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In-Home Performance of Certified Pellet Stoves in Medford and Klamath Falls, Oregon

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In-Home Performance of Certified Pellet Stoves in Medford and Klamath Falls, Oregon

Prepared for:

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and
The Oregon Department of Environmental Quality

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Executive Summary

Six pellet stoves representing two models, one simple in operation (Whitfield) and another complex (Crossfire), were continuously monitored for four week-long sample periods from January through March, 1990. Three stoves were placed in Medford homes and three in Klamath Falls.

Objectives

- To determine the performance of pellet stoves that have low lab certification particulate emissions rates in "real world" settings.
- To evaluate the effect of altitude on performance. Klamath Falls is at 4200 ft. elevation, whereas Medford is at 1300 ft.
- To gain a broader, more complete knowledge of these stoves' performances by measuring CO and PAH emissions, net thermal efficiency, and heat output. The Automated Woodstove Emissions Sampler (AWES) was modified specifically for this study to include collection of an integrated flue gas sample to allow for measurements of CO.
- To document the comparative field performance of the two stove models.

Results and Conclusions

- Average overall particulate emissions were 1.05 g/hr, about 75% lower than the best performing cordwood stoves. These values are very close to lab certification values.
- There appears to be no effect of altitude on particulate emissions. Average Klamath Falls emissions were 1.01 g/hr versus 1.14 g/hr for Medford.
- CO emissions averaged a low 14 g/hr.
- PAH emissions were very low. Compounds such as Benzo[a]pyrene had low flue gas concentrations.
- Average net thermal efficiency was 68% and average net output was 8747 Btu/hr. Higher efficiencies were attained when stoves were run continuously, but homeowners switched stoves on and off as the weather warmed.
- There was no detectable difference in particulate emissions for the two stove models. The two Crossfires averaged 1.05 g/hr and the four Whitfields averaged 1.03 g/hr. Interestingly, the model with the highest and lowest emissions was the Crossfire.

While the pellet stove technology evaluated in this study shows the potential to provide significant reductions in particulate emissions, questions about durability, emissions and efficiency of the wide range of pellet technologies available, including exempt stoves remain unanswered. In addition, the long term security of the fuel supply, stability of fuel costs and purchase and operational costs are in need of investigation.

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Introduction

This report summarizes the work conducted by OMNI Environmental Services, Inc. under contract to the Oregon Department of Environmental Quality (DEQ) and funded by the U.S. Department of Energy on "in-home" evaluation of pellet-fueled stove performance. The work involved "in-home" sampling of pellet-fired stoves during the 1989-90 heating season in Medford and Klamath Falls, Oregon.

Pellet-fueled stoves are designed to burn pellets made from compressed biomass residue (typically sawdust). Biomass pellets are currently used in many small boilers throughout the western and northern United States. Several firms have recently introduced pellet-fueled appliances for use in residential heating.

Pellet-fueled stoves have two significant differences from most other residential woodstoves: (1) they continually introduce small amounts of fuel into the combustion chamber, instead of "batch-burning" a single fuel load; and (2) they use mechanically generated draft (induced or forced) to control air flow into the combustion chamber. These features provide substantial theoretical improvements in combustion efficiency which offer the potential to produce lower particulate emission rates relative to conventional cordwood stoves.

Airborne particulate material is the most serious pollutant associated with residential wood combustion and has been the subject of numerous studies.[1-20] The generally accepted need to reduce particulate emissions has been the primary impetus behind the promulgation of Oregon Department of Environmental Quality (ODEQ) and U.S. Environmental Protection Agency (EPA) woodstove certification regulations.

Due to an anticipated increase in the number of homes heating with pellet stoves in the Northwest and the current lack of data on "real world" particulate emission rates for pellet stoves, the U.S. Department of Energy and the Bonneville Power Administration contracted with OMNI through the Oregon DEQ to conduct an "in-home" study of pellet stove performance. To document the "in-home" particulate emission values for pellet-fueled stoves, OMNI deployed the Automated Woodstove Sampling System (AWES) data logger systems (with minor modifications). This sampling system has been used in many "in-home" cordwood stove studies. 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 as compared to cordwood stoves. Before field deployment, laboratory testing of the modifications was conducted to assure system comparability and precision.

The comparability testing consisted of first running one of the modified AWES samplers and a Method 5G sampler simultaneously for two 24-hour tests. Then five modified AWES units were run simultaneously for a 24-hour period on a single pellet-stove to provide a measure of precision of the pellet stove sampling system and to serve as a final pre-field "shake-down".

The modified AWES units (Figure 1) were placed in six homes, three in Medford and three in Klamath Falls. Each home had either a Crossfire or a Whitfield stove. Four one-week-long time-integrated tests were performed on each stove.

In addition to the collection of particulates with the modified AWES sampling system and the collection of CO and CO_2 with the flue gas collection system, PAH samples were collected. Because condensation, agglomeration, volatilization, and secondary chemical reactions can all modify the character of source particles OMNI used a dilution/cooling system for the collection of samples for PAH analyses. One sampling sequence was conducted on one stove of each model with the results analyzed by the DEQ laboratory using thermal desorption and Standard Method 8310 (liquid chromatograph).

Objectives

- To evaluate the field performance of two pellet stove models that have produced low lab certification particulate emission rates.
- To evaluate the effect of altitude on performance. Klamath Falls is at 4,200 ft. elevation, whereas Medford is at 1300 ft.
- To gain a broader perspective of pellet stove emissions performance by measuring PAH and CO emissions.
- To measure net thermal efficiency and heat output.
- To determine if a complexly operated pellet stove model (Crossfire) performs superior to a simply operated one (Whitfield).

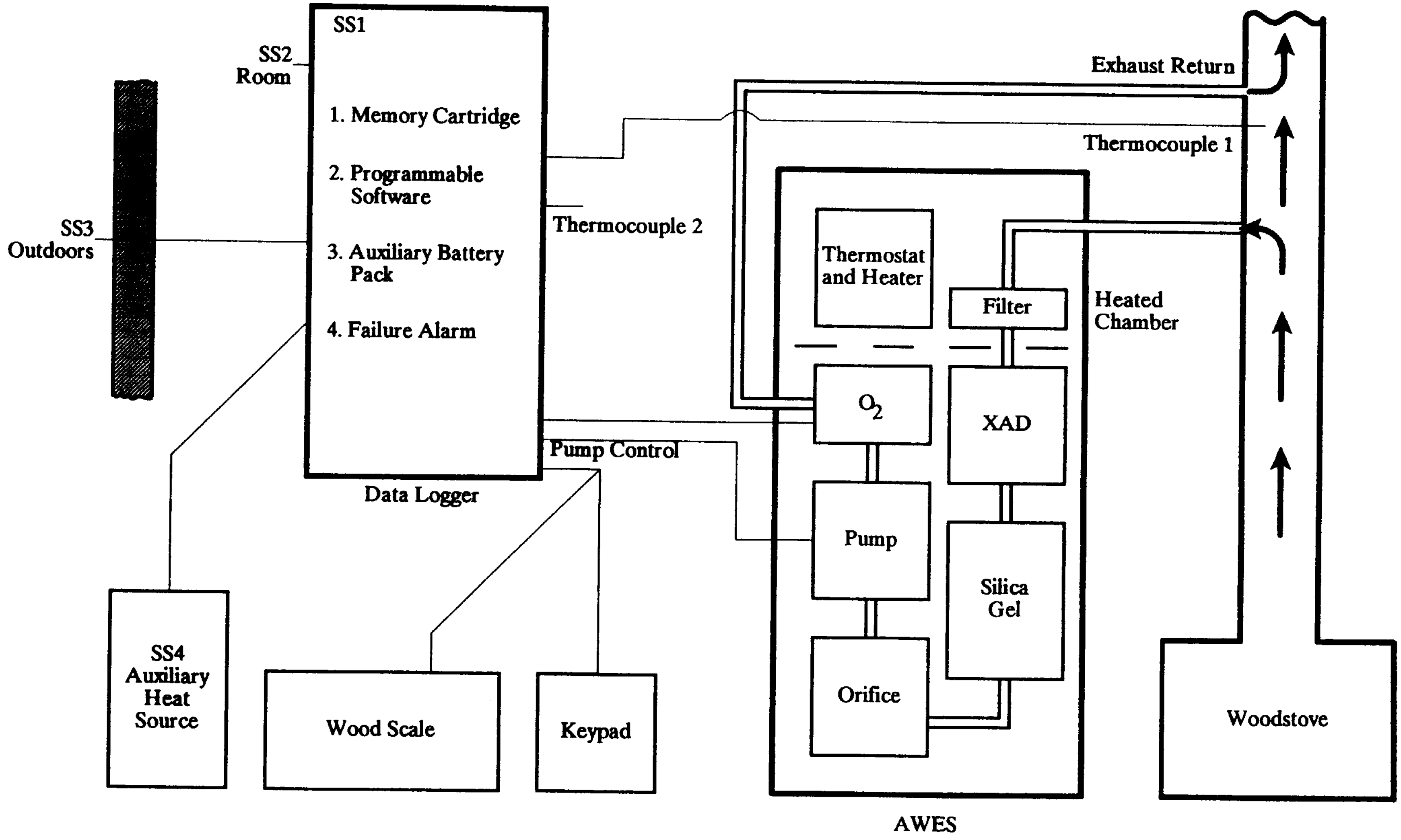


Figure 1. Schematic of AWES/data logger system.

Methodology

Emissions Sampling

The Modified AWES Emission Sampling System

AWES 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 #XX5000002) 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 units returned 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.

The flue gas collection system discussed previously takes a dried, particle-free sample of flue gas from the sample stream after the pump. The gas flows into the Tedlar bag 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 Log'r

The Data Log'r is a multi-channel programmable microprocessor/controller with the capability of processing both digital and analog signals. The unit has a data storage capacity of 32 kilobytes on a field-replaceable, non-volatile memory data cartridge. The data loggers used during the "in-home" tests were programmed to record and store the following information:

- Starting date, time, and unit serial number for data recording periods;

- Daily date and time, recorded in five-minute intervals;
- Flue gas temperatures averaged over five-minute intervals;
- Data logger ambient temperature in 15-minute intervals;
- Fuel weights recorded as the stoves were fueled;
- Oxygen measurements when the AWES unit was sampling; and
- AC power status, measured at five-minute intervals.

The Data Log'r system uses external sensors which generate analog voltages that are processed by the data logger microprocessor. Solid state temperature sensors (National Semiconductor LM334) were used to monitoring data logger box temperature (SS#1) to ensure that the electronic data logging equipment was not being overheated by the radiant heat of the appliance being evaluated. A type K ground-isolated stainless steel sheathed thermocouple (Pyrocom 1K-27-5-U) was used to monitor combustion gas temperature at 30 cm (1 foot) above the woodstove's flue collar in the center of the flue gas stream (TC#1). Thermocouple channel 2 (TC#2) was converted to a millivolt input device to measure auger speed.

As a backup to the auger feed rate indicator, all pellet bags loaded in the pellet hopper by the homeowner were weighed electronically and the weights recorded automatically on the data logger's data file. This was done by attaching an electronic scale/woodbasket unit which supplied an analog voltage output to the data logger which is linearly proportional to the weight placed in the wood holder. Scale readings were recorded by having the participant use an attached keypad in a prescribed sequence.

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, and AWES unit 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.

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; the data logger was programmed with the proper sampling interval and start/stop times; and wood moisture measurements were performed on the fuel in the home's storage area. 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 unit, sampling line, and sampling probe were removed.

Data Processing and Quality Assurance

Data files stored in the data logger memory cartridges were downloaded in the field with a portable computer onto floppy disks at the conclusion of each sampling period. 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. See table 3 for a complete listing of parameters. 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).

Emissions Calculations

The basic emissions equation produces grams per dry kilogram of fuel burned (gm/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) but varies slightly with wood species and completeness of combustion.

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 5.5.

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

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

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

Uncertainty in Emissions Results

Particulate emissions values are presented along with associated uncertainty levels. Each individual 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.

The issue of sample blank-induced error was investigated at length in the 1988-1989 Northwest 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 ±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"[21]. 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 flue pipe for additional heat transfer, efficiencies would be higher than stated herein by up to about 5 percentage points.

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 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 with cordwood stoves to determine fuel mass was used with the pellet stoves as well. Wood moisture measurements were not required for each test burn stove since pellet moisture content was determined by proximate/ultimate analysis of the fuel.

Since the fuel is fed to the firebox by an auger, real-time fuel rate measurements were also made. A system to measure auger rate was integrated with the data logger. This system did not work well in the field due to inter-stove variability and a stack temperature system was used instead.

The sampling period was also slightly modified to accommodate the low emissions of the pellet stoves. The sampling frequency that has been found to provide optimal sample catches for analysis from cordwood stoves during a one-week period was one minute of sampling out of every fifteen minutes at a flow rate of one liter per minute. Due to the predicted lower particulate emission rates characteristic of pellet stoves, a shorter sampling frequency of one minute out of every ten minutes off 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 2). 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 should the flue oxygen levels exceed about 18%. Such high oxygen values were not encountered in this project but probably would be with exempt pellet stoves that run more dilute.

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

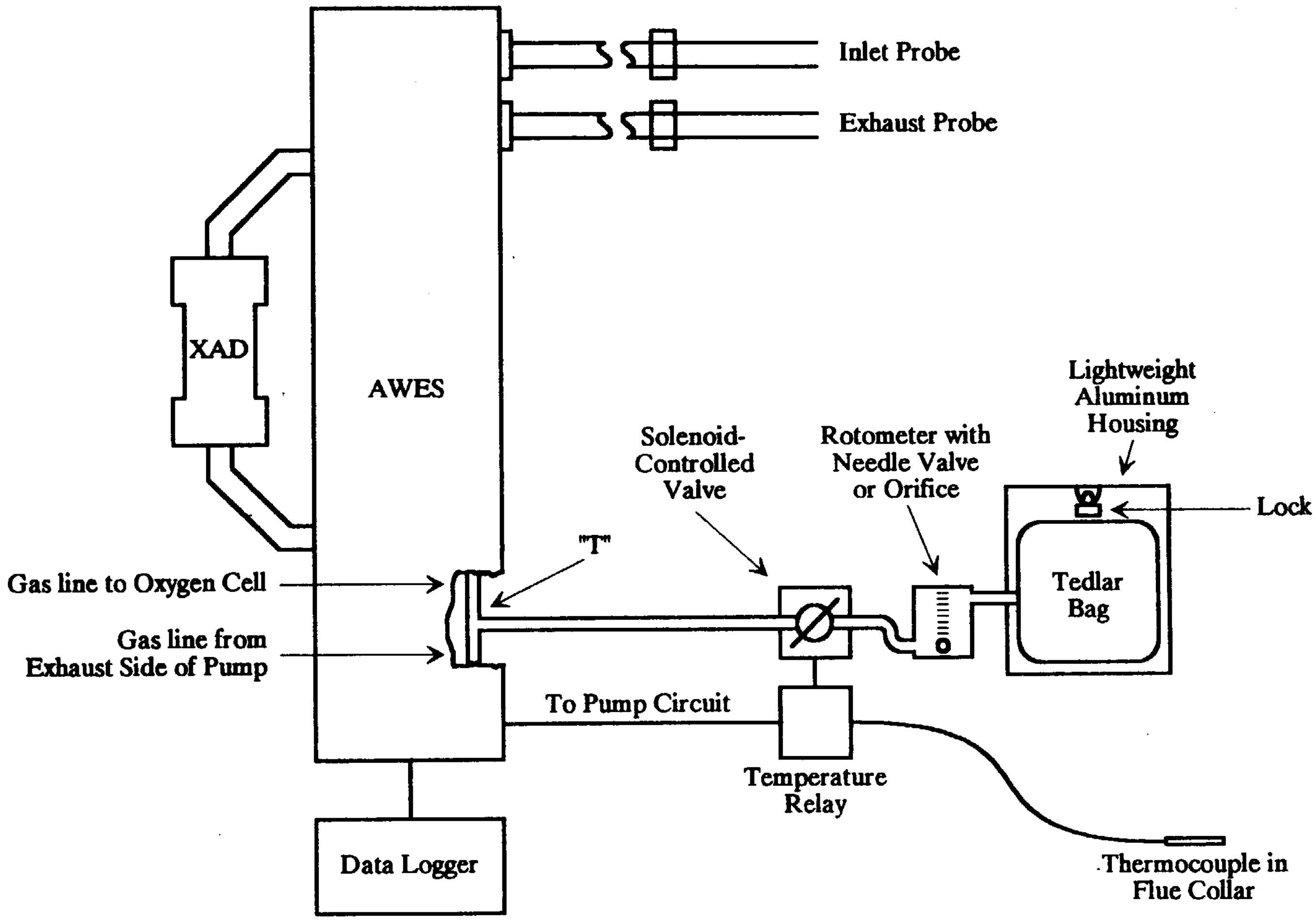


Figure 2. Schematic of AWES system modified for pellet stove application.

carcinogenic. Particulate samples collected by OMNI with a dilution/cooling tunnel were analyzed by DEQ for PAHs.

Figure 3 is a general schematic of the dilution source sampling system (DSS) which was used in this study. 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 point of particle loss 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 well 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. Impactor systems ($<1\mu$, $<2.5\mu$, $<10\mu$, and TSP) withdraw samples from the dilution chamber. The impactor systems were developed for the California Air Resources Board and have undergone extensive evaluation[26]. A flow collimating tube is placed in front of the impactors to ensure evenly-loaded filters. While the diameter of the inlets of the collimating tubes could be restricted to achieve isokinetic sampling conditions, this is not essential since the majority of particles originating from combustion sources are significantly less than 5μin aerodynamic diameter. Similarly, the flow in the inlet to the dilution chamber can be adjusted to remove the aerosol from the source isokinetically although, as mentioned, it is not critical. In addition to 47-mm filters positioned behind the impactors sampling at 10 lpm, an 8 × 10-inch high-volume filter is placed in the system exhaust line to collect larger quantities of TSP particulate material.

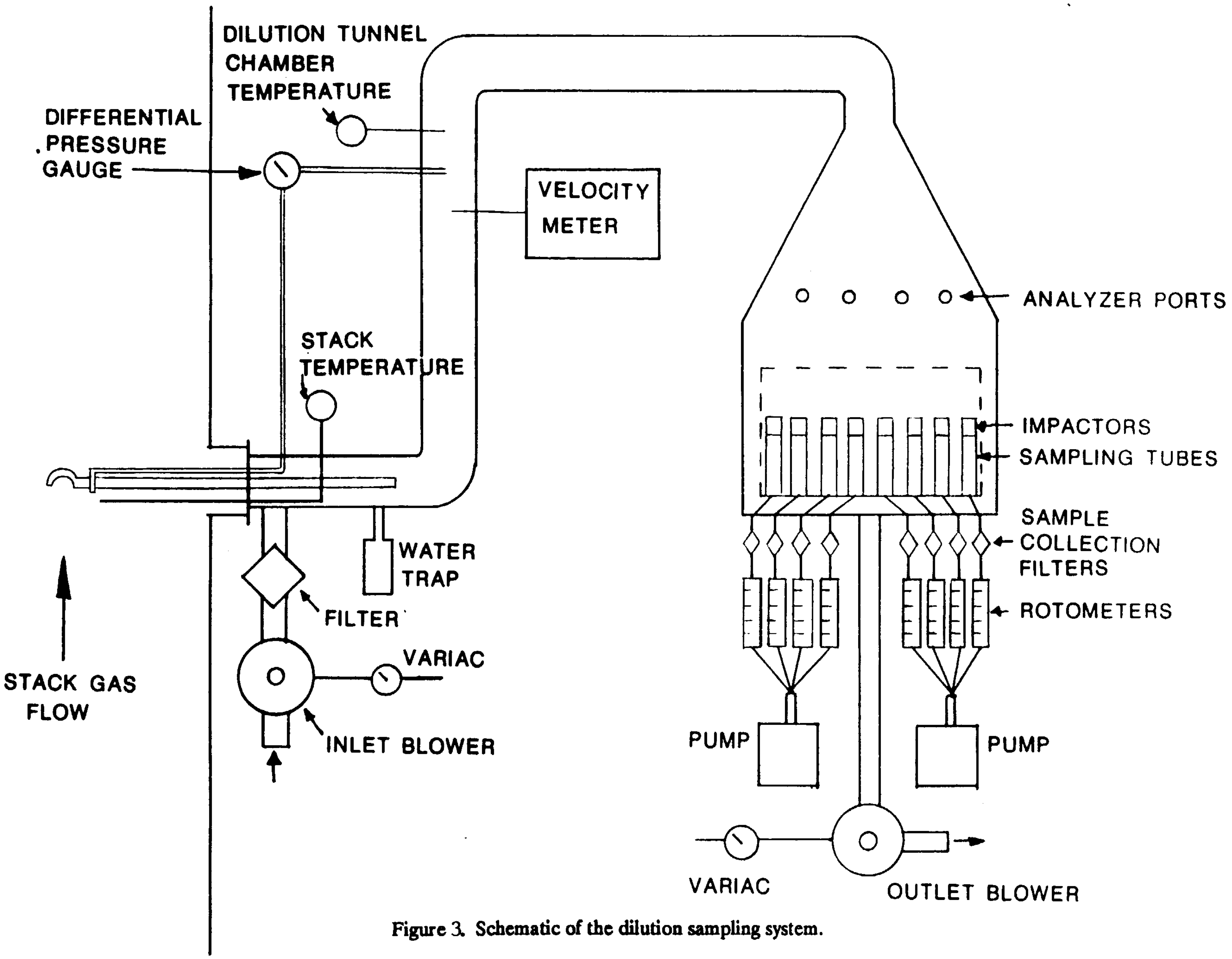


Figure 3. Schematic of the dilution sampling system.

The transfer of particulate-bearing stack gases via the heated probe to the dilution chamber is accomplished by maintaining a pressure differential between the dilution chamber and the interior of the stack. From Bernoulli's equation of continuity, it can be shown that the linear velocity of gas entering the inlet is dependent only on the pressure drop (ΔP) and density of the source gas (ρ), i.e.,

$$V = \sqrt{\Delta\rho/0.5\rho} \tag{1}$$

Bernoulli's equation is only strictly applicable to idealized fluids but is illustrative for design consideration. Since the inlet will collect gas parallel with the direction of flow, the pressure value used to calculate ΔP in Equation 5 must take into account the effect of velocity pressure, i.e.,

$$\Delta P = [P_{S,S}+0.5\rho_S V_S 2]-P_{d,S} \tag{2}$$

where $P_{S,S}$ is the static pressure within the source;
ρ_S is the density of gas within the source;
V_S is the linear velocity of gas within the source; and
$P_{d,S}$ is the static pressure within the dilution chamber.

Measurement of ΔP can be accomplished by the use of commercially available tips connected to a manometer or Magnehelic gauge.

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.

The 47-mm quartz filters collected behind the impactors were submitted to the DEQ for subsequent analysis using a thermal desorption GC/MS technique. This technique was developed for the DEQ as part of its Pacific Northwest Source Profile program[24] and provides data that is compatible with data generated from that study. Analysis was also conducted on the 8 × 10-inch high-volume filter that is placed on the exhaust side of the system. This filter collected a larger mass of particulate material and was subjected to the U.S. EPA Standard Method 8310. Sixteen PAH compounds were determined by this liquid chromatographic technique (Table 1). These sixteen PAH compounds were measured in the U.S. EPA's Integrated Air Cancer Project (IACP) which was conducted during the winter of 1986-1987 in Boise, Idaho, where woodstove emissions are recognized as a major component of the air quality degradation.

Table 1
Polycyclic Aromatic Hydrocarbons Selected for Analysis

Compound

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

Results and Discussion

Quality Assurance Testing

The modified AWES samplers were evaluated in the laboratory for comparability and precision before field deployment. Comparison testing was conducted by simultaneously testing a pellet stove with both an AWES unit and a EPA Method 5G. The results of two test runs (see Figure 4) show that AWES emissions are within 0.2 gram/hr of the unadjusted 5G.

Precision testing was conducted by running five AWES units simultaneously on one pellet stove. Results of the precision test (see Figure 5) show that all five AWES units were within 0.25 gram/hr of one another.

Comparison of Flue Gas O_2 and AWES O_2

As discussed in the methodology section of this report, it was necessary to add a flue gas collection system to measure CO, CO_2 and O_2. This procedure offers an opportunity to compare the O_2 of this sample with the average of real time measurements made by the AWES. As can be seen in Figure 6, they compare favorably. All but one comparison was between -0.2 and 0.2%.

