = __ (lbs)			

Maintenance Screen

Fill in all blanks on the right of the Maintenance screen in the Software settings block.

Menu
ConLog version 1.3

Unlock

Logged Data

Date	Time	CJC	TC1	TC2	TC3	TC4	O2	Aux
12/27/90	1445	72	410	505	623	734	_____	off

Comments:

Hardware Settings

Software Settings

O2 Calibration _____

Pump Cycle Length _____

TC Cycle Length _____

Aux Heat Trip Point 90

AES Start _____

AES End _____

AES Duration, Days _____

Hours:Minutes _____

File _____

Current Data

Date	Time	CJC	TC1	TC2	TC3	TC4	O2	Cal	Aux	Pump	TCs	O2s	Logging
12/27/90	15:15:34	72	410	504	625	733	20.9	353	off	off	238	0	ON

Message

AWES Cumulative Time Counter _____ (pump off)					
Start of File Calibrations					
Calibrator:	100 °F ^a	1000 °F ^a	2000 °F ^a	Ice Bath ^a	Boiling Water ^b
TC1	_____	_____	_____	_____	_____
TC2	_____	_____	_____	_____	_____
TC3	_____	_____	_____	_____	_____
a. Do these only when first setting a sampling system in the house.					
b. Check this before each test. If in error, correct and check with calibrator and ice bath as well.					

Service Call Information

1. Check one: Initial Planned Unplanned (if unplanned, state reasons in Field Notes.)
 2. Service Call Date: ____ / ____ / ____ Military Time: ____ :

AWES Cumulative Time Counter _____ # of minutes for this test _____

1. O₂ cell calibration Ambient = _____% _____ O₂ Tank = _____%
 _____% O₂ Tank = _____% _____ O₂ Tank = _____%

2. Scale calibration with 10 lb wt: CBS 1 = __ 2 = __ 3 = __ 4 = __ ave. = __ (lbs)

Maintenance Screen
 Fill in all blanks on the right of the Maintenance Screen in the Software Settings block.

Menu										ConLog version 1.3			
Unlock										Hardware Settings			
Logged Data										Software Settings			
Date	Time	CJC	TC1	TC2	TC3	TC4	O2	Aux		O2 Calibration	_____		
12/27/90	1445	72	410	505	623	734	_____	off		Pump Cycle Length	_____		
Comments:										TC Cycle Length _____ Aux Heat Trip Point 90 AES Start _____ AES End _____ AES Duration, Days _____ Hours:Minutes _____ File _____			
Current Data													
Date	Time	CJC	TC1	TC2	TC3	TC4	O2 Cal	Aux Pump	TCs	O2s	Logging		
12/27/90	15:15:34	72	410	504	625	733	20.9	353 off off	238	0	ON		
Message													

End of File Calibrations

Calibrator:	100 °F ^a	1000 °F ^a	2000 °F ^a	Ice Bath ^a	Boiling Water ^a
TC1	_____	_____	_____	_____	_____
TC2	_____	_____	_____	_____	_____
TC3	_____	_____	_____	_____	_____

a. Do these only after last sample run in this house.

Copy data file onto your A drive. Name of File: _____

Planned and Unplanned Maintenance Record (note any change to system parameters or hardware)		
Date	Comments	Technician

Figure 4

Data File Names

Names for data files created during the downloading process are to be created using the following format:

¹ ² ³ ⁴ ⁵ ⁶ . ⁷ ⁸

Character #	Description
1	Single letter indicating geographical area, e.g., Y for New York (designates 1988-89 sampling season)
2 - 3	Two-digit house code; e.g., 01. . . 25
4	Single letter indicating stove technology type: C = Integrated catalyst L = Low emissions non-catalytic
5 - 6	Two-digit file number; e.g., 10 . . . 50. (Assume a decimal point, that is, 1.0 and 5.0. The first digit indicates the rotation. If multiple files are necessary for one sampling rotation due to data logger problems, the second digit will indicate the files in addition to the first file, that is, 51 would be the first additional file for the fifth rotation).
7 - 8	Two-letter technician's initials; these should be the initials of the field technician creating the file.

Between characters 6 and 7 type a mandatory period (.).

Examples:

The initial (and only) file for the second rotation created by Tim Ward at home 12 in New York, which has a catalytic stove, would be called:

Y12C20.TW

The second file created for rotation 4 by Tim Ward at home 03 in New York, which has a low emission stove, would be called:

Y03L41.TW

Figure 5
AES Log Book

Home Code: _____

Sampling Rotation: 1 2 3 4 5 B

Sample I.D.: _____

AES Box # _____	Filter # _____	XAD # _____
Teflon Line # _____	Probe # _____	

<p>Installation Date AES Installed _____</p> <p>by: _____</p> <p>1. Programmed Start Time Date: _____ Time: _____</p> <p>2. Leak Check (inlet plugged, outlet open)</p> <p>max. vacuum, upper gauge _____ " Hg max. vacuum, lower gauge _____ " Hg</p> <p>Close toggle, turn off pump, wait 30 seconds</p> <p>max. vacuum, upper gauge _____ " Hg max. vacuum, lower gauge _____ " Hg</p> <p>3. Free-flow check (inlet open, outlet open)</p> <p>vacuum, upper gauge _____ " Hg vacuum, lower gauge _____ " Hg rotameter _____ " Hg</p> <p>4. Heater works: Yes <input type="checkbox"/> (if no, use substitute AES)</p>	<p>Removal Date AES Removed: _____</p> <p>by: _____</p> <p>1. Programmed Stop Time Date: _____ Time: _____</p> <p>2. Leak Check (inlet plugged, outlet open)</p> <p>max. vacuum, upper gauge _____ " Hg max. vacuum, lower gauge _____ " Hg</p> <p>Close toggle, turn off pump, wait 30 seconds</p> <p>max. vacuum, upper gauge _____ " Hg max. vacuum, lower gauge _____ " Hg</p> <p>3. Free-flow Check (inlet open, outlet open)</p> <p>vacuum, upper gauge _____ " Hg vacuum, lower gauge _____ " Hg rotameter _____ " Hg</p>
---	---

Figure 6

Sample Data	
Lab Cleanup Date _____	Technician _____
Probe Rinse—Sample No. _____	
Filter # _____	
XAD # _____	
Samples Delivered to OMNI?	<input type="checkbox"/> Yes <input type="checkbox"/> No
Delivered by: _____	

Comments

Figure 10

OBSERVATIONS YOU, THE HOMEOWNER, CAN MAKE TO ASSURE THE SAMPLING SYSTEM IS WORKING PROPERLY:

1. Sampling pump must come on for one minute every three minutes for a fireplace, one in 10 for a pellet stove, and one in 15 for a woodstove.
2. Observe computer and screen twice daily to:
 - a. assure that computer and monitor are working;
 - b. observe that TCs 1 & 2 on screen display reasonable values in the columns on the left (about 70 when no burning is taking place);
 - c. observe that O₂ readings are between 20.5 and 21.2 when no burning is taking place (20.9 is optimal).
3. Observe daily that the gas bag in the box is filling. Filling should be visible after two days of burnings. Thereafter, filling should continue to increase.

If you notice any irregularities in these items, please notify us. Thank you for your help.

OMNI Environmental Services, Inc.

(503) 643-3755

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END

**DATE
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11/18/91