Particulate Emissions

The overall average particulate emissions for the six pellet stoves (four Whitfields and two Crossfires), three located in Medford and three located in Klamath Falls, averaged 1.05 g/hr, or 1.63 g/kg, (Table 2). These emissions are about 75% lower than the best "high-tech" cordwood stoves and about 95% lower than most conventional stoves. Emissions during each test varied from a low of 0.20 g/hr, or 0.23 g/kg, generated from one of the Crossfire stoves on the first test run, to a high of 2.54 g/hr, or 5.51 g/kg, also generated by a Crossfire. The Whitfield results varied from a low of 0.43 g/hr, or 0.55 g/kg, to a high of 1.81 g/hr, or 2.67 g/kg. As can be seen in figures 7 and 8 the emissions of the two Crossfire stoves were higher and lower respectively than the emissions of the Whitfields for all of the test runs. Complete results for all parameters are shown in table 3.

Emissions trends over the course of the study display an increase after Run 1 after which they remained relatively constant (Figure 9). Figure 7 shows that this increase comes almost entirely from homes 2 and 6.

COMPARISON OF G/HR SIMULTANEOUS AWES AND METHOD 5G EMISSIONS.
TWO TESTS ON A WHITFIELD PELLET STOVE.

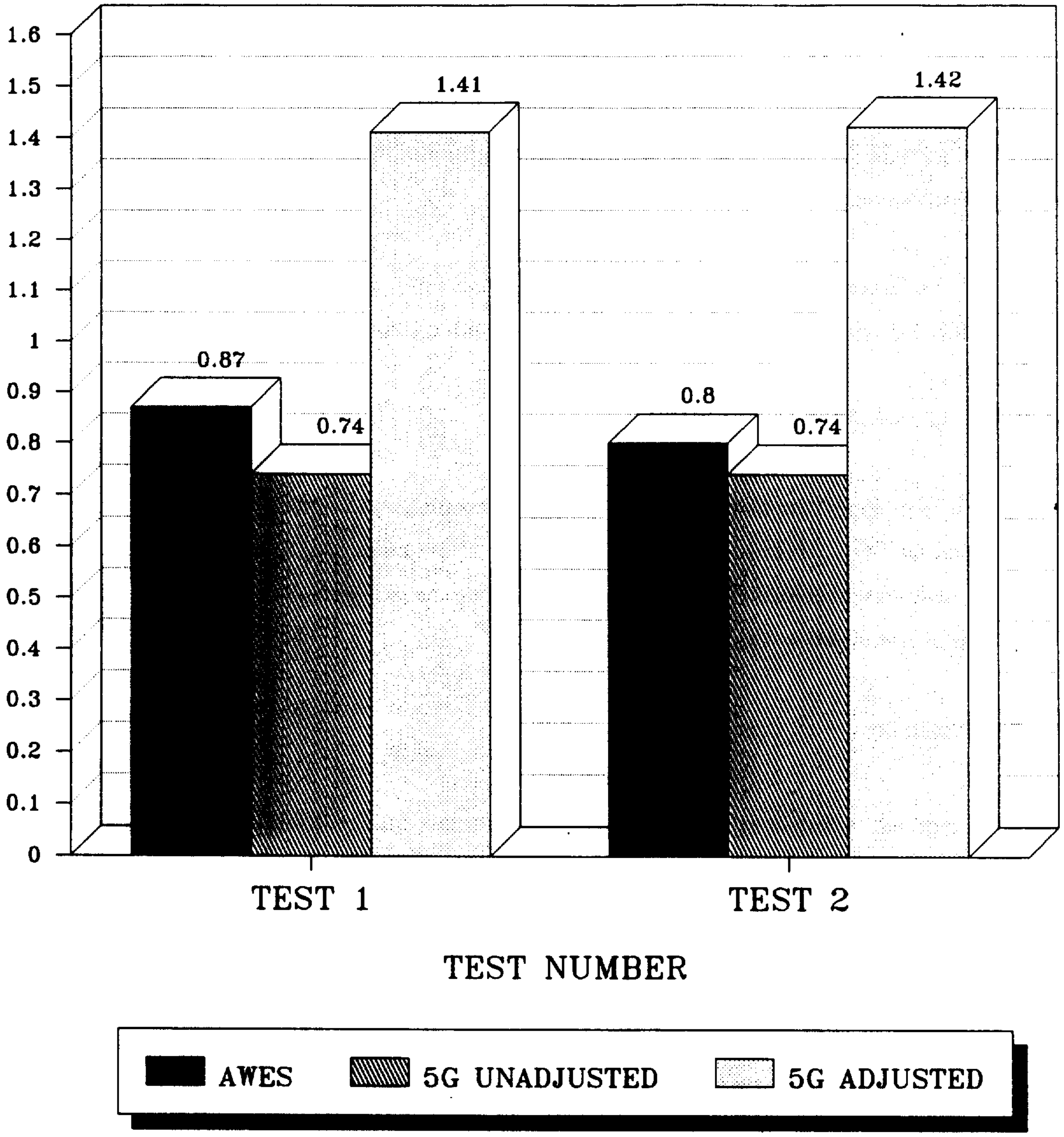
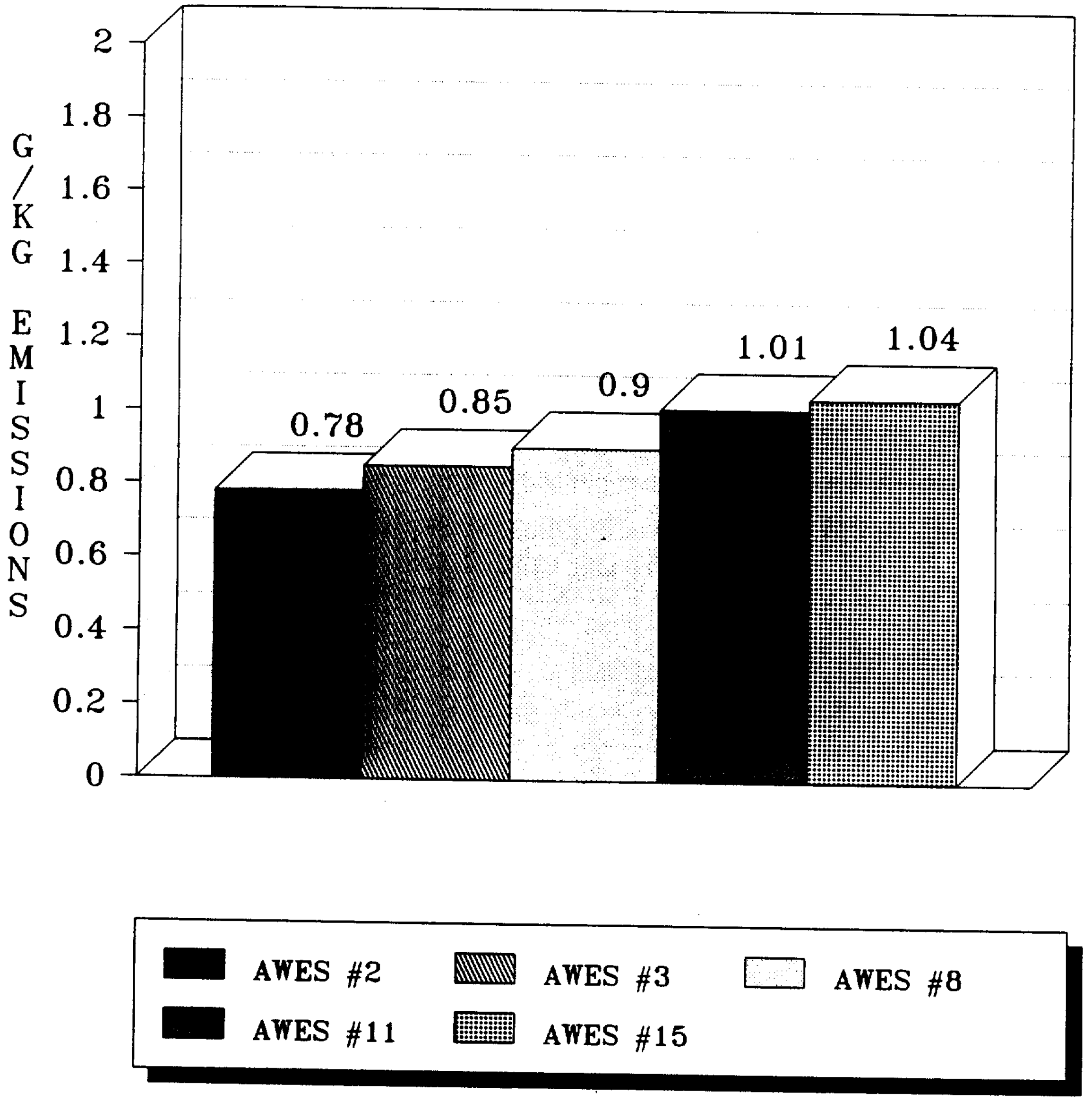


Figure 4



FIVE SIMULTANEOUS AWES TESTS
ON A WHITFIELD PELLET STOVE.
(G/KG PARTICULATE EMISSIONS)

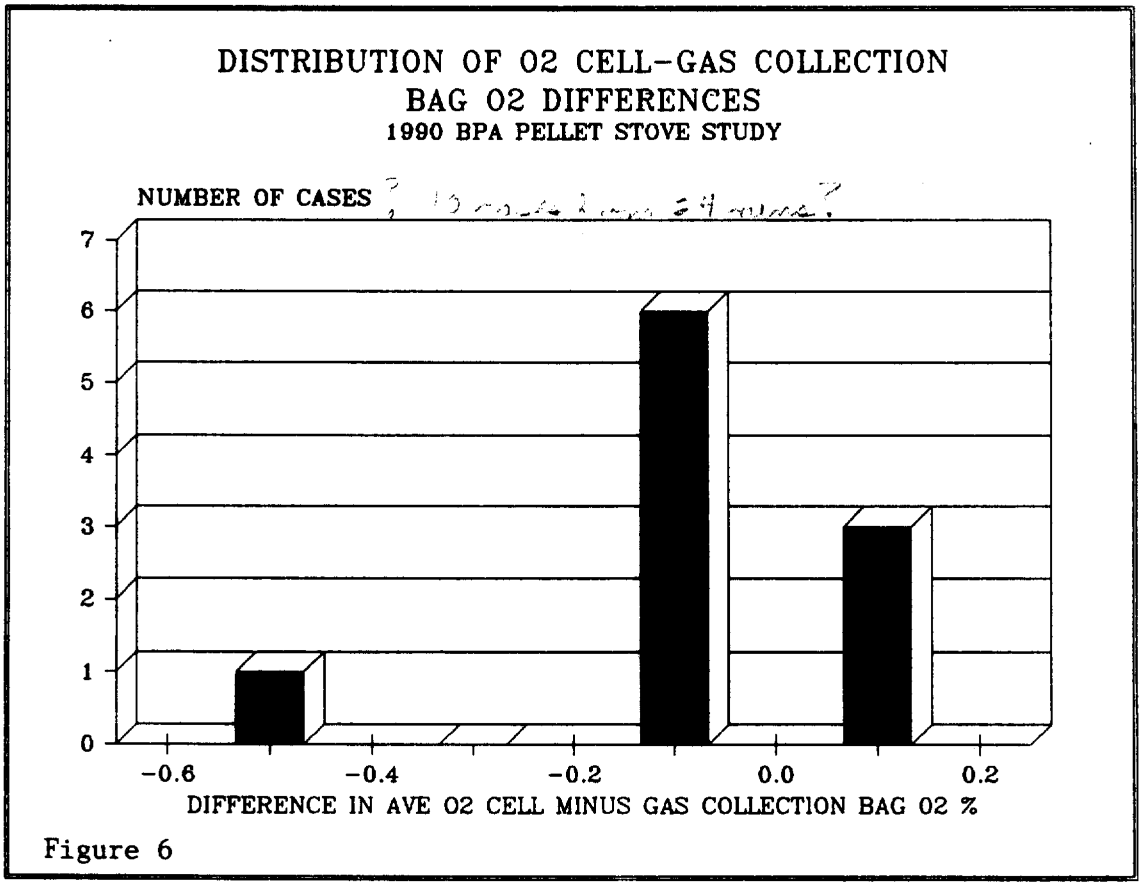
Figure 5

Table 2. Summary - Particulate Emissions And Burn Rate Data.

HOUSE NO.	STOVE BRAND	EMISSIONS, GRAMS/HOUR				EMISSIONS, GRAMS/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
2	WHITFIELD	1.1	1.2	1.8	1.6	1.4	1.7	2.4	1.9	0.78	0.74	0.74	0.84	1.4	1.8	0.78
3	WHITFIELD		1.8	1.5	1.5		2.7	2.1	2.2		0.68	0.72	0.69	1.6	2.3	0.70
4	WHITFIELD	0.4	1.0	0.5	0.6	0.7	1.3	0.8	1.0	0.66	0.78	0.63	0.63	0.6	0.9	0.68
5	WHITFIELD	0.4	0.7	1.0	0.6	0.6	0.9	1.2	0.8	0.78	0.73	0.78	0.78	0.7	0.9	0.77
1	CROSSFIRE	0.2	0.4	0.4	0.5	0.2	0.4	0.7	0.7	0.85	0.92	0.63	0.63	0.4	0.5	0.76
6	CROSSFIRE	0.7	1.7	2.5	1.9	1.2	3.4	5.5	3.7	0.59	0.50	0.46	0.52	1.7	3.4	0.52
	RUN AVERAGE	0.59	1.14	1.29	1.12	0.82	1.73	2.13	1.71	0.73	0.73	0.66	0.68			

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
WHITFIELD	0.66	1.18	1.19	1.08	0.88	1.64	1.64	1.47	0.74	0.73	0.72	0.74
CROSSFIRE	0.46	1.06	1.49	1.20	0.72	1.92	3.11	2.21	0.72	0.71	0.55	0.58

	OVERALL AVERAGES: G/HR	OVERALL AVERAGES: G/KG	OVERALL AVERAGES: BURN RATE
WHITFIELD	1.03	1.40	0.73
CROSSFIRE	1.05	1.99	0.64
KLAMATH FALLS	1.01	1.75	0.65
MEDFORD	1.14	1.56	0.74

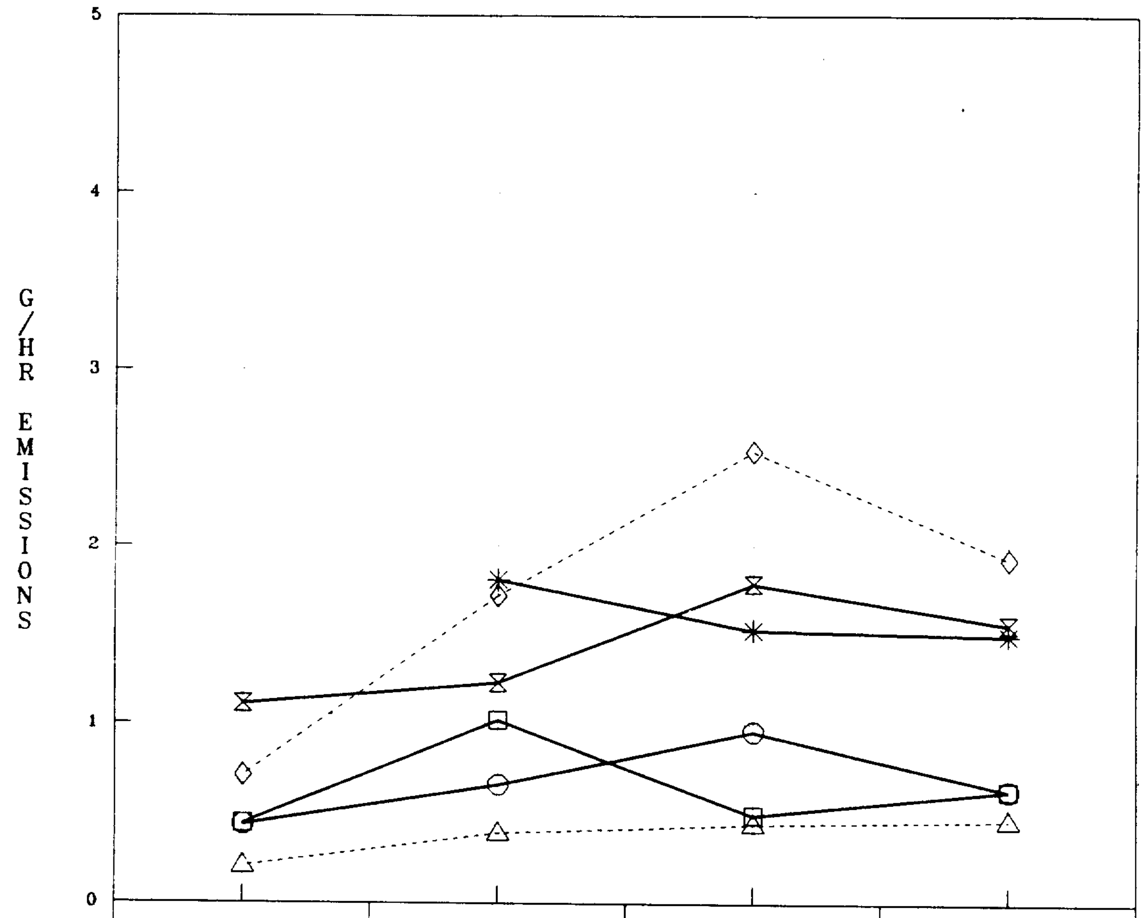


? 13 [illegible] 2 [illegible] = 4 [illegible]?

Figure 6

1×(-.5) = -0.5
6×(-.1) = -0.6
3×(+.1) = +0.3
-0.8

TRENDS: G/HR PARTICULATE EMISSIONS PELLET STOVES; 1990 "IN-HOME" TESTS

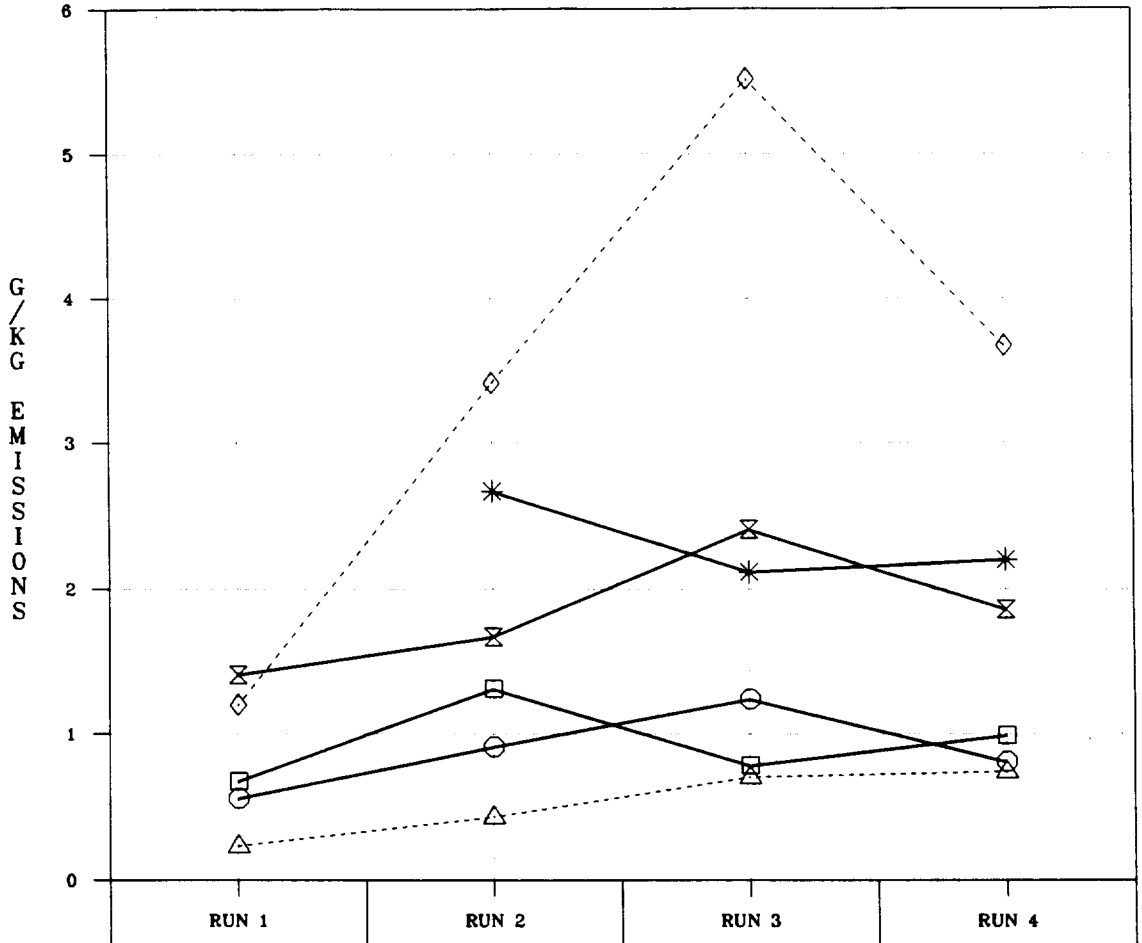


	RUN 1	RUN 2	RUN 3	RUN 4
HOUSE 1	0.2	0.39	0.44	0.46
HOUSE 2	1.11	1.23	1.79	1.56
HOUSE 3		1.81	1.53	1.5
HOUSE 4	0.44	1.02	0.49	0.63
HOUSE 5	0.43	0.66	0.96	0.63
HOUSE 6	0.71	1.72	2.54	1.93

WHITFIELD= SOLID LINES
CROSSFIRE= DASHED LINES

Figure 7 .

TRENDS: G/KG PARTICULATE EMISSIONS PELLET STOVES; 1990 "IN-HOME" TESTS



	RUN 1	RUN 2	RUN 3	RUN 4
HOUSE 1	0.23	0.43	0.7	0.74
HOUSE 2	1.41	1.67	2.41	1.86
HOUSE 3		2.67	2.12	2.2
HOUSE 4	0.67	1.31	0.78	0.99
HOUSE 5	0.55	0.91	1.24	0.81
HOUSE 6	1.2	3.41	5.51	3.67

-△- HOUSE 1 ⧖ HOUSE 2 ✳ HOUSE 3 ⊟ HOUSE 4 ⊖ HOUSE 5 -◇- HOUSE 6

WHITFIELD= SOLID LINES
CROSSFIRE= DASHED LINES

Figure 8

TRENDS IN AVERAGE G/HR, G/KG EMISSIONS AND BURN RATE.
PELLET STOVES;1990 "IN-HOME" TESTS

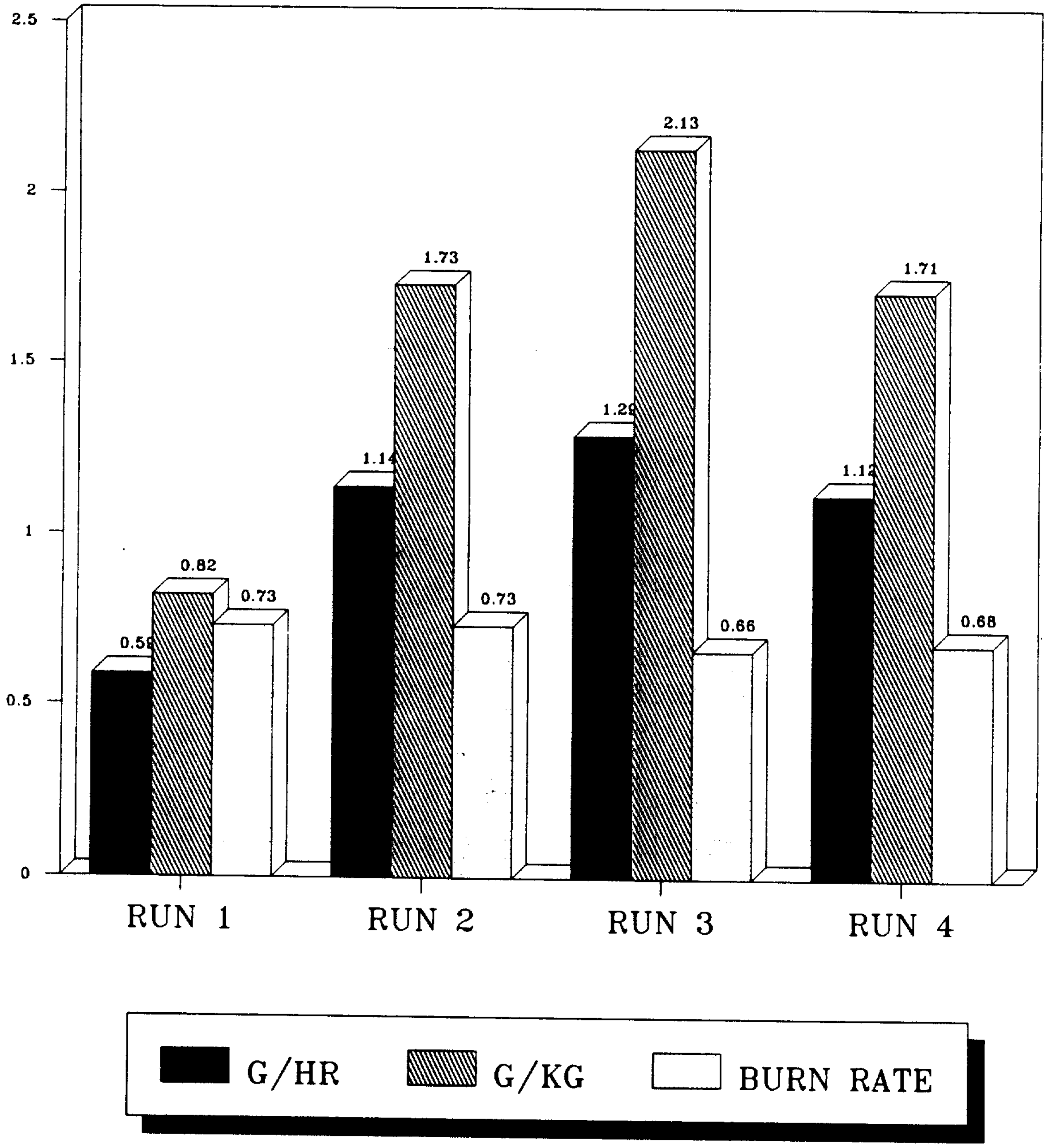


Figure 9 .

Table 3. Summary of Pellet Stove Data

HOUSE AND RUN #:	BM0101	BM0102	BM0103	BM0104	BM0201	BM0202	BM0203	BM0204	BM0302	BM0303	BM0304	BK0401	BK0402	BK0403	BK0404	BK0501	BK0502	BK0503	BK0504	BK0601	BK0602	BK0603	BK0604	AVERAGES:	HOUSE AND RUN #
SAMPLE START DATE:	1/28	2/8	2/20	3/5	1/25	2/9	2/23	3/6	2/14	2/22	3/7	1/25	2/7	2/20	3/2	1/28	2/7	2/20	3/1	1/28	2/7	2/21	3/2		SAMPLE START DATE
SAMPLE END DATE:	2/3	2/14	2/26	3/11	1/31	2/14	2/28	3/12	2/20	2/28	3/13	1/31	2/13	2/26	3/8	2/3	2/13	2/26	3/7	2/3	2/13	2/27	3/8		SAMPLE END DATE
STOVE TYPE:	CROSS				WHIT				WHIT			WHIT				WHIT				CROSS					STOVE TYPE
TOTAL STOVE BURNING HOURS-	168.00	168.00	168.00	168.00	165.58	142.92	94.50	148.67	150.50	72.83	106.92	166.42	162.58	167.83	166.00	167.33	167.92	168.00	166.50	168.00	167.92	105.75	133.83	150.52	TOTAL STOVE BURNING HOURS
% OF TIME STOVE BURNED-	100.00	100.00	100.00	100.00	98.56	99.25	65.63	88.49	89.58	43.35	63.61	99.06	96.78	99.90	98.81	99.60	100.00	100.00	99.16	100.00	100.00	62.95	79.66	90.63	% OF TIME STOVE BURNED
AVE. STACK TEMP (DEGREES F)-	334.32	312.82	263.04	258.31	NA	300.67	291.53	279.64	310.81	305.75	290.90	272.97	240.87	264.07	171.57	279.41	330.35	316.71	317.27	222.34	230.08	200.13	195.28	260.38	AVE. STACK TEMP (DEGREES F)
AVE. OXYGEN % (STACK>100)-	14.21	14.44	16.02	15.83	18.22	17.95	18.39	18.62	18.06	18.02	17.96	17.29	17.46	17.46	18.05	16.27	16.59	16.90	16.67	16.16	17.72	17.50	17.34	17.09	AVE. OXYGEN % (STACK>100)
AVE. OXYGEN % (SAMPLE BAG)-			15.9	16			18.4		17.7	18.1	17.9			17.6	18			17.09	16.8			17.6	17.9	17.42	AVE. OXYGEN % (SAMPLE BAG)
TOTAL WOOD USED, WET LBS.-	327	353	240	240	296	240	160	284	233	120	167	250	290	240	240	299	280	298	295	225	193	111	160	240.91	TOTAL WOOD USED, WET LBS.
HEATING DEGREE DAYS-	179	188	114	159	187	164	82	164	217	98	177	239	250	194	190	248	250	194	179	248	250	175	190	188.52	HEATING DEGREE DAYS
WOOD MOISTURE (DRY BASIS %)-	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	WOOD MOISTURE (DRY BASIS %)
AMES FLOW RATE (L/MIN)-	1.067	1.067	1.067	1.067	1.051	1.051	1.051	1.051	1.084	1.084	1.084	0.978	0.978	0.978	0.978	0.944	0.944	0.944	0.944	0.965	0.955	0.955	0.955		AMES FLOW RATE (L/MIN)
AVERAGE CO % (SAMPLE BAG)-			0.05	0.06			0.05			0.05	0.07			0.04	0.05			0.03	0.04			0.14	0.13	0.065	AVERAGE CO % (SAMPLE BAG)
AVERAGE CO2 % (SAMPLE BAG)-			4.8	4.7			2.3			2.6	2.9			3.1	2.9			3.5	4.0			2.9	2.9	3.33	AVERAGE CO2 % (SAMPLE BAG)
PARTICULATE EMISSIONS																		8							PARTICULATE EMISSIONS
RINSE (mg)-	4.7	17.6	22.6	19.1	17.6	28.5	18.8	10.1	48.9	15.9	23.2	11.5	25.0	16.7	17.1	15.4	19.9	22.0	20.4	39.9	65.4	58.8	67.5	26.37	RINSE (mg)
XAD (mg)-	10.4	4.6	3.5	12.2	7.4	6.2	12.6	10.3	7.4	6.3	5.8	13.0	5.1	2.3	1.5	9.5	4.7	17.2	2.9	14.1	8.3	15.1	4.8	8.05	XAD (mg)
FILTER (mg)-	4.8	10.0	12.8	11.0	4.1	11.8	7.1	21.5	18.6	9.4	17.9	2.0	14.9	10.1	11.5	2.2	14.9	9.8	11.6	2.9	30.3	38.7	27.4	13.27	FILTER (mg)
SUB TOTAL (mg)-	19.9	32.2	38.9	42.3	29.1	46.5	38.5	41.9	74.9	31.6	46.9	26.5	45.0	29.1	30.1	27.1	39.5	49.0	34.9	56.9	104.0	112.6	99.7	47.70	SUB TOTAL (mg)
MINUS AVE. BLANK (mg)-	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.90	MINUS AVE. BLANK (mg)
TOTAL PARTICULATES (mg)-	16.0	28.3	35.0	38.4	25.2	42.6	34.6	38.0	71.0	27.7	43.0	22.6	41.1	25.2	26.2	23.2	35.6	45.1	31.0	53.0	100.1	108.7	95.8	43.80	TOTAL PARTICULATES (mg)
TOTAL DRY WOOD USED (KG)-	143.44	154.85	105.28	105.28	129.85	105.28	70.19	124.58	102.21	52.64	73.26	109.67	127.21	105.28	105.28	131.16	122.83	130.72	129.41	98.70	84.66	48.69	70.19	105.68	TOTAL DRY WOOD USED (KG)
BURN RATE (DRY KG/HR)-	0.85	0.92	0.63	0.63	0.78	0.74	0.74	0.84	0.68	0.72	0.69	0.66	0.78	0.63	0.63	0.78	0.73	0.78	0.78	0.59	0.50	0.46	0.52	0.70	BURN RATE (DRY KG/HR)
BURN RATE/HDD-	0.80	0.82	0.92	0.66	0.69	0.64	0.86	0.76	0.47	0.54	0.41	0.46	0.51	0.54	0.55	0.53	0.49	0.67	0.72	0.40	0.34	0.28	0.37	0.58	BURN RATE/HDD
PARTICULATE EMISSIONS:																									PARTICULATE EMISSIONS
GM/KG-	0.23	0.43	0.70	0.74	1.41	1.67	2.41	1.86	2.67	2.12	2.20	0.67	1.31	0.78	0.99	0.55	0.91	1.24	0.81	1.20	3.41	5.51	3.67	1.63	GM/KG
GM/KG UNCERTAINTY-	0.07	0.08	0.12	0.12	0.35	0.31	0.52	0.41	0.44	0.49	0.41	0.17	0.23	0.18	0.24	0.13	0.16	0.20	0.16	0.17	0.50	0.77	0.51	0.29	GM/KG UNCERTAINTY
GM/HR-	0.20	0.39	0.44	0.46	1.11	1.23	1.79	1.56	1.81	1.53	1.50	0.44	1.02	0.49	0.63	0.43	0.66	0.96	0.63	0.71	1.72	2.54	1.93	1.05	GM/HR
GM/HR UNCERTAINTY-	0.06	0.08	0.08	0.08	0.28	0.23	0.39	0.34	0.30	0.35	0.28	0.11	0.18	0.11	0.15	0.10	0.12	0.16	0.12	0.10	0.25	0.36	0.27	0.20	GM/HR UNCERTAINTY
CO EMISSIONS:																									CO EMISSIONS
GM/KG-			12.44	14.38			24.16			21.08	28.88			14.11	21.31			9.12	11.48			44.94	44.40	22.39	GM/KG
GM/HR-			7.79	9.01			17.95			15.23	19.79			8.85	13.51			7.09	8.92			22.99	23.29	14.04	GM/HR
GM/HR UNCERTAINTY-			4.91	4.74			13.51			11.13	9.89			6.98	8.67			9.22	8.71			4.03	4.96	7.89	GM/HR UNCERTAINTY
EFFICIENCY 1' ABOVE STOVE:																									EFFICIENCY 1' ABOVE STOVE
COMBUSTION EFFIC.-	98.01	99.84	98.29	98.05	99.46	99.36	96.28	99.29	98.98	96.75	95.82	99.74	99.50	98.07	97.16	99.79	99.65	98.47	98.36	99.54	98.69	92.11	93.45	98.03	COMBUSTION EFFIC.
HEAT TRANS. EFFIC.-	75.76	76.56	76.01	76.92		61.48	57.76	56.41	58.98	60.07	62.66	69.74	72.30	69.72	77.81	73.82	67.98	67.53	68.75	78.94	72.13	76.74	77.87	69.82	HEAT TRANS. EFFIC.
NET EFFICIENCY-	74.25	76.44	74.72	75.42		61.08	55.61	56.01	58.38	58.12	60.04	69.56	71.93	68.38	75.59	73.66	67.74	66.50	67.63	78.57	71.19	70.68	72.77	68.38	NET EFFICIENCY
ADDITIONAL ITEMS:																									ADDITIONAL ITEMS
AVE. PELLET USAGE/DAY-	46.71	50.43	34.29	34.29	42.29	34.29	22.86	40.57	33.29	17.14	23.86	35.71	41.43	34.29	34.29	42.71	40.00	42.57	42.14	32.14	27.57	15.86	22.86	34.42	AVE. PELLET USAGE/DAY
AVE. AMBIENT TEMP.-	74.81	75.71	76.42	74.27	63.16	64.94	66.99	64.01	73.55	73.53	72.73	64.86	67.35	68.12	69.52	67.79	70.08	78.20	70.05	67.00	68.55	73.01	73.93	70.37	AVE. AMBIENT TEMP.
% TIME CENTRAL HEAT ON-	0.00	0.00	0.00	0.00	0.00	14.29	14.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.40	0.00	0.00	0.05	0.00	0.00	1.26	% TIME CENTRAL HEAT ON
AVE. NET BTU'S PER HOUR-	11715	13020	8653	8734		8316	7633	8674	7327	7762	7602	8471	10401	7927	8860	10670	9157	9562	9713	8531	6633	6014	7053	8747	AVE. NET BTU'S PER HOUR

These two homes experienced more frequent appliance startups and shutdowns in the last three tests. The smoldering associated with shutdowns probably caused the increased emissions.

Emissions - Whitfield verses Crossfire

The overall average emissions of the Crossfire stoves were 1.05 g/hr, or 1.40 g/kg, as compared to the Whitfield's emissions of 1.03 g/hr, or 1.99 g/kg. The fact that the highest and lowest emissions values were generated by the same stove type (Crossfire) indicates that the variation within a stove type is greater than the variation between stove types, and such variation appears to be closely tied to operational practices. Definitive comparisons cannot be made without a larger sample size.

Emissions - The Effect of Altitude

The average emissions for the three pellet stoves in Medford (elevation ~1300 feet) were 1.14 g/hr or 1.56 g/kg, as compared to the three pellet stoves in Klamath Falls (elevation ~4200 feet), which were 1.01 g/hr or 1.75 g/kg. The higher altitude of Klamath Falls seemed to have a negligible effect, if any, on the emission values of these two brands of stoves, although a larger sample size would be needed to a draw definitive conclusion.

CO Emissions

The CO emissions averaged a low 14.04 g/hr or 22.4 g/kg over the test period. The highest levels of CO (22.99 g/hr or 44.94 g/kg) were found in the stove with the highest particulate emissions, and the lowest CO levels (7.79 g/hr or 12.44 g/kg) were found in the stove with the lowest emissions. There is a strong correlation ($R = 0.93$) between CO and particulate emissions (Figure 10).

PAH Concentrations

Two tests were conducted with a dilution source sampling system, one on a Crossfire stove and one on a Whitfield. Samples were collected on two separate filter media and analyzed using two separate techniques: the GC/MS thermal desorption method and SW846 Method 8310.

The TSP filter results indicate low PAH emissions for the two pellet stoves (Figure 11a). The correlation between the two test methods on the Whitfield stove seems to be in close agreement (see Figure 12a), while on

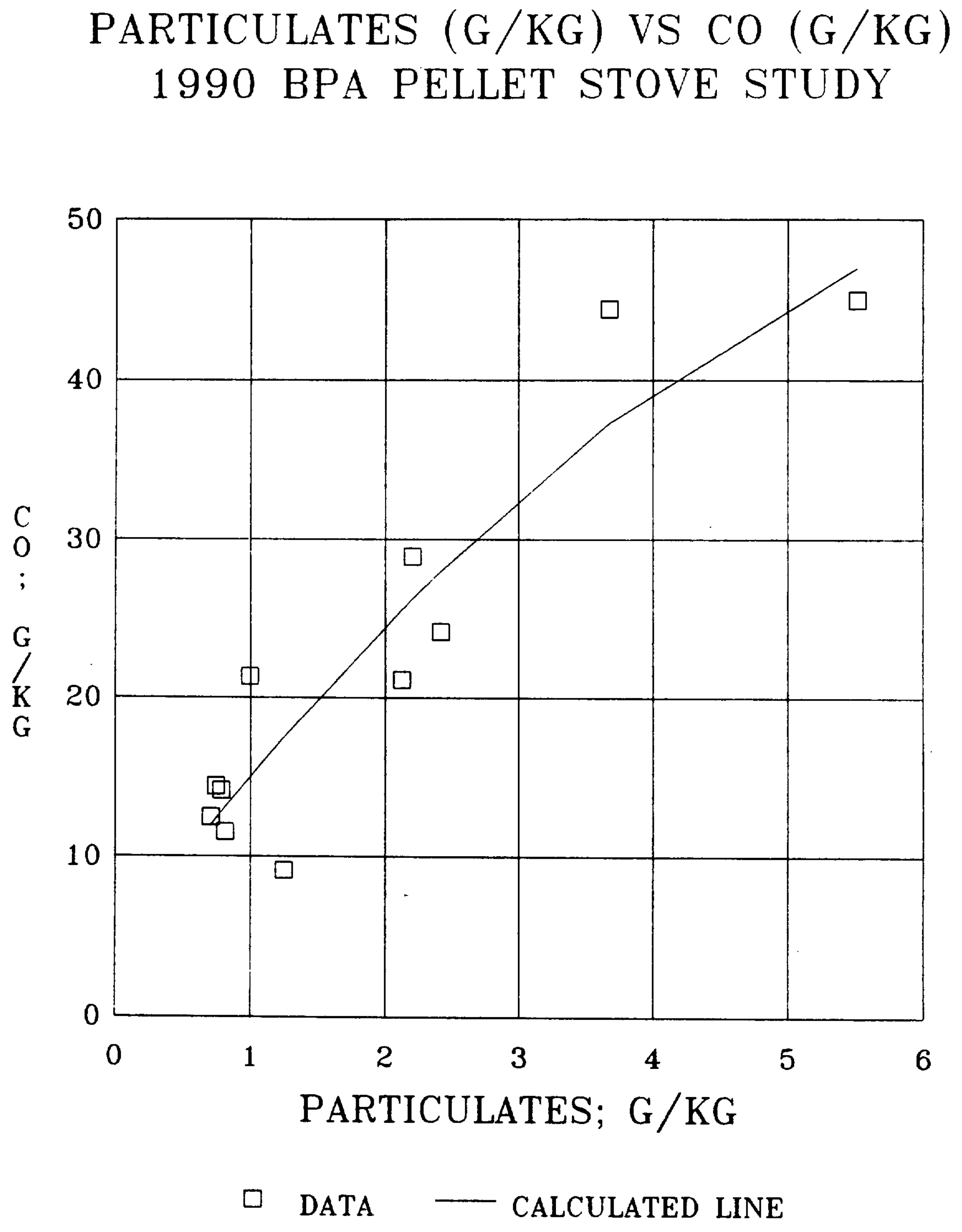
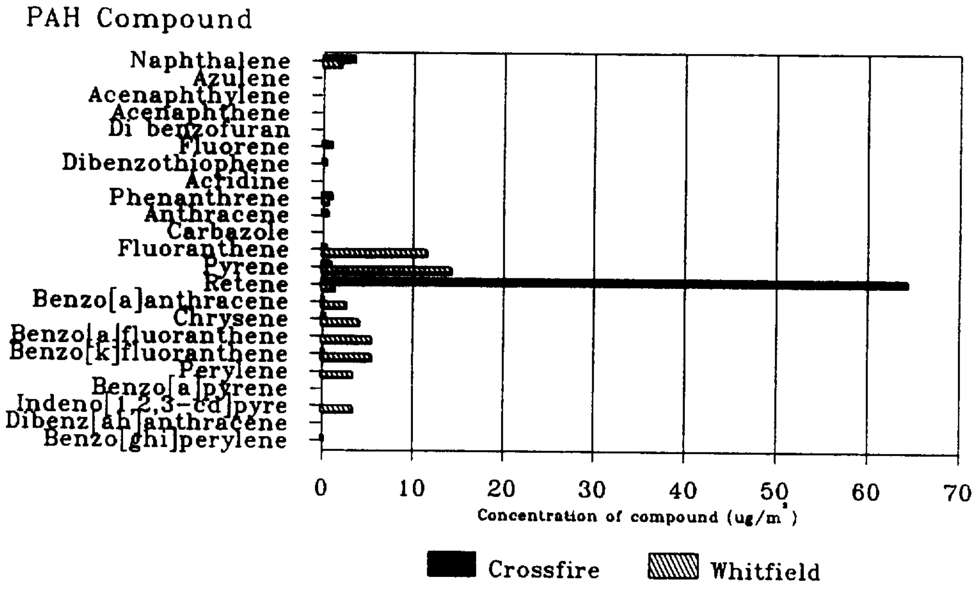

PARTICULATES (G/KG) VS CO (G/KG)
1990 BPA PELLET STOVE STUDY
CO; G/KG
0
10
20
30
40
50
0
1
2
3
4
5
6
PARTICULATES; G/KG
DATA
CALCULATED LINE

Figure 10

PAH Concentrations (ug/m^3); TSP filter from Crossfire and Whitfield Stoves.

(Thermal Desorption Analysis Method)

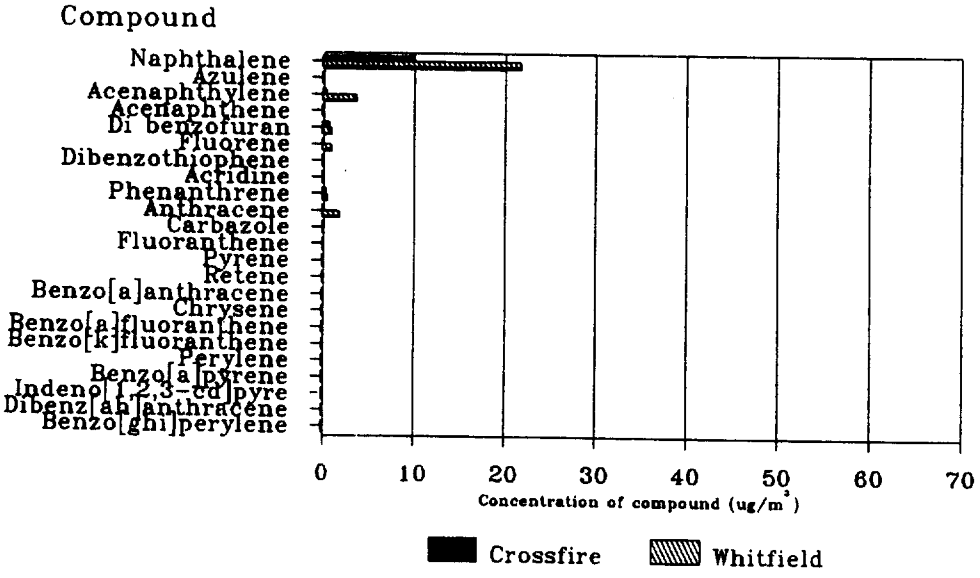


Values are averages of 2 tests

Figure 11a

PAH Concentrations (ug/m^3); XAD behind TSP filter

from Crossfire and Whitfield stoves.



(Thermal Desorption Analysis Method)

Figure 11b

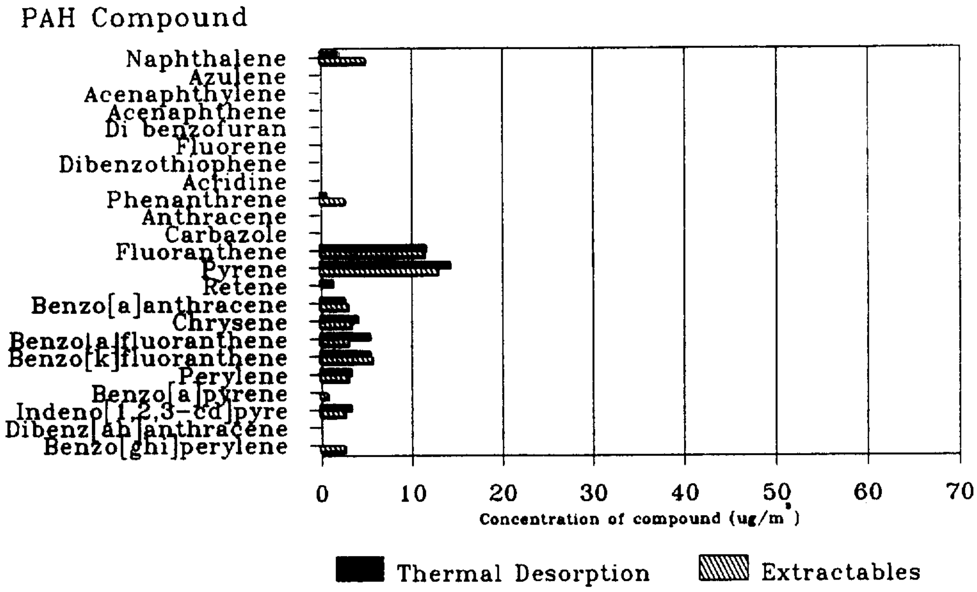

PAH Conc. (ug/m^3) from a Whitfield Stove
Comparison of Thermal Desorption VS. acid-base/neutral Extractables methods.

Figure 12a

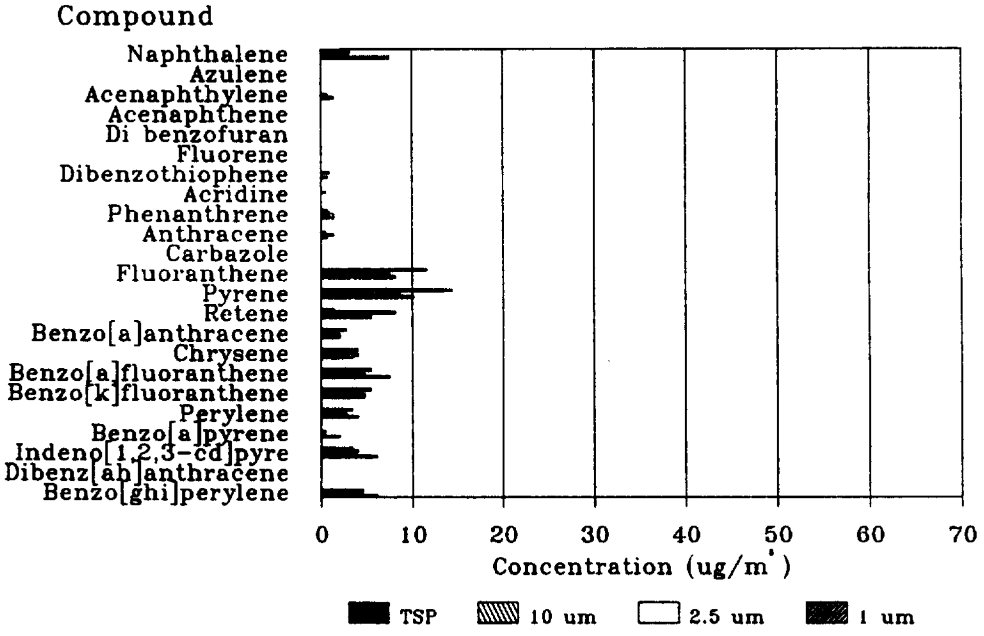

PAH Concentrations from a Whitfield:
A comparison by size fraction

Figure 12b

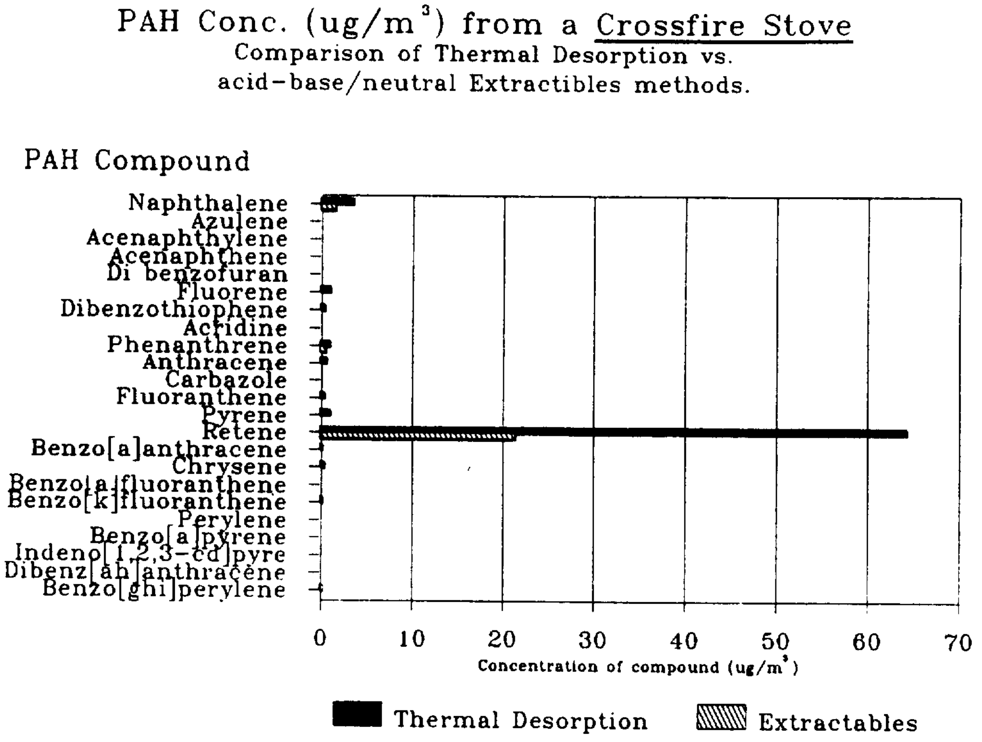


Figure 13a

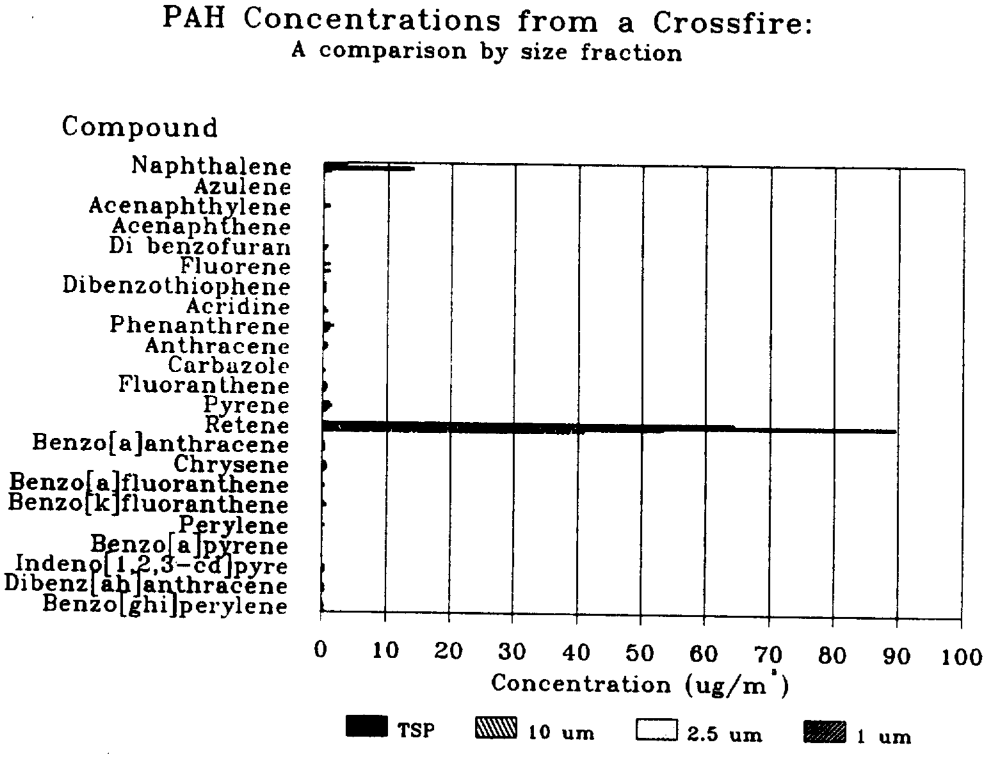


Figure 13b

the Crossfire stove, one discrepancy is present; concentrations of Retene do not correlate well (see Figure 13a).

Figure 11b indicates that there is little catch on the XAD that backs up the filter. Only the relatively light molecular weight naphthalene collected in significant quantities. This suggests that the filter is an effective PAH trap. Concentrations are quite similar for all particle size fractions (Figures 12b and 13b) suggesting that most PAH matter is less than 1 micron in size.

Trends in Burn Rate

The burn rate for all tests averaged 0.70 kg/hr. Differences between stoves were small, and the variation from test to test was insignificant (see Figure 14). These burn rates are considerably lower than those reported for cordwood stoves which usually average 1.0 to 1.1 kg/hr.

There is a tendency for particulate emissions to be lowest when burn rate is high (Figure 15) and when the stove is operated 100 percent of the time (Figure 16) rather than part-time.

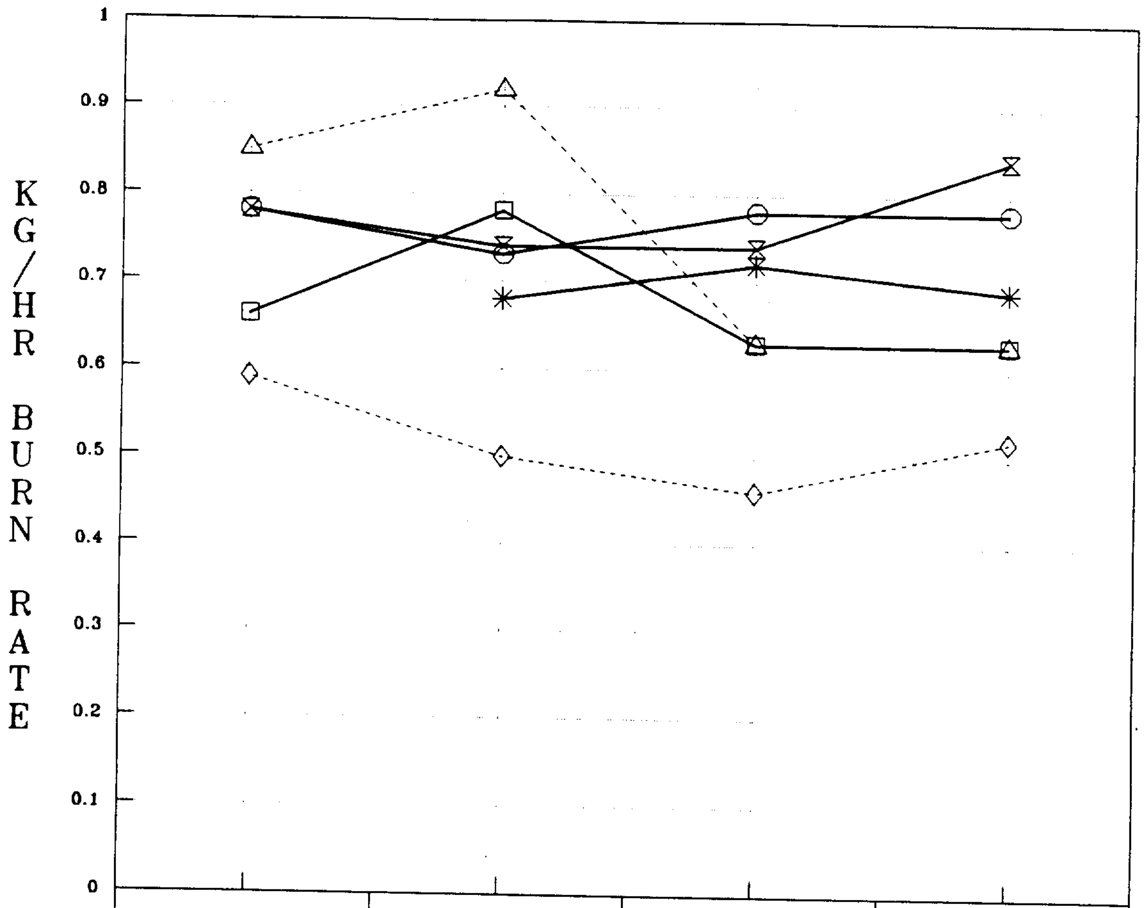
Efficiency and Heat Output

The average efficiency for all tests is 68.4%. The distribution of net efficiencies (see Figure 17) shows two populations of efficiencies, one in the range of 68-80% for constantly running stoves, and one in the range of 56-62% for stoves which experienced many shutdowns.

The average heat output was 8,747 Btu per hour. For all test runs the distribution of outputs was generally between 8,000 and 10,000 (see Figure 18). This is 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 may be the byproduct of the steadier output of pellet stoves compared to most cordwood stoves. This effect was quantified in the 1982 New York-Ohio "in-home" study[15] 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%.

There is no correlation between net heat output and degree days (Figure 19). This could be the result of homeowners tending to run the stoves on only one or two settings with few changes (see performance graphs in Appendix A).

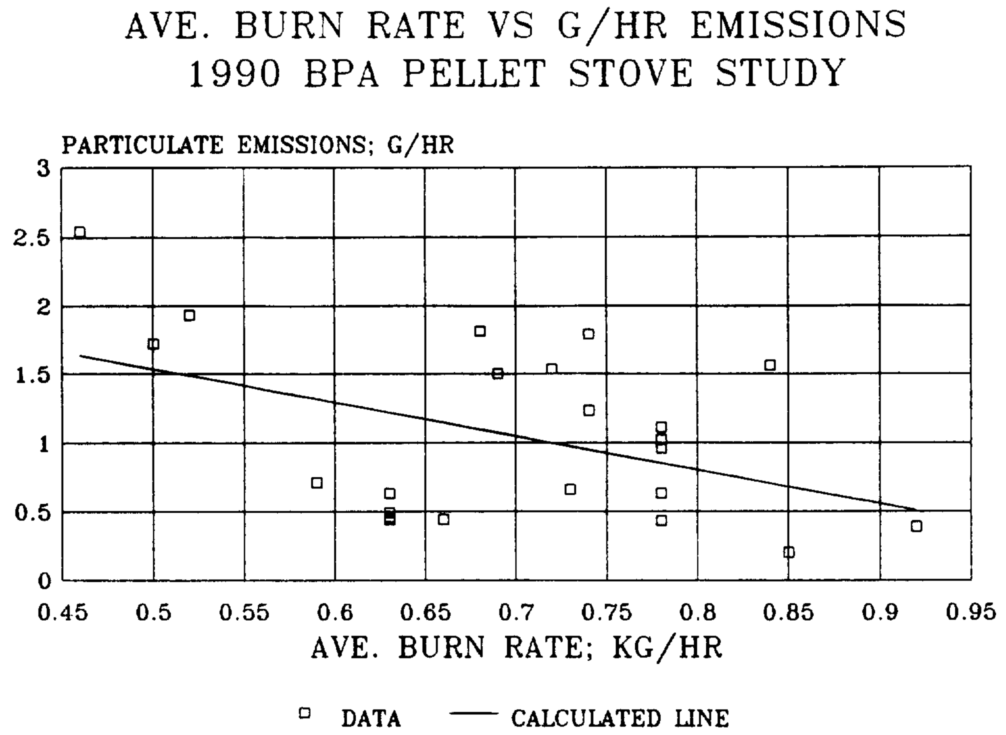
TRENDS: KG/HR BURN RATE
PELLET STOVES; 1990 "IN-HOME" TESTS



	RUN 1	RUN 2	RUN 3	RUN 4
HOUSE 1	0.85	0.92	0.63	0.63
HOUSE 2	0.78	0.74	0.74	0.84
HOUSE 3		0.68	0.72	0.69
HOUSE 4	0.66	0.78	0.63	0.63
HOUSE 5	0.78	0.73	0.78	0.78
HOUSE 6	0.59	0.5	0.46	0.52

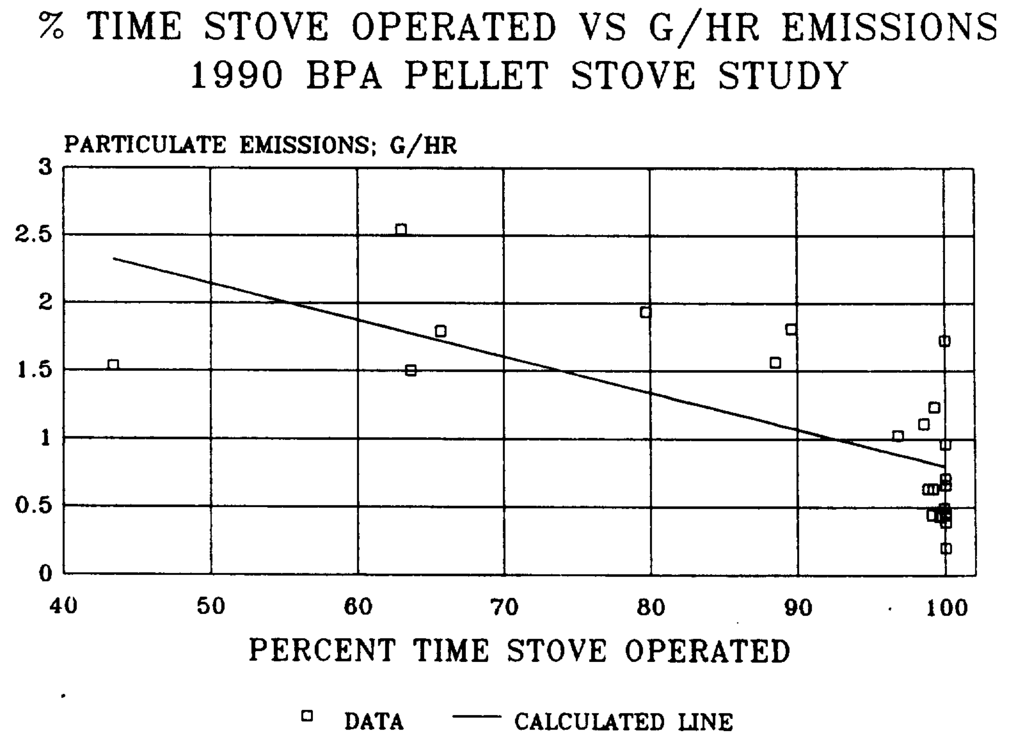
WHITFIELD= SOLID LINES
CROSSFIRE= DASHED LINES

Figure 14



AVE. BURN RATE VS G/HR EMISSIONS
1990 BPA PELLET STOVE STUDY

Figure 15



% TIME STOVE OPERATED VS G/HR EMISSIONS
1990 BPA PELLET STOVE STUDY

Figure 16

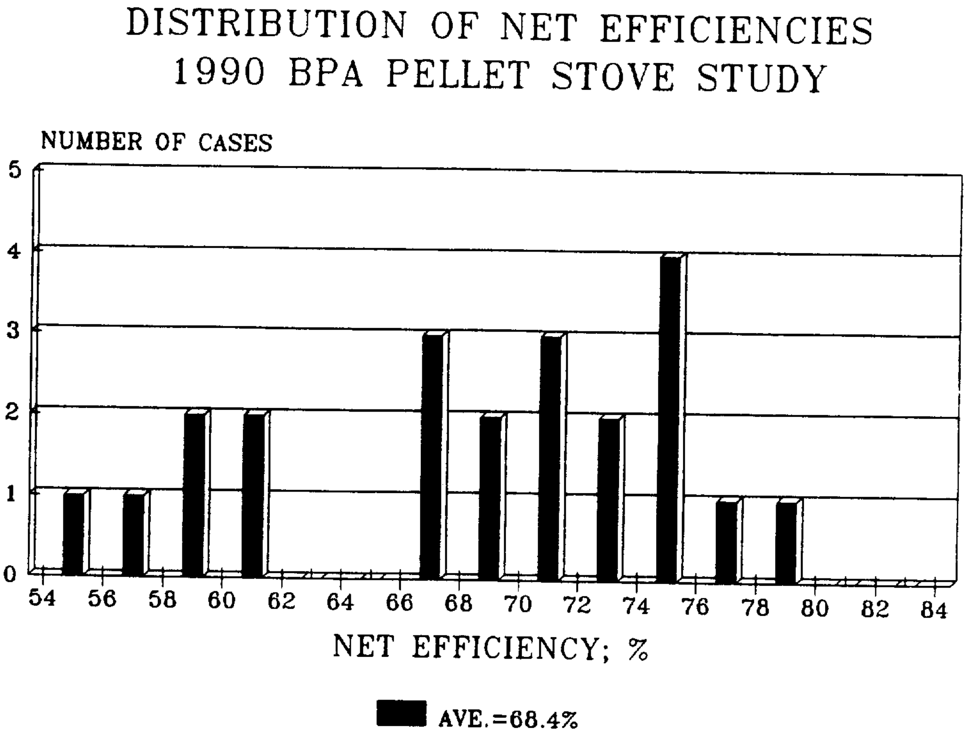


Figure 17

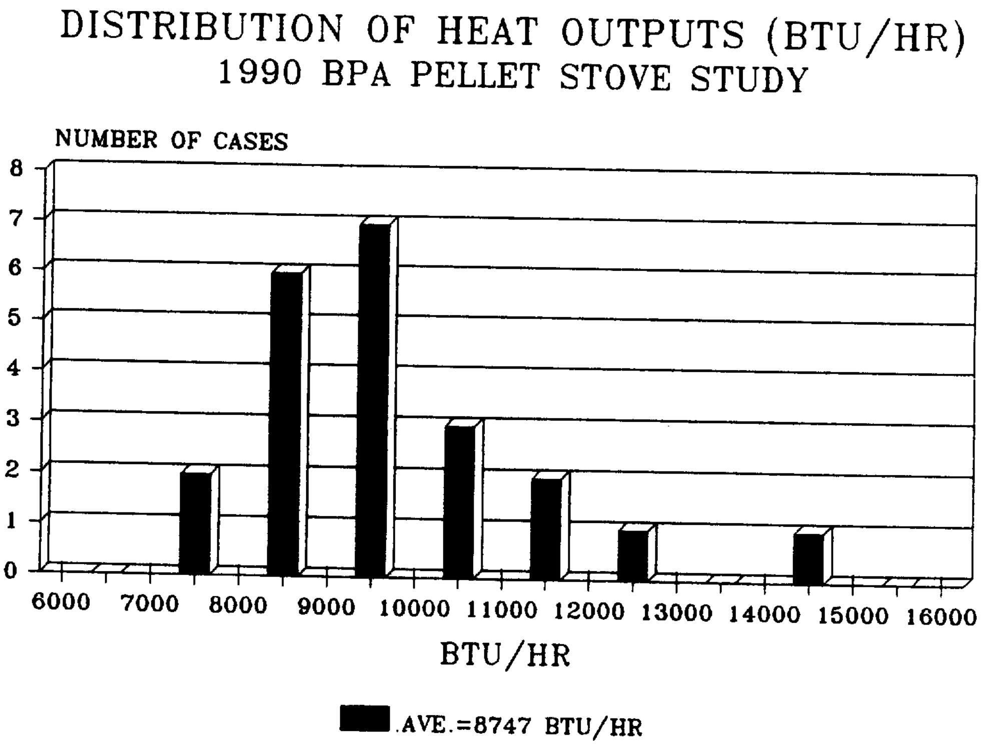


Figure 18

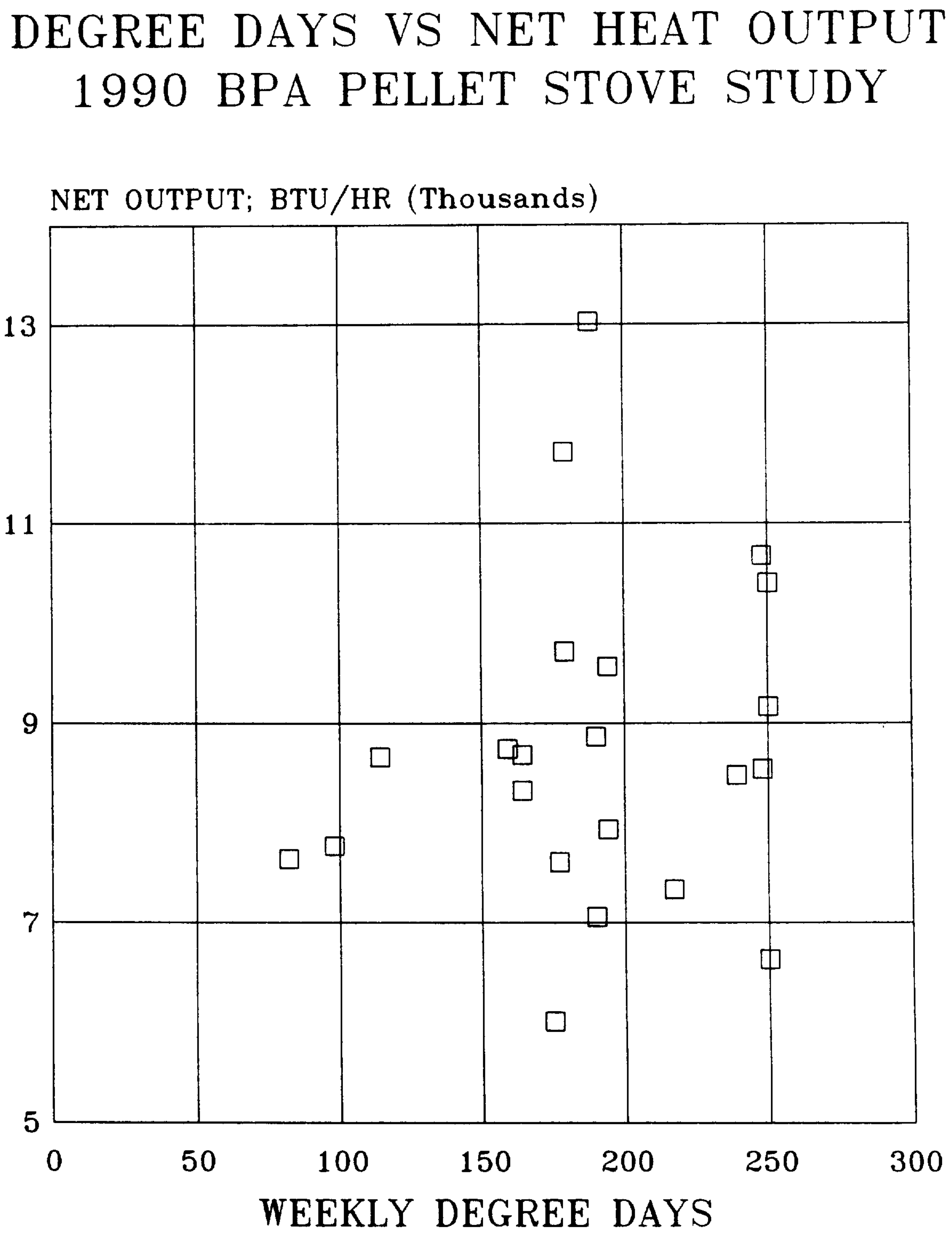

DEGREE DAYS VS NET HEAT OUTPUT
1990 BPA PELLET STOVE STUDY
NET OUTPUT; BTU/HR (Thousands)
13
11
9
7
5
0
50
100
150
200
250
300
WEEKLY DEGREE DAYS

Figure 19

Conclusions

Emissions of the pellet stoves investigated in this study were very low, averaging about 1 g/hr, or about 75% lower than the best performing high technology cordwood stoves. However, this study reports on only six stoves representing two stove models of certified pellet stoves. There are a growing number of pellet stoves exempt from certification that have not been evaluated, and drawing a conclusion on existing pellet stove technologies as a group is clearly premature at this time.

The variation in particulate emissions is low compared to cordwood stoves. Existing variation appears to be more affected by how the stove was operated than the stove model. In the current tests, the stove with the highest and lowest emissions was the Crossfire.

The results show that altitude appears to have no effect on particulate emissions. However, only a small stove sample was evaluated in this study.

Emissions increased after the first test run and then remained relatively constant. The increase was apparently caused by homeowners turning stoves off and on as the study progressed, especially in Homes #2 and 6.

PAH and CO emissions are low. The pellet stoves tested in this project demonstrate nearly complete combustion. Additionally, the relationship between CO and particulate is close enough that CO could be used as a surrogate for particulate in future pellet stove studies.

The pre-test Quality Assurance evaluation demonstrated that the sampling system has both excellent comparability with EPA Method 5G and excellent precision for evaluating pellet stove performance.

Net thermal efficiency averaged 68%. This is somewhat lower than anticipated. However, when the stoves are run for longer periods of time, which the system is essentially designed to do, then the efficiencies are in the 70-80% range.

Heat outputs were considerably lower than those reported for field cordwood studies.

Only two of the six stoves used in this study are new. The four that have been in homes for over a year did not show higher emissions. In fact, the stove with the highest emissions was a new stove. Durability, however, could become an issue with pellet stoves in the long run because the more complex design could be more prone to breakdown. Component durability 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 stoves and high efficiency catalytic and secondary burn stoves. 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 cordwood stove heating. Stoves in this study were installed as follows:

Home 1 - December 1988
Home 2 - February 1989
Home 3 - February 1990
Home 4 - September 1989
Home 5 - January 1990

Of the pellet stoves evaluated in this study, only two stoves had one heating season prior to the study. The performance of these stoves should be followed to evaluate deterioration potential.

Not all pellet technologies currently available are likely to perform as well as the two evaluated in this study. The stove selection criteria for this study were to pick two stoves, one representing simple pellet stove technology and one representing complex pellet stove technology. Both stoves had to be EPA 1990 certified. This stove sample possibly represents the best of the pellet stove market, and in terms of emissions these stoves may not be representative of all pellet stove technology. Many of the stoves currently being sold are exempt models because they operate highly dilute and are therefore exempt from the certification process. Future work should take into consideration not only the other certified pellet stoves, but also exempt stoves 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.

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 completing 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 very considerably.

An analysis of the security of the future supply of pellets should be conducted. For example, what effect might competing uses for sawdust have on pellet supply and prices?

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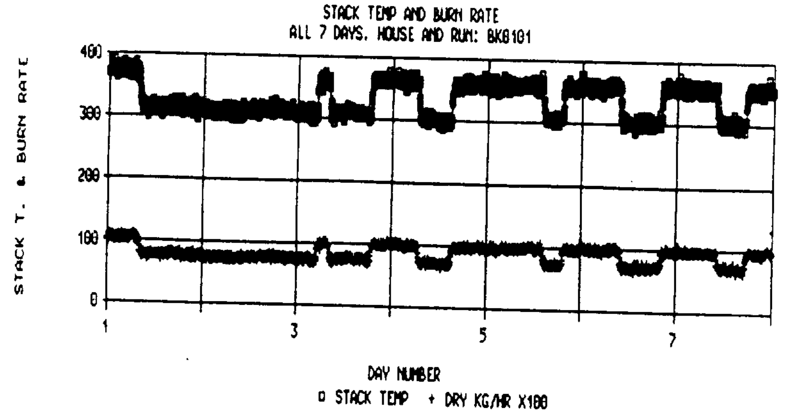
Appendix A

Graphs of stove performance and
Photographs of stoves and stove installations

Contents

Home 1; Crossfire
Stack Temperature and Burn Rate

Run 1



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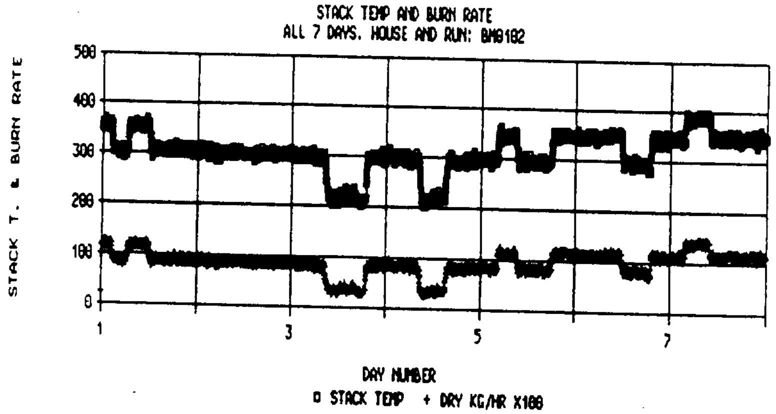

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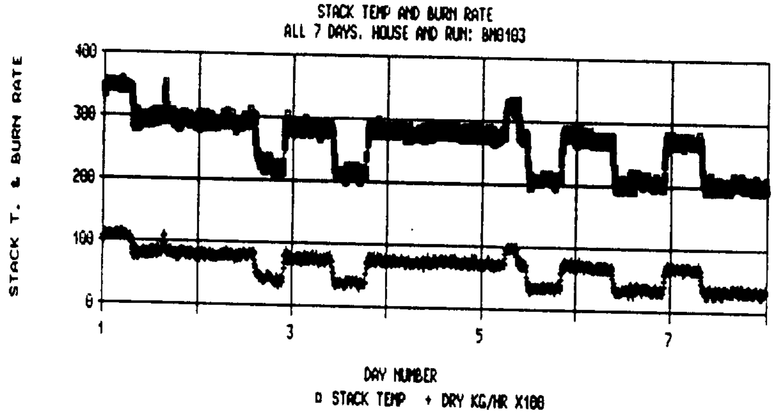

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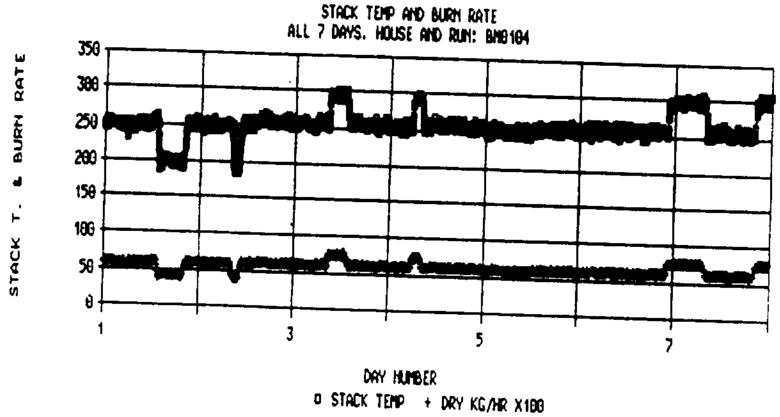
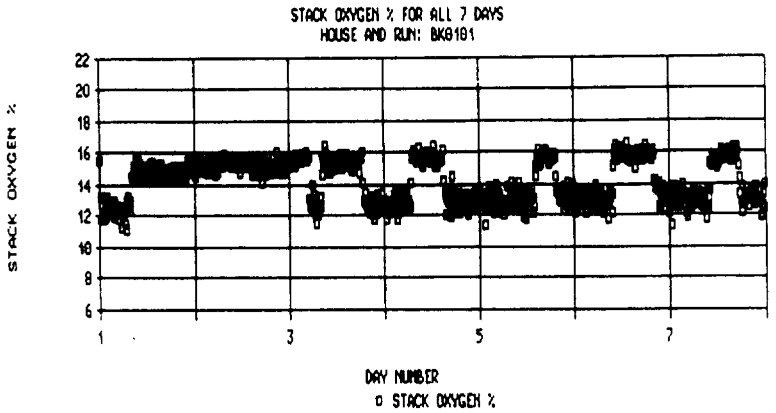


Home 1; Crossfire
Stack Oxygen

Run 1



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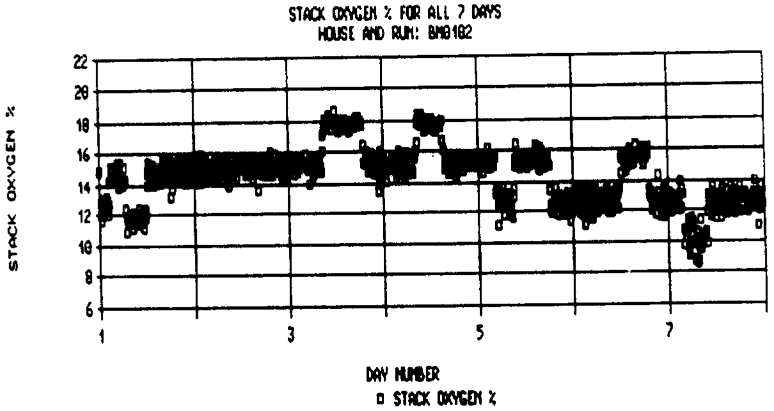

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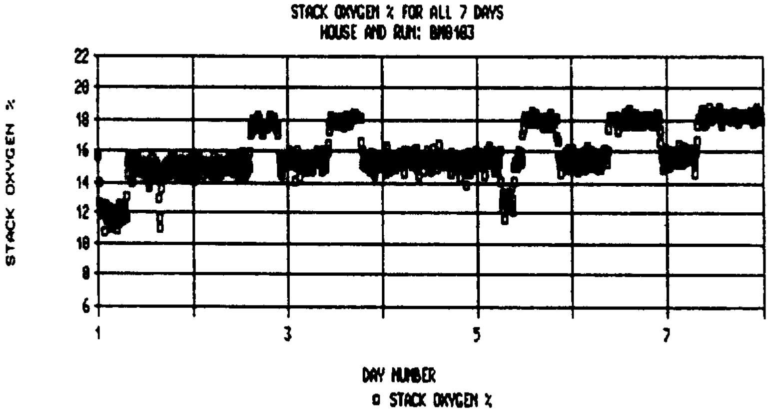

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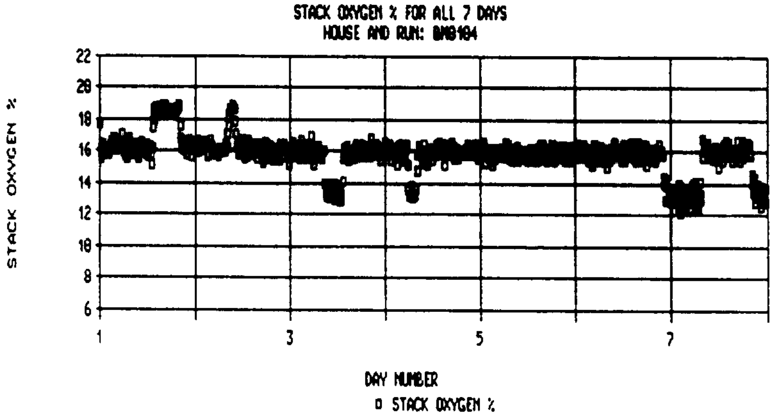
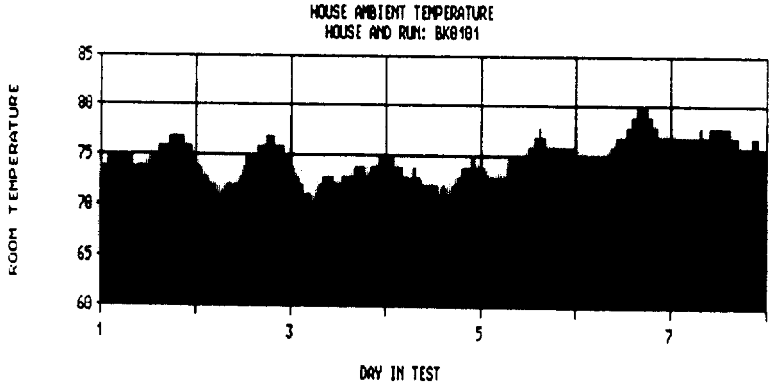


Home 1; Crossfire
Ambient Temperature

Run 1



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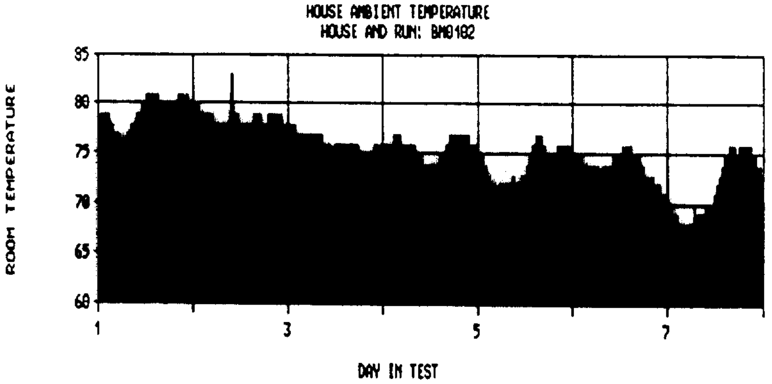

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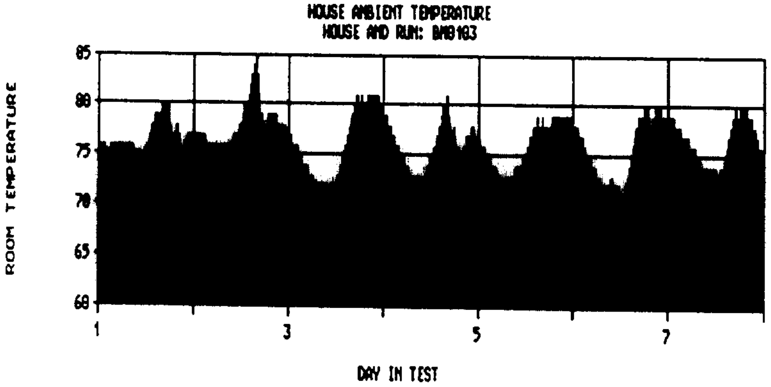

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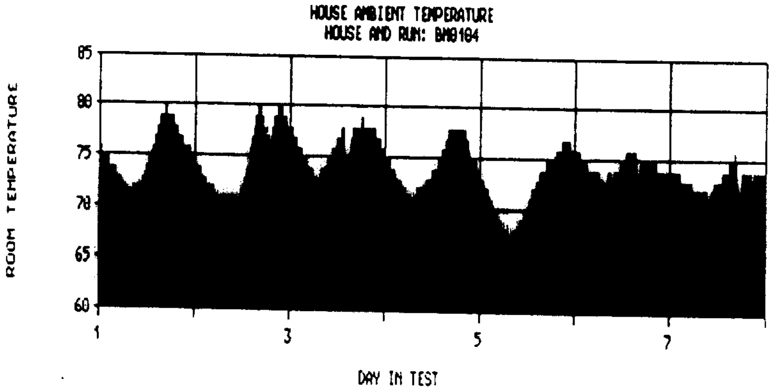
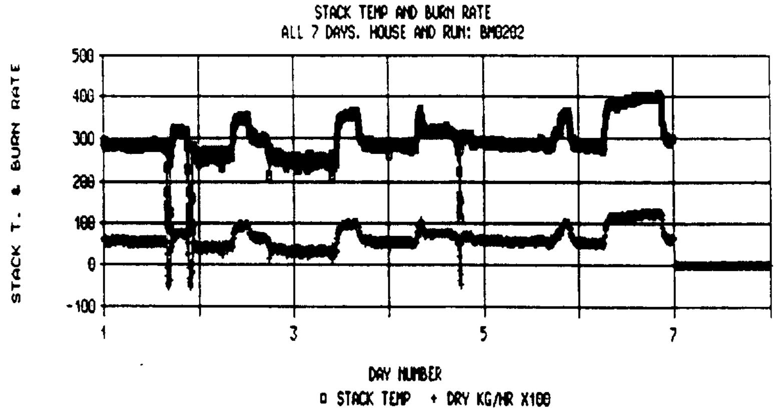


Home 2; Whitfield
Stack Temperature and Burn Rate

Run 1

Run 2



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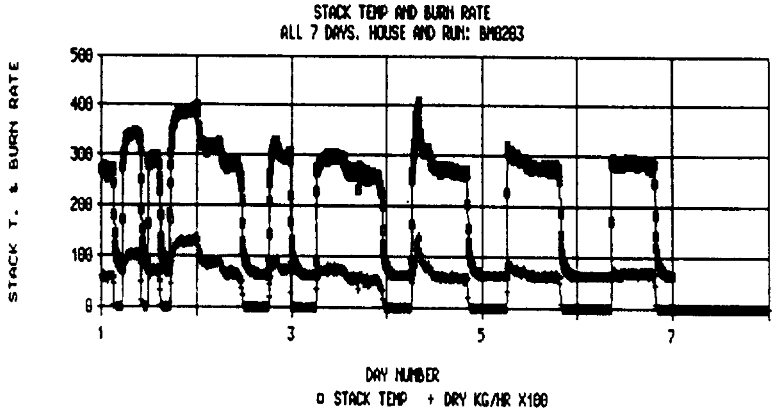

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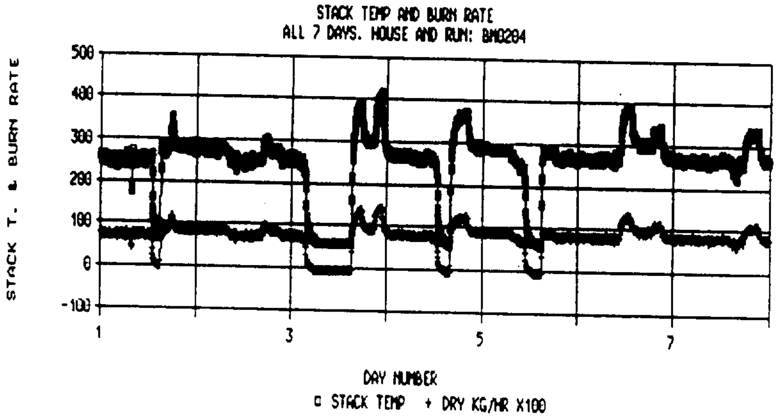
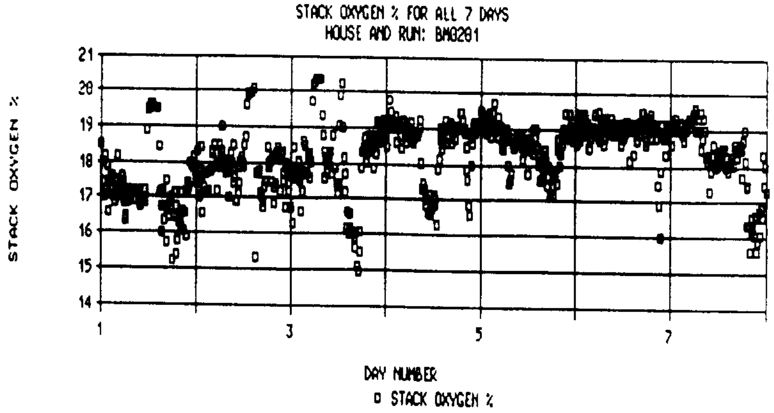


Home 2; Whitfield
Stack Oxygen

Run 1



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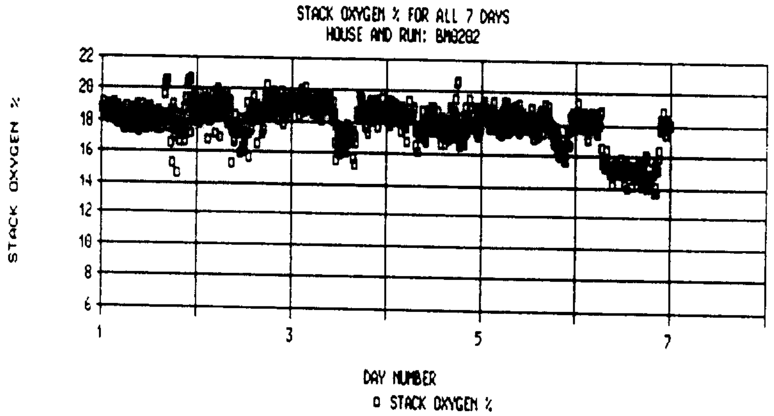

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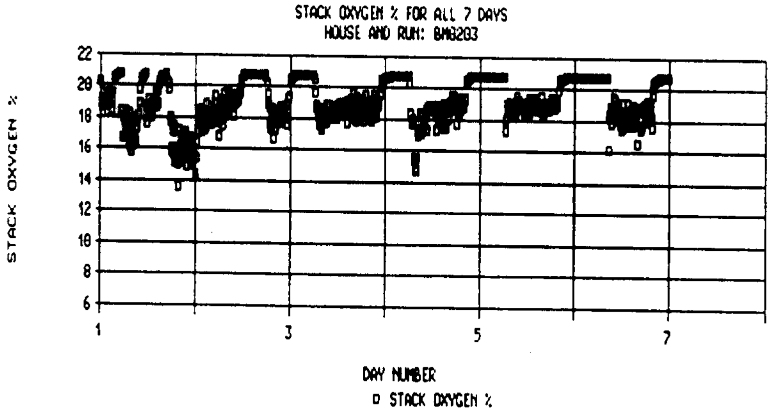

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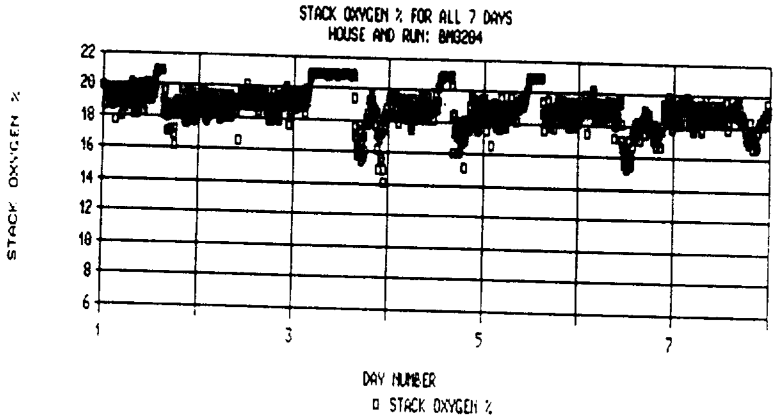
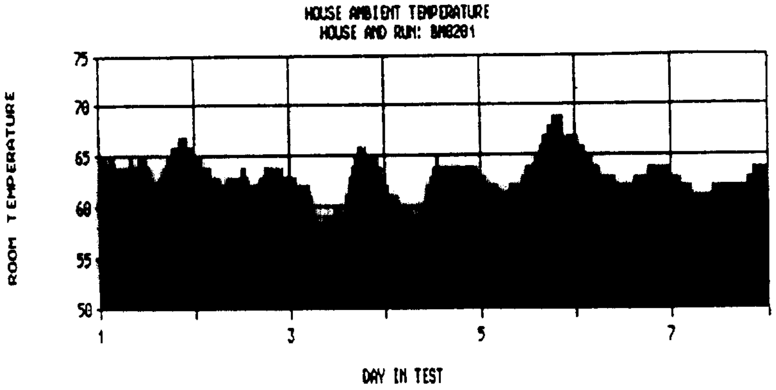


Home 2; Whitfield
Ambient Temperature

Run 1



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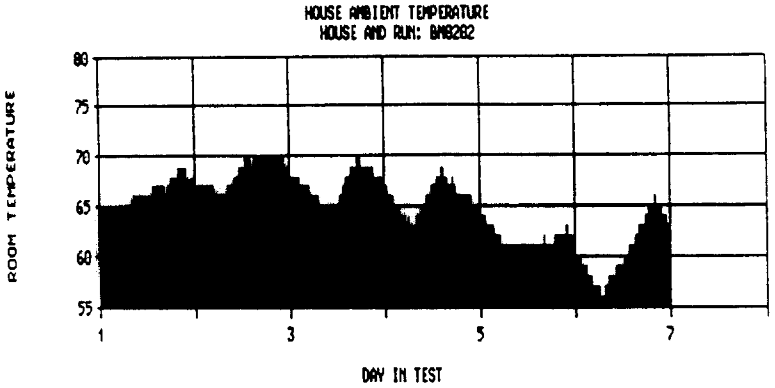

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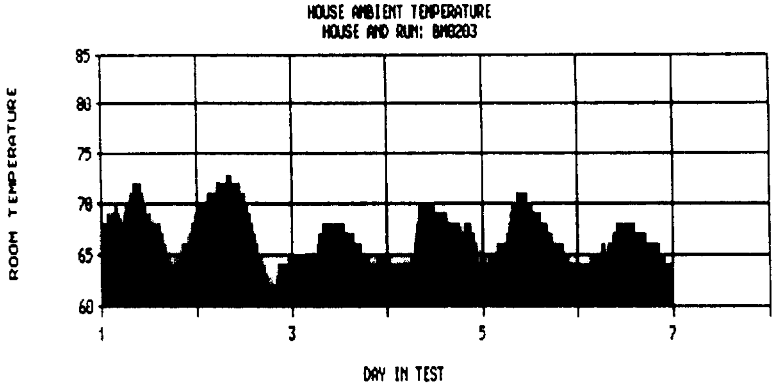

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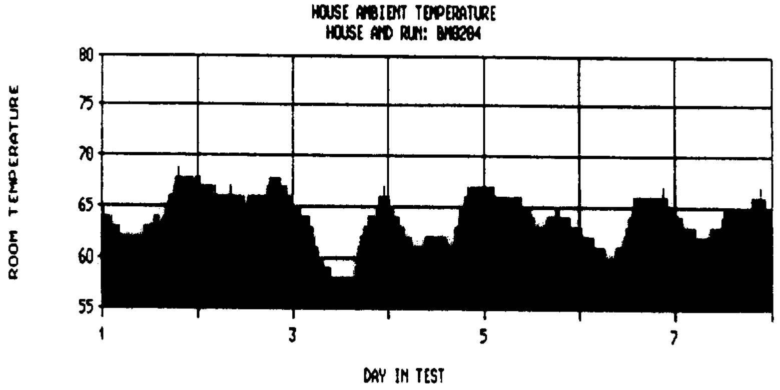
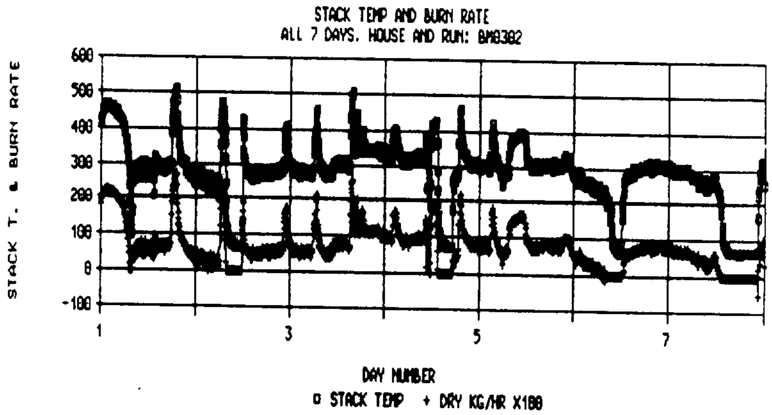


Home 3; Whitfield
Stack Temperature and Burn Rate

Run 1

Run 2



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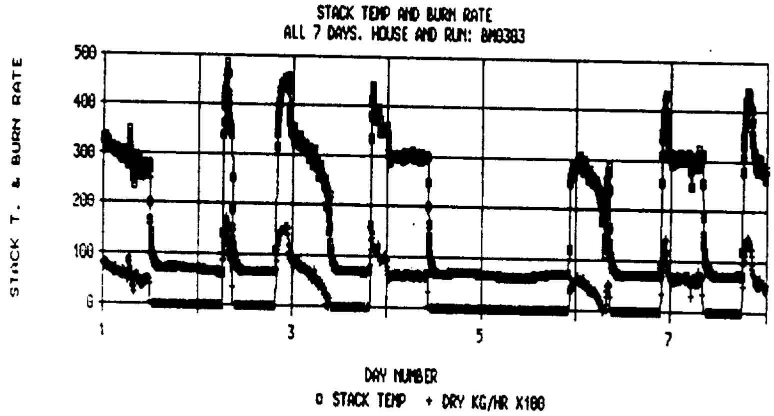

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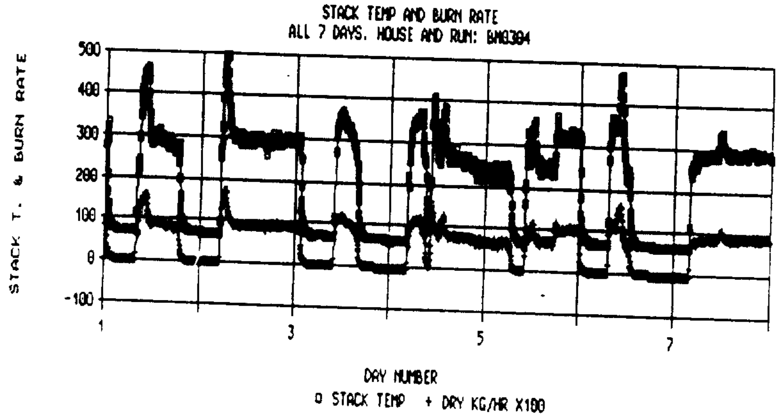
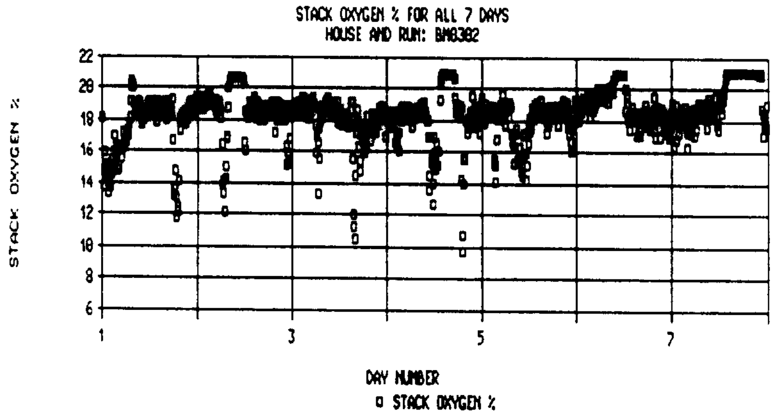


Home 3; Whitfield
Stack Oxygen

Run 1

Run 2



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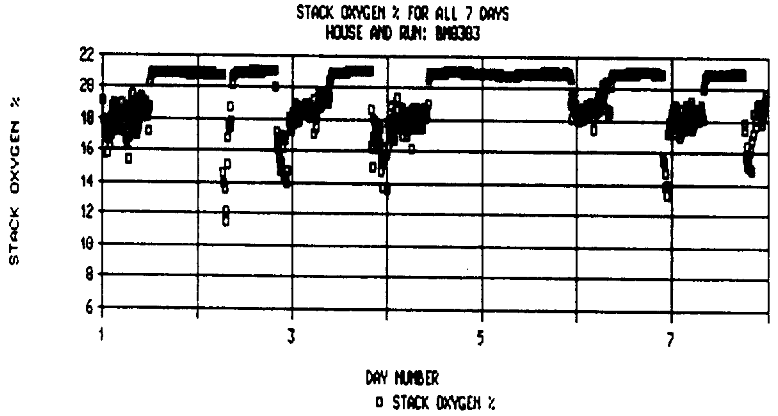

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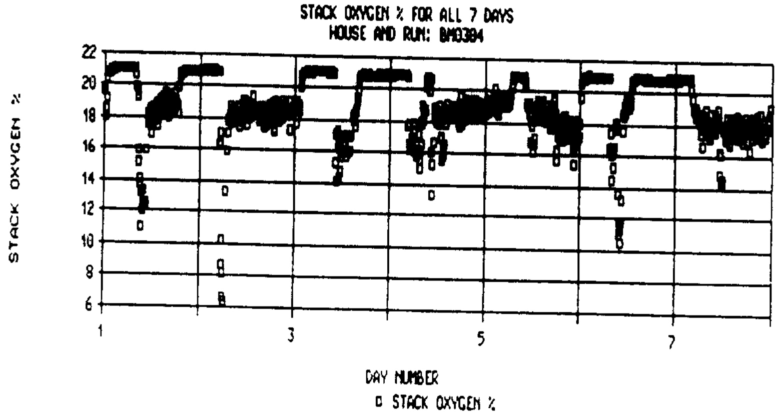
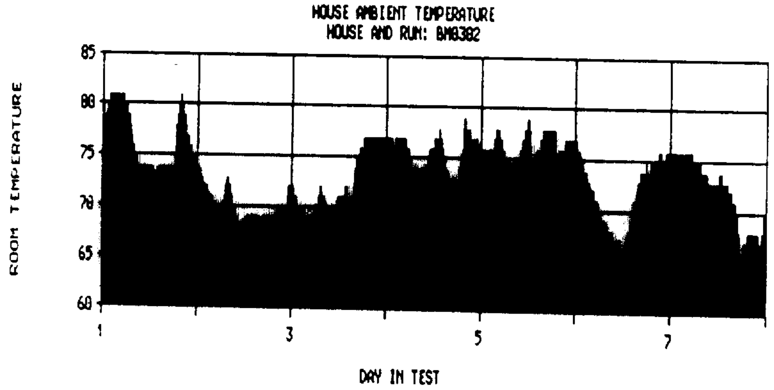


Home 3; Whitfield
Ambient Temperature

Run 1

Run 2



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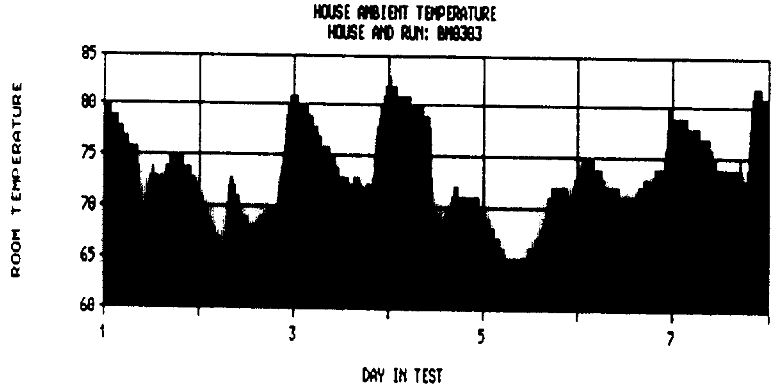

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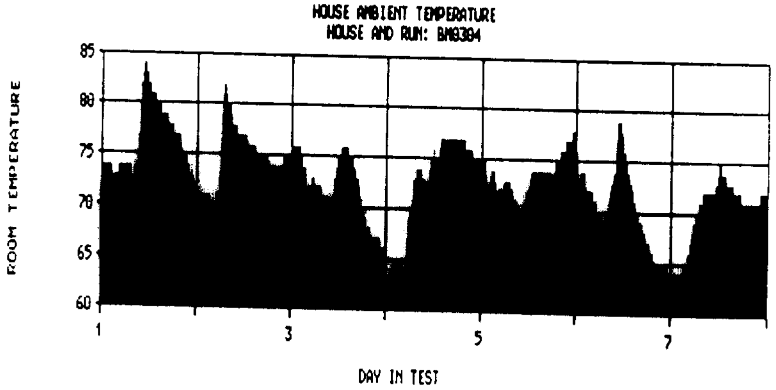
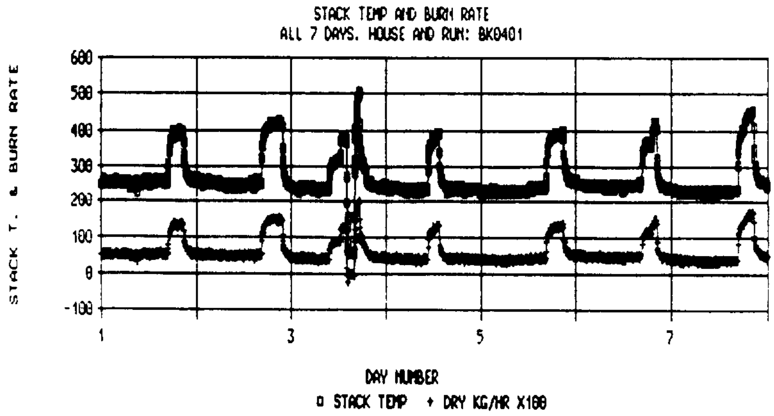


Home 4; Whitfield
Stack Temperature and Burn Rate

Run 1



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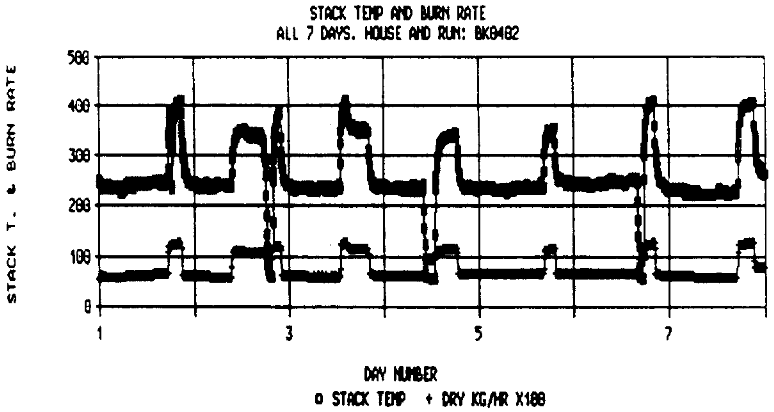

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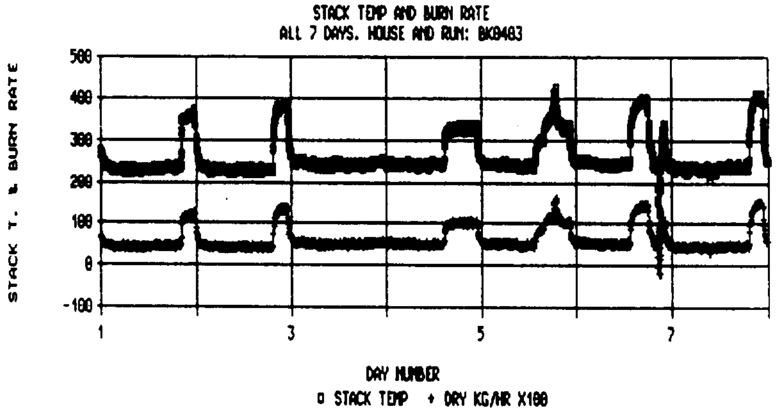

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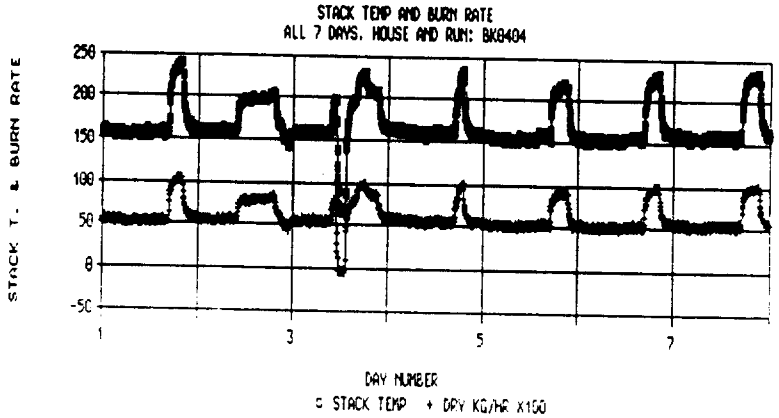
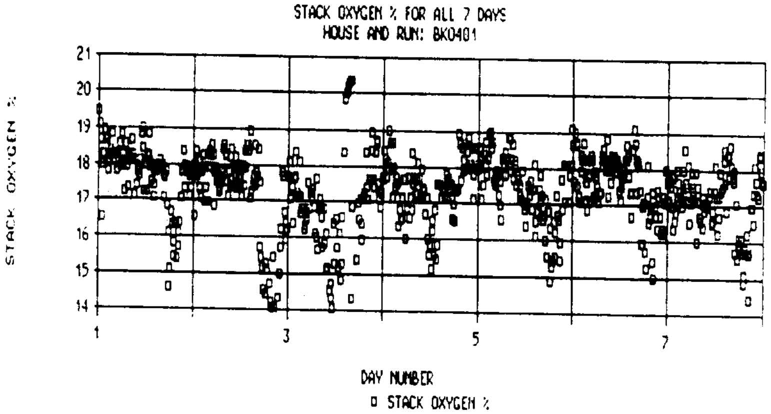


Home 4; Whitfield
Stack Oxygen

Run 1



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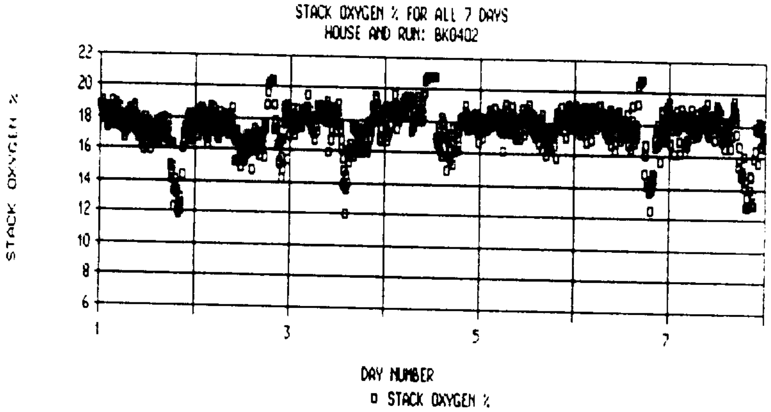

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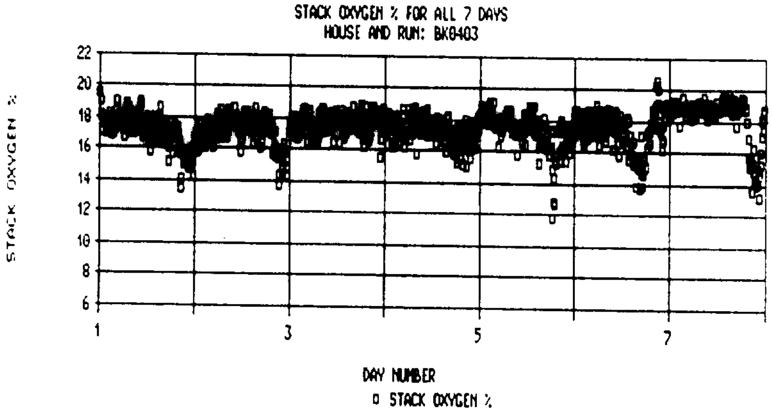

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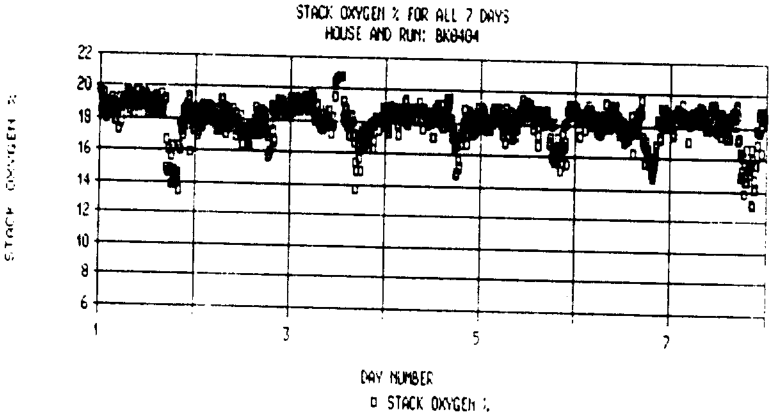

Home 4; Whitfield
Ambient Temperature

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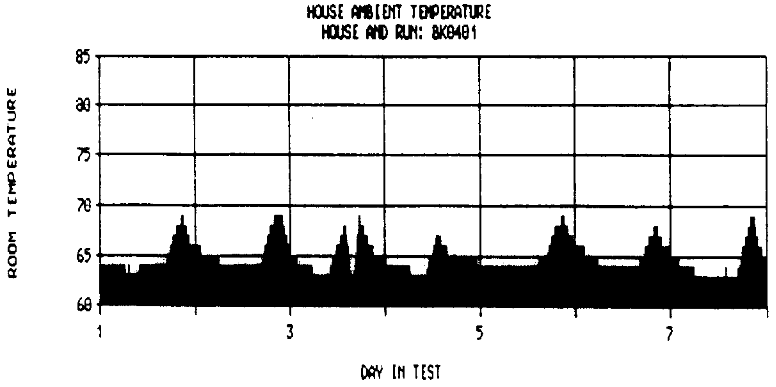

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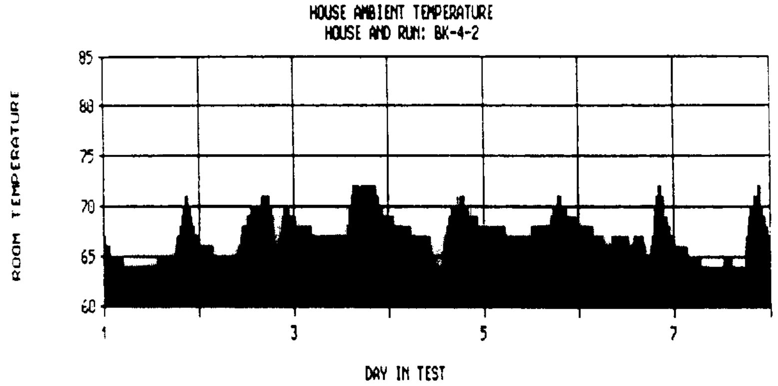

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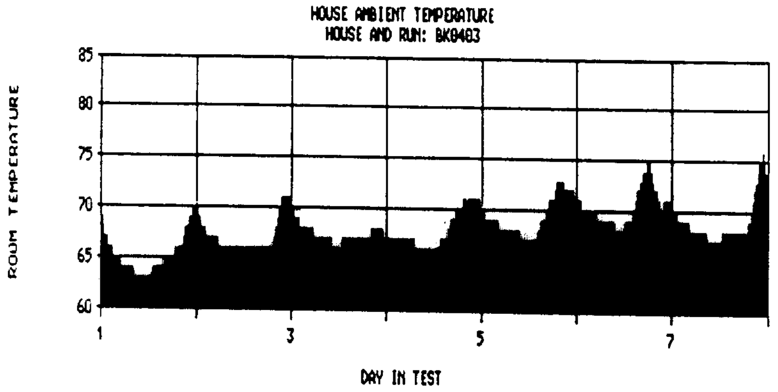

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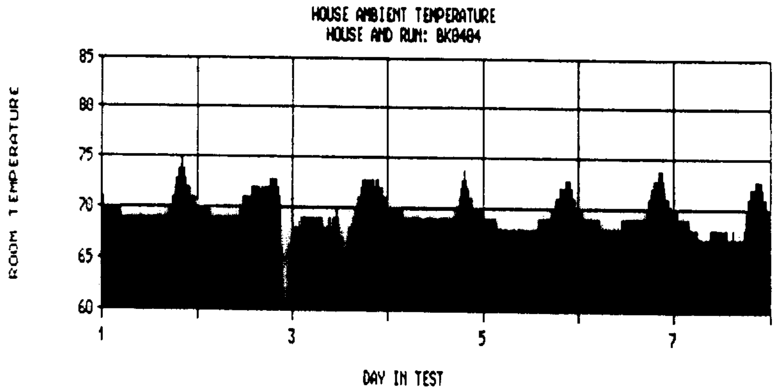
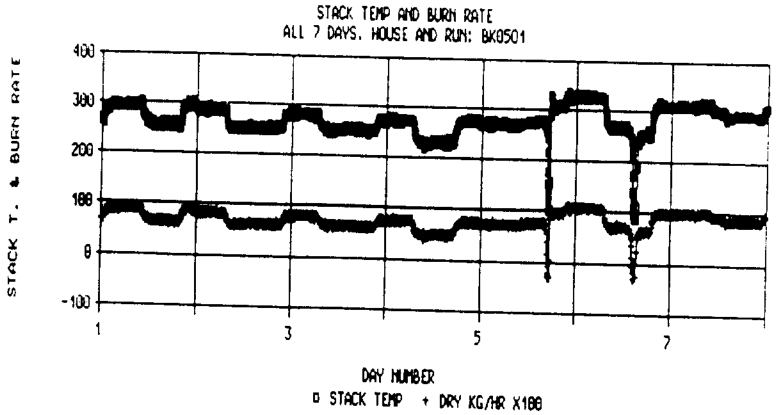


Home 5; Whitfield
Stack Temperature and Burn Rate

Run 1



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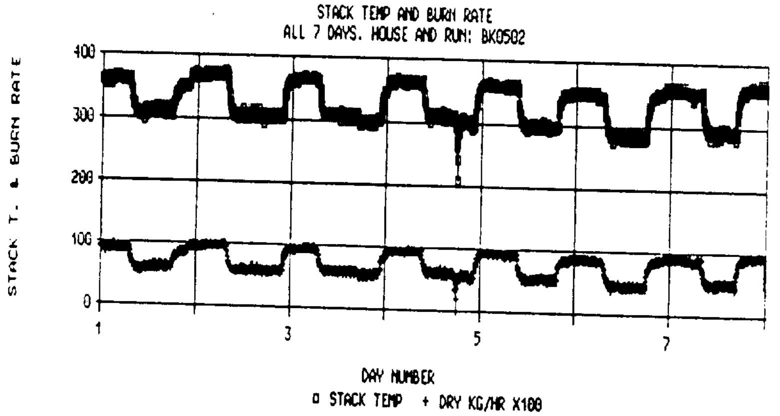

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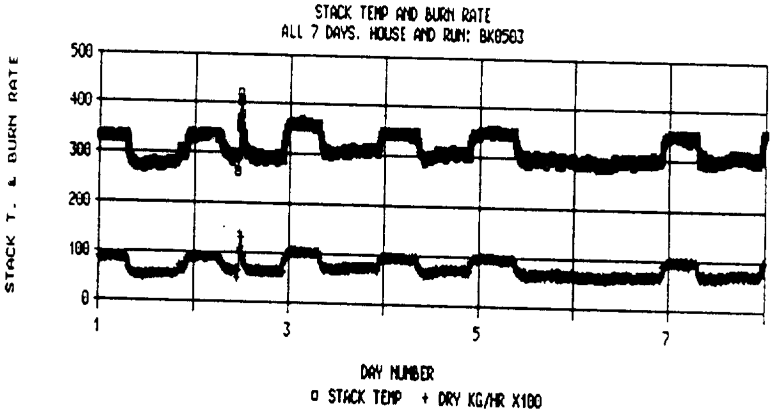

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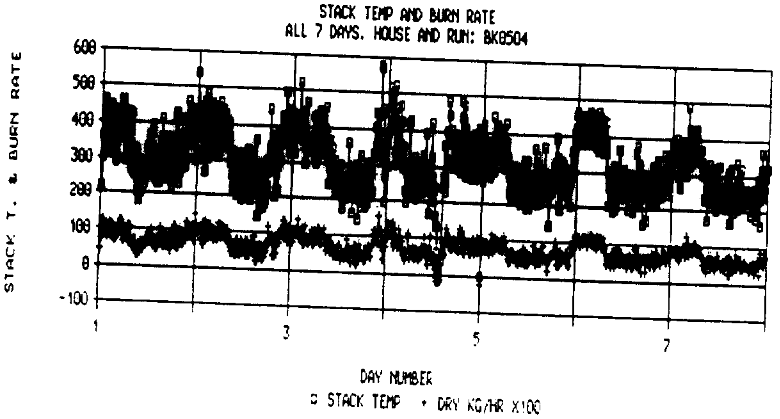
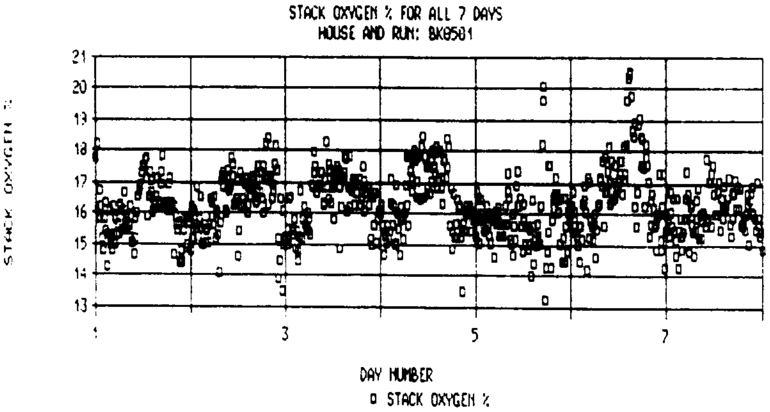


Home 5; Whitfield
Stack Oxygen

Run 1



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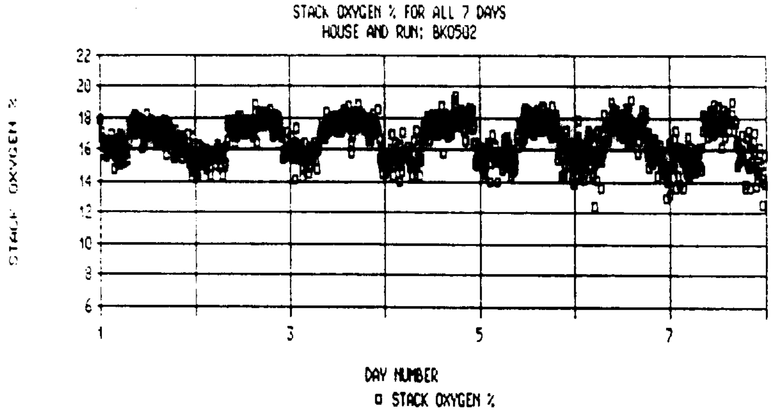

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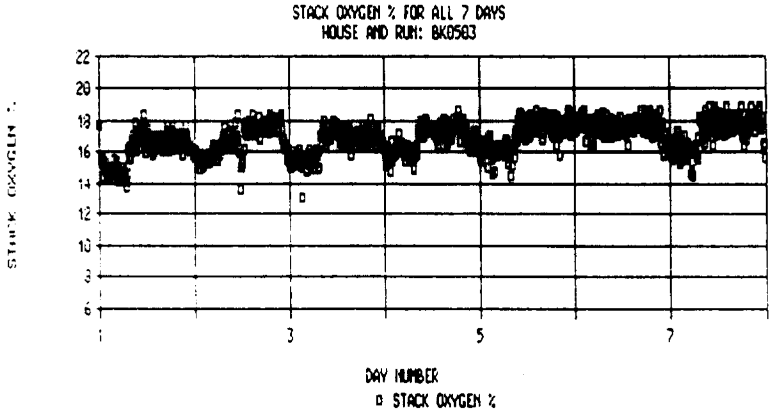

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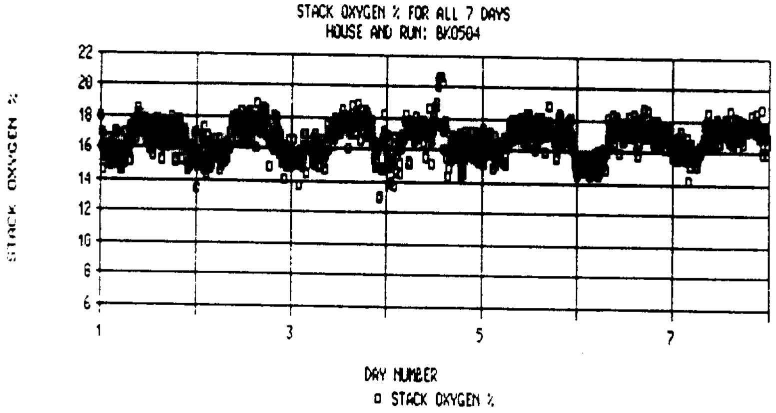
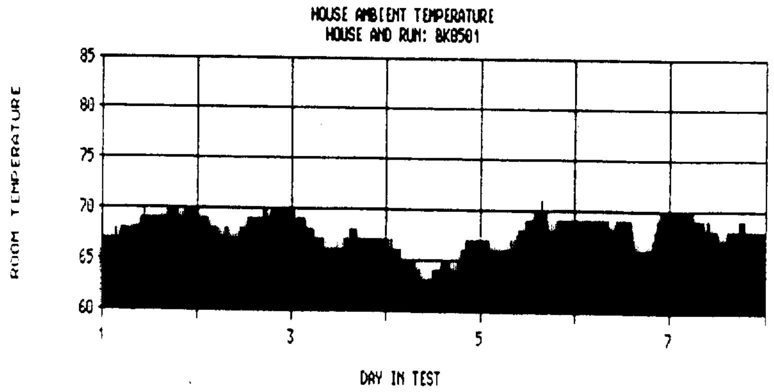


Home 5; Whitfield
Ambient Temperature

Run 1



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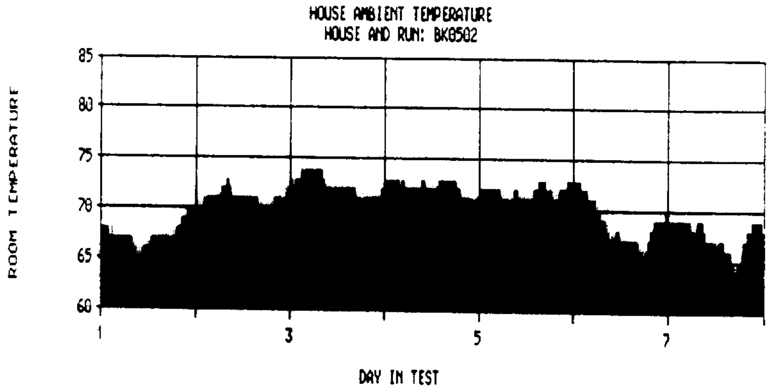

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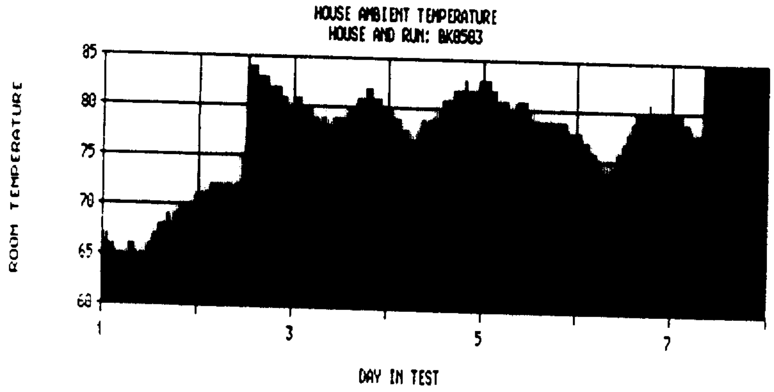

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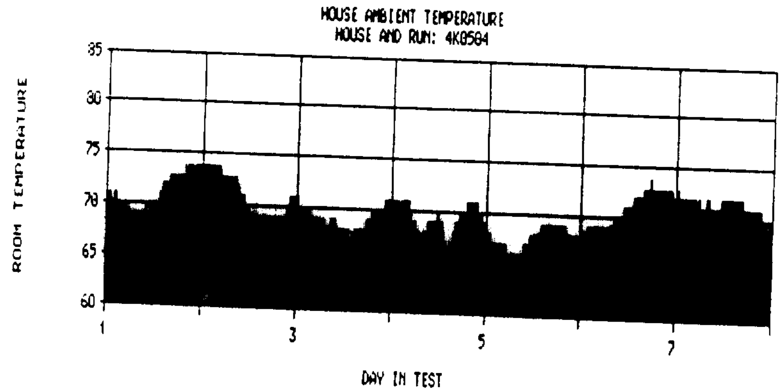
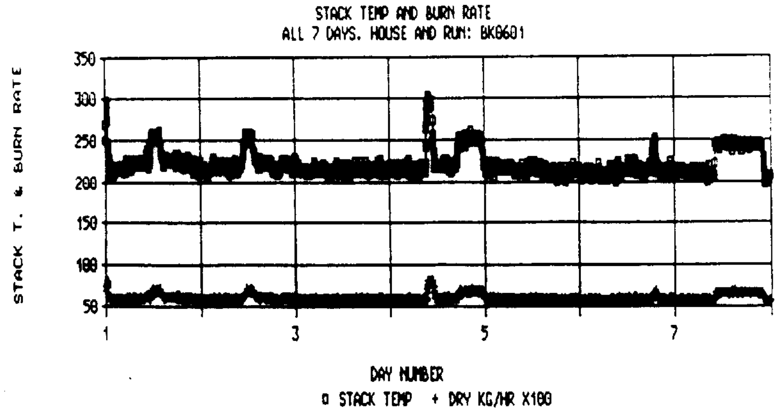


Home 6; Crossfire
Stack Temperature and Burn Rate

Run 1



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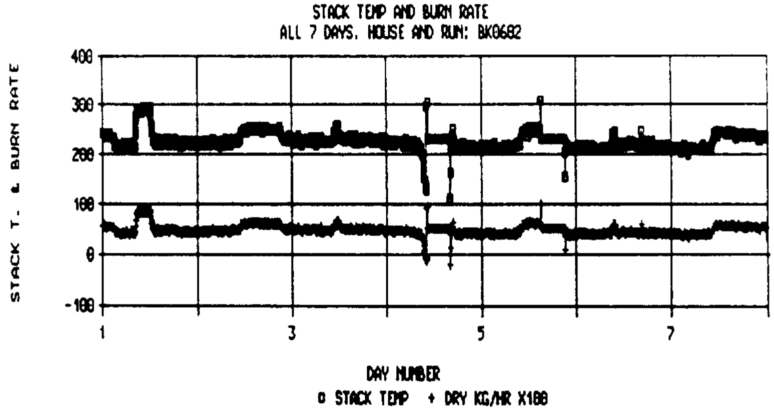

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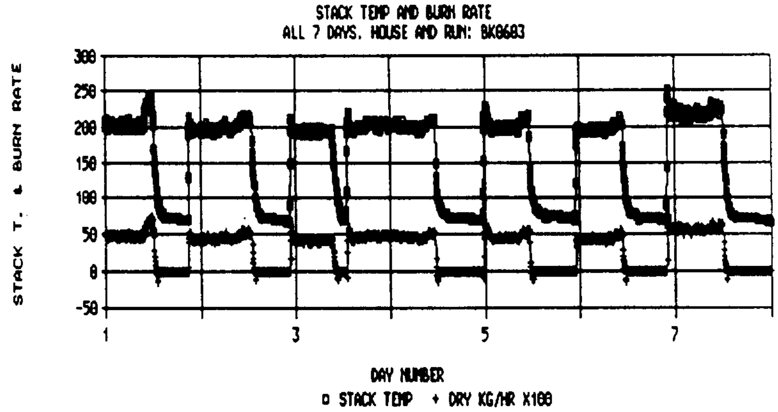

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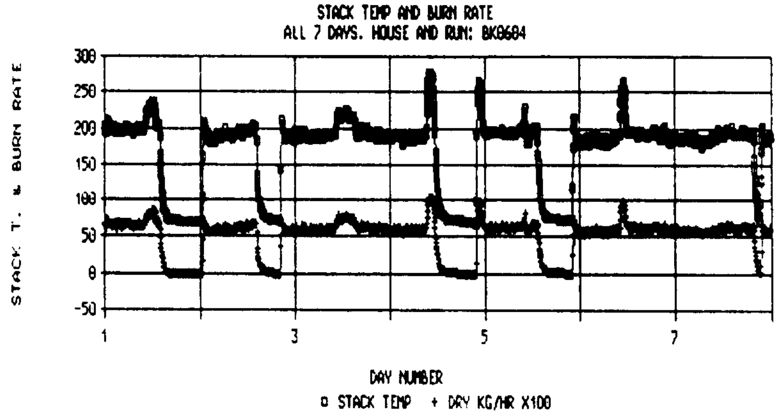
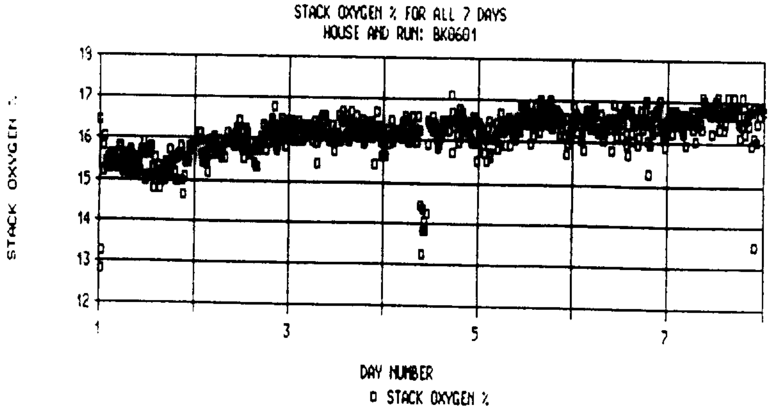
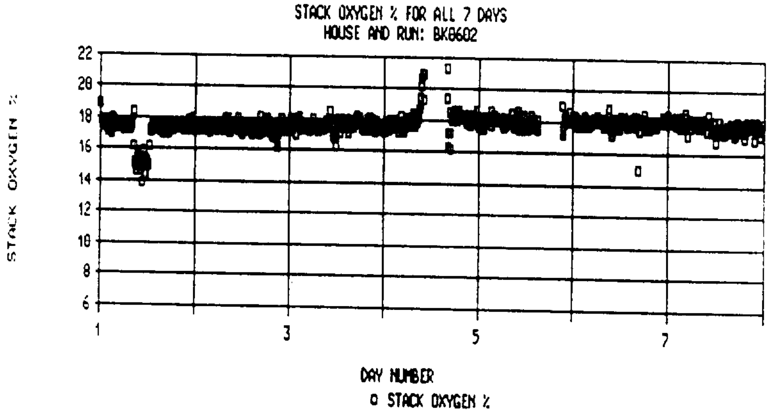


Home 6; Crossfire
Stack Oxygen

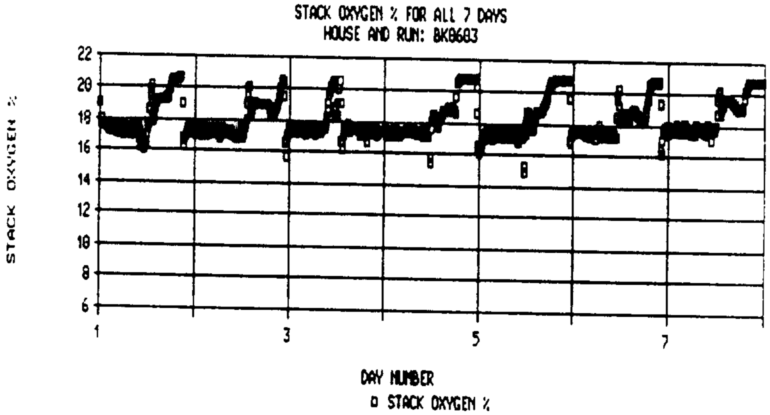
Run 1


STACK OXYGEN % FOR ALL 7 DAYS
HOUSE AND RUN: BK0601

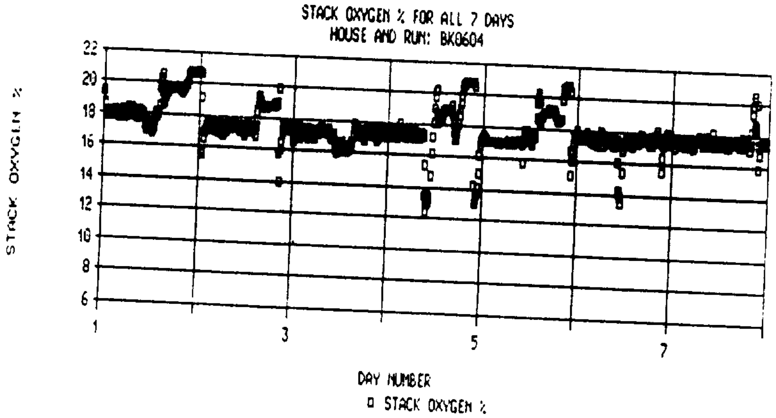
Run 2


STACK OXYGEN % FOR ALL 7 DAYS
HOUSE AND RUN: BK0602

Run 3

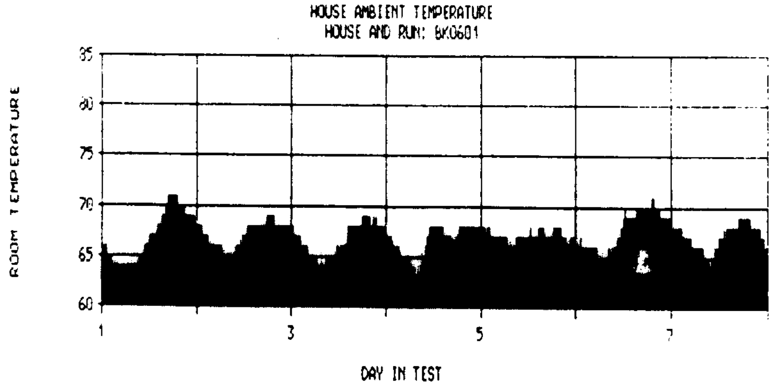

STACK OXYGEN % FOR ALL 7 DAYS
HOUSE AND RUN: BK0603

Run 4


STACK OXYGEN % FOR ALL 7 DAYS
HOUSE AND RUN: BK0604

Home 6; Crossfire
Ambient Temperature

Run 1



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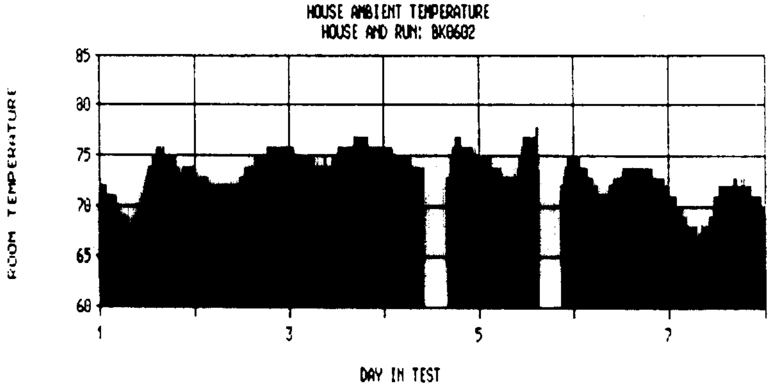

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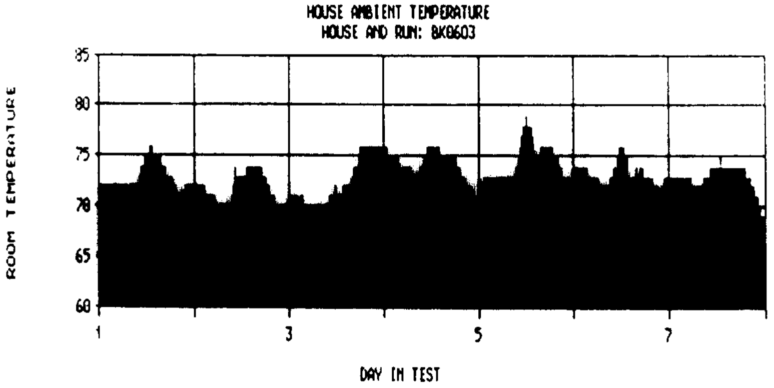

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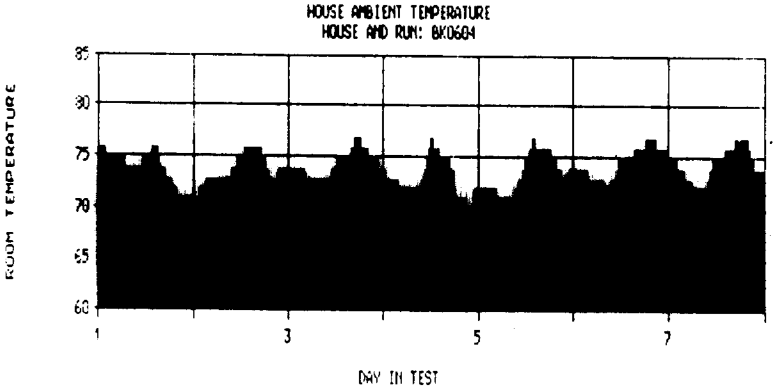


Home 1; Crossfire

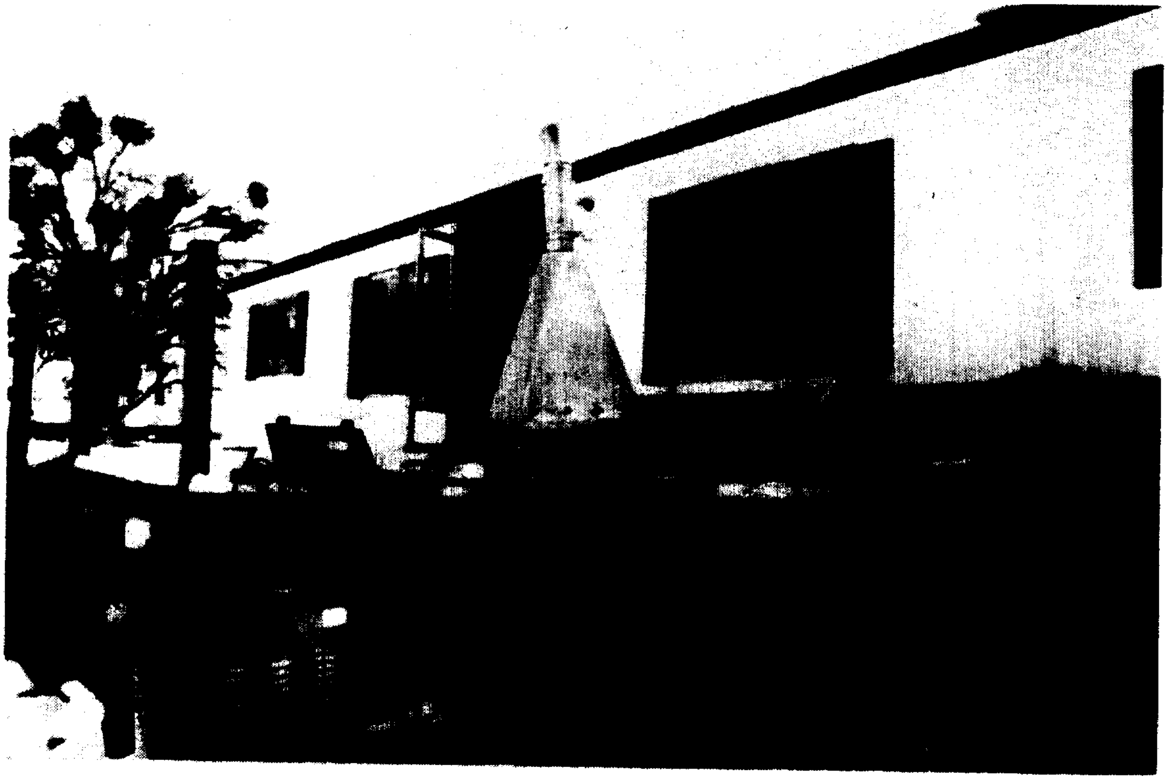


Photo 1. Exterior of home 1 with Dilution Source Sampler unit (DSS).

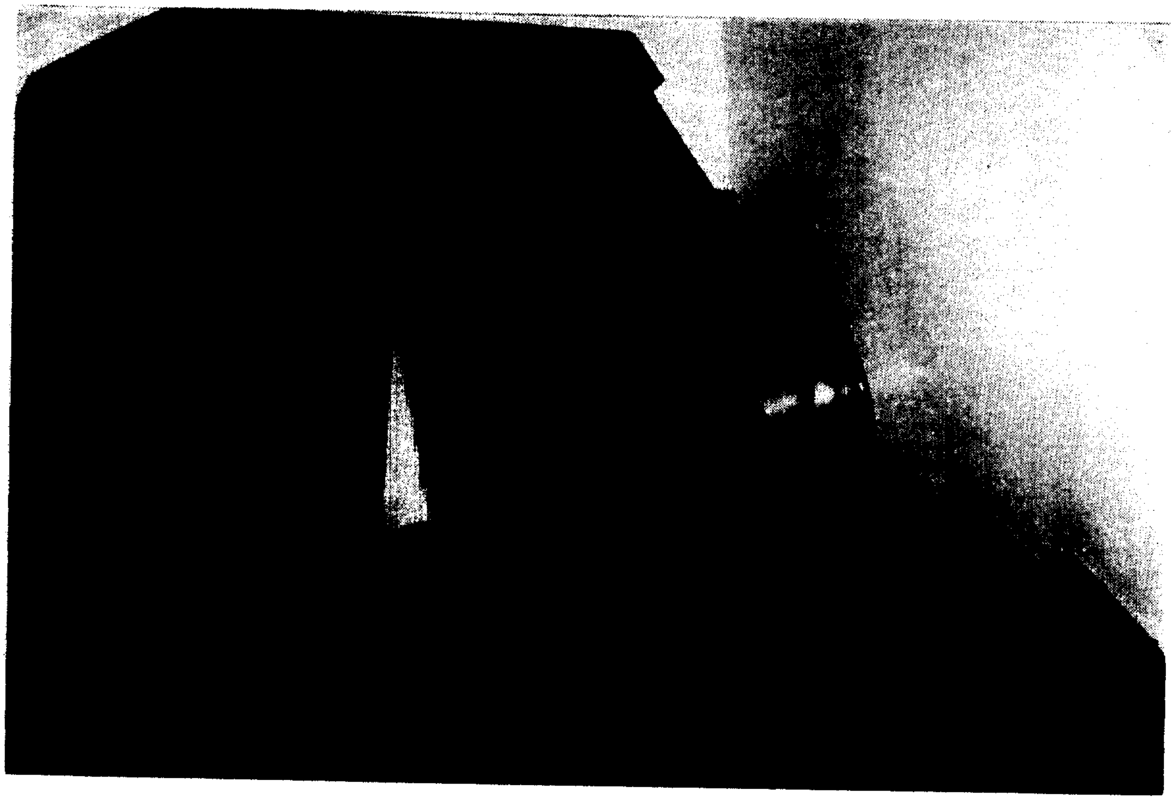


Photo 2. Stove installation.

Home 2; Whitfield

Photo 3. Exterior of home 2.

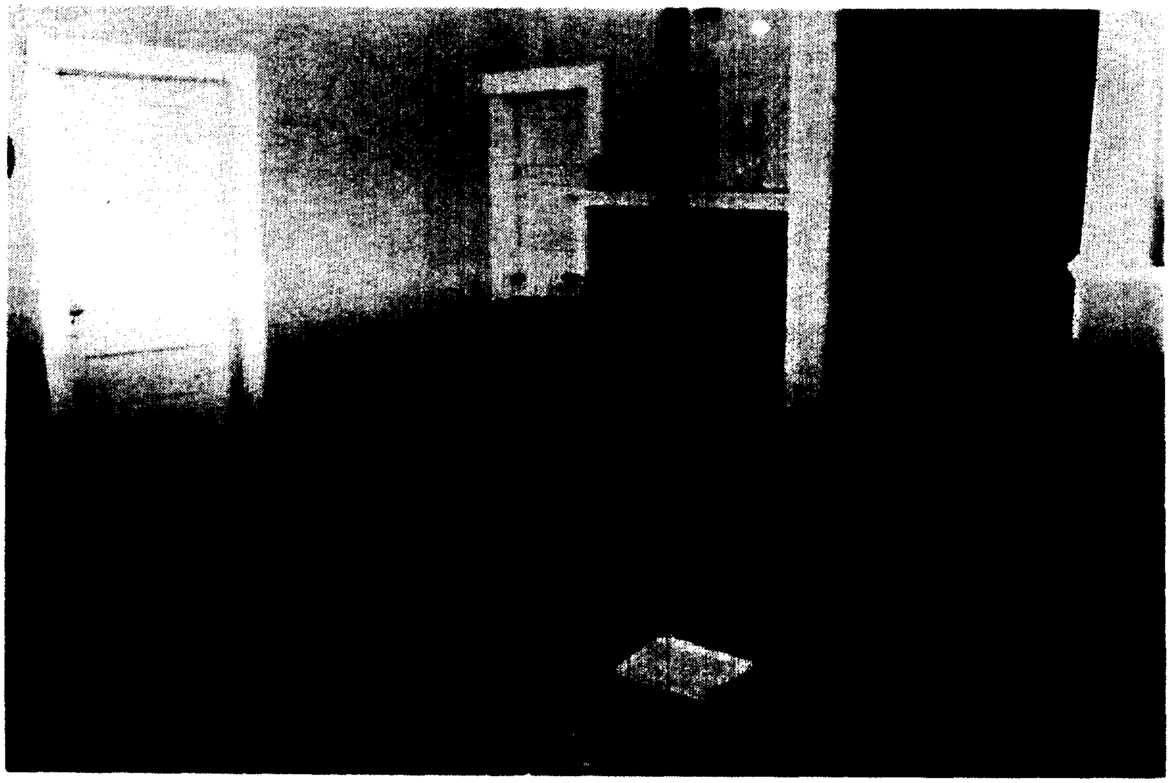


Photo 4. Stove installation and AWES sampling system.

Home 3; Whitfield

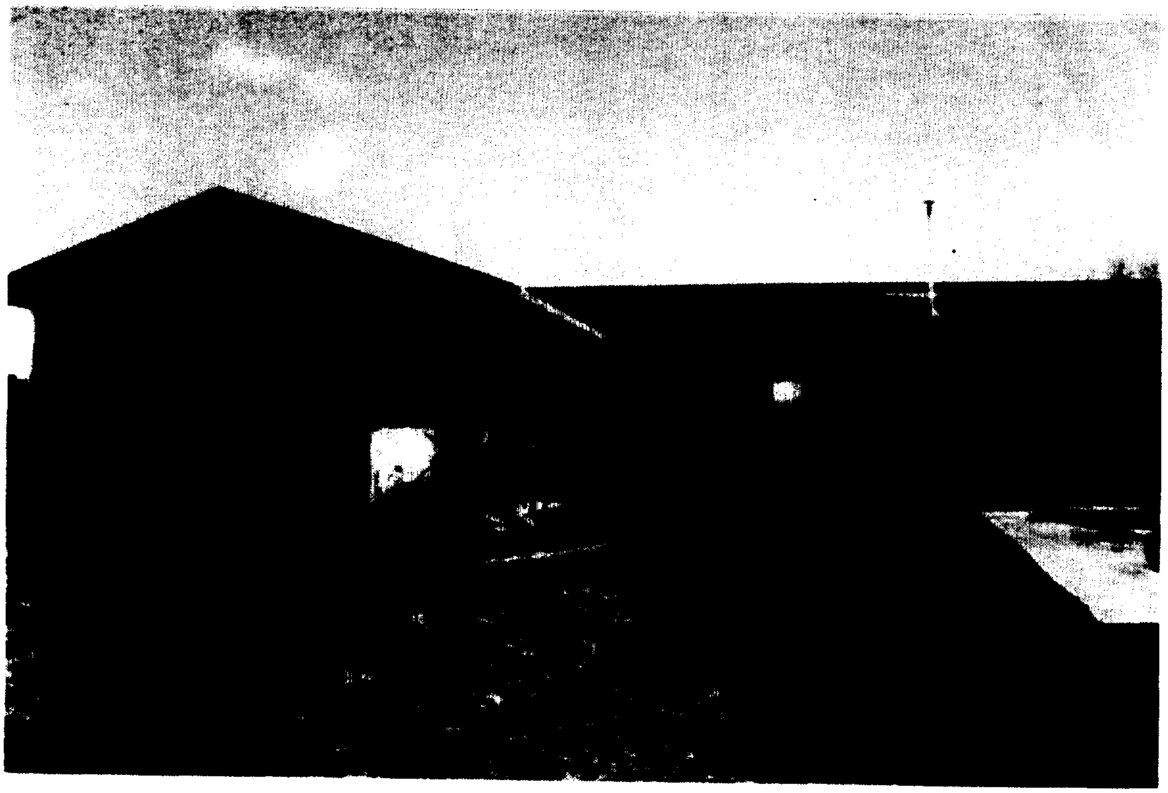


Photo 5. Exterior of home 3.

Photo 6. Stove installation and AWES sampling system.

Home 4; Whitfield

Photo 7. Exterior of home 4.

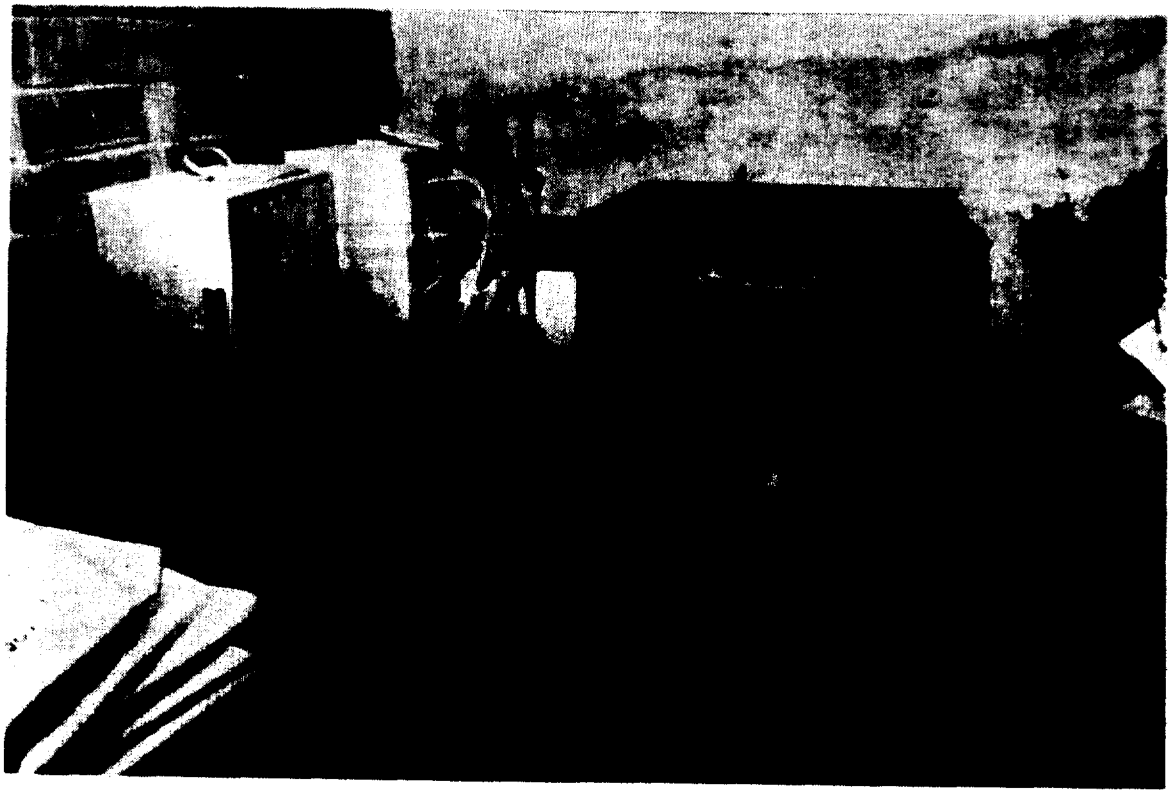


Photo 8. Stove installation and AWES sampling system.

Home 5; Whitfield

Photo 9. Exterior of home 5.

Photo 10. Stove installation and AWES sampling system.

Home 6; Crossfire

Photo 11. Exterior of home 6.

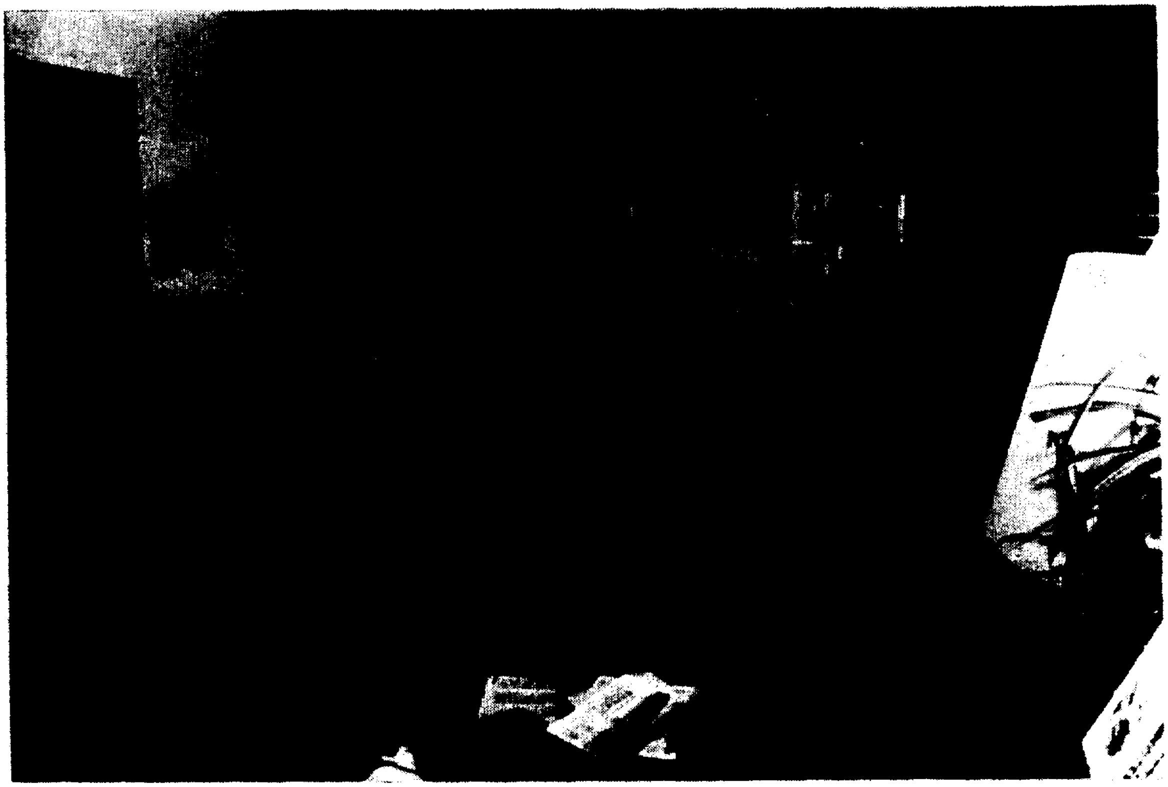


Photo 12. Stove installation and AWES sampling system.

Appendix B

Description of home installations, operator practices and opinions

Contents

1990 BPA Pellet Stove Study Homes

House No.: BM01

House square footage and # of stories:
1440 sq.ft. - 1 story

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

Type of conventional heat: None

% of heat owner believes pellet stove provides: 100%

Type of stove used in this study: Crossfire

Installation type: specify pipe diameter, elbows, chimney height, etc.:
Corner, 3 1/2" pipe, elbow

Previous stove type:

Participated in any previous study and what one?

Owner reactions and opinions of new stove (compare with old stoves):
Needs more heat control. Overheats sometimes.

Creosote condition in pipe (notes changes during season):

Daily burning habits (include details on how owner starts the stove):
Burn 24 hours. Firestarter to start.

1990 BPA Pellet Stove Study Homes

House No.: BM02

House square footage and # of stories:
1400 sq.ft.; $1^1/_2$ stories; upstairs not finished.

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

Type of conventional heat:
None (pellet stove only)
% of heat owner believes pellet stove provides: 100%

Type of stove used in this study:
Whitfield Advantage
Installation type: specify pipe diameter, elbows, chimney height, etc.:

Previous stove type:

Participated in any previous study and what one?

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

Creosote condition in pipe (notes changes during season):

Daily burning habits (include details on how owner starts the stove):
Burn all day usually.

1990 BPA Pellet Stove Study Homes

House No.: BM03

House square footage and # of stories:
1600 sq.ft.; 1 story.

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

Type of conventional heat:
Electrical ceiling heat
% of heat owner believes pellet stove provides: 100%

Type of stove used in this study:
Whitfield Advantage
Installation type: specify pipe diameter, elbows, chimney height, etc.:
elbow then 2' into garage, 12' high (roof) corner installation

Previous stove type:
None
Participated in any previous study and what one?

Owner reactions and opinions of new stove (compare with old stoves):
Better than ceiling heat; cheaper, heats good; like better than woodstove, less hassle, no cutting wood.

Creosote condition in pipe (notes changes during season):

Daily burning habits (include details on how owner starts the stove):
Off during the day when it's hot; on during the night.

1990 BPA Pellet Stove Study Homes

House No.: BK04

House square footage and # of stories:
3800 sq.ft., 2 stories

Describe portion of house heated by woodstove and estimated square footage:
Downstairs and back bedrooms: 1500-1800 sq.ft.

Type of conventional heat:
Electricity only in bathrooms (2), used in morning
% of heat owner believes pellet stove provides: 95-98%

Type of stove used in this study:
Whitfield Advantage
Installation type: specify pipe diameter, elbows, chimney height, etc.:
Out stove 6" then elbow, 4' to outside vent (horizontal)

Previous stove type:

Participated in any previous study and what one?

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

Creosote condition in pipe (notes changes during season):

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

1990 BPA Pellet Stove Study Homes

House No.: BK05

House square footage and # of stories:
1400 sq.ft.; 2 stories

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

Type of conventional heat:
Baseboard heat (just in kitchen)
% of heat owner believes pellet stove provides: 95-99%

Type of stove used in this study:
Whitfield Advantage I
Installation type: specify pipe diameter, elbows, chimney height, etc.:
Goes into 6" flue (existing brick chimney); 2 ft of $3^1/_2$ pipe out of stove, then elbow

Previous stove type:

Participated in any previous study and what one?

Owner reactions and opinions of new stove (compare with old stoves):
Had over one year

Creosote condition in pipe (notes changes during season):

Daily burning habits (include details on how owner starts the stove):
Down just for cleaning; load whenever needed

1990 BPA Pellet Stove Study Homes

House No.: BK06

House square footage and # of stories:
1400 sq.ft.; 1 story

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

Type of conventional heat:
Electric wall heater in back bedroom (in morning or night if really cold)
% of heat owner believes pellet stove provides: 95-99%

Type of stove used in this study:
Thermic Crossfire
Installation type: specify pipe diameter, elbows, chimney height, etc.:
3" 2-ft section into exhaust blower (outside of house)

Previous stove type:
woodstove
Participated in any previous study and what one?

Owner reactions and opinions of new stove (compare with old stoves):
Feasible down the road? city restrictions later? Have to clean too often, shut down and restart but don't have to cut wood, some advantages, 2 tons of pellets for winter, made for much larger house, can only run on setting #1, his house is well-insulated, too small; pellets - some bad batches, just deteriorate, not compressed; what kind of wood? Btu rating?

Creosote condition in pipe (notes changes during season):

Daily burning habits (include details on how owner starts the stove):
Fire starter to start, mostly at night, some mornings, off during day.

Appendix C

Quality Assurance and Propogation of Uncertainty Analysis

Contents

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 estamates 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 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)
4. Fuel carbon conversion to CO	% of C to CO	Laboratory experience	±25%	±25%
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 Logegr system control logic and data-recording capabilities is presented in Section 10.

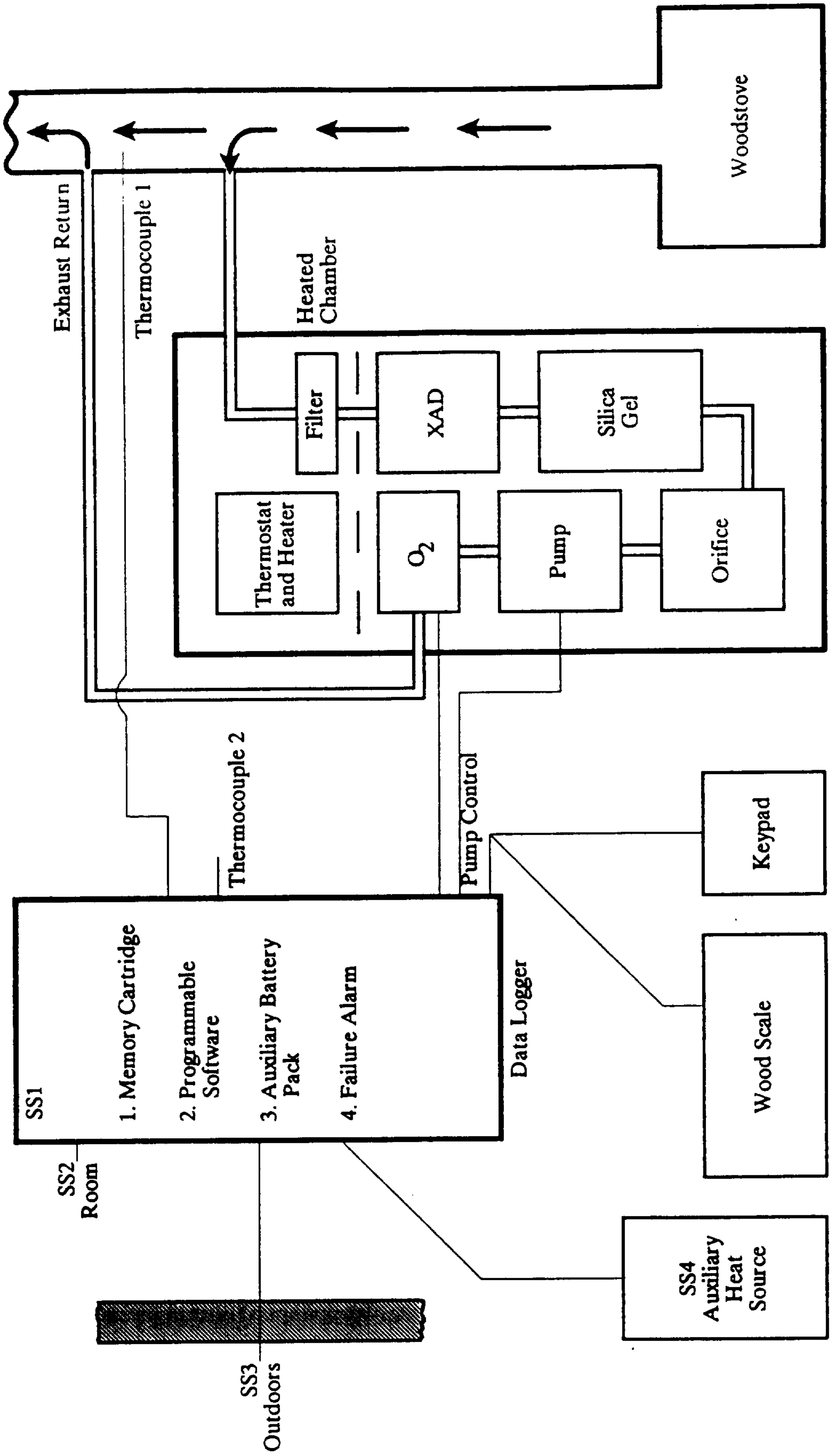


Figure 2-1. Schematic of the Automatic Woodstove Emission Sampler (AWES).

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 ±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.

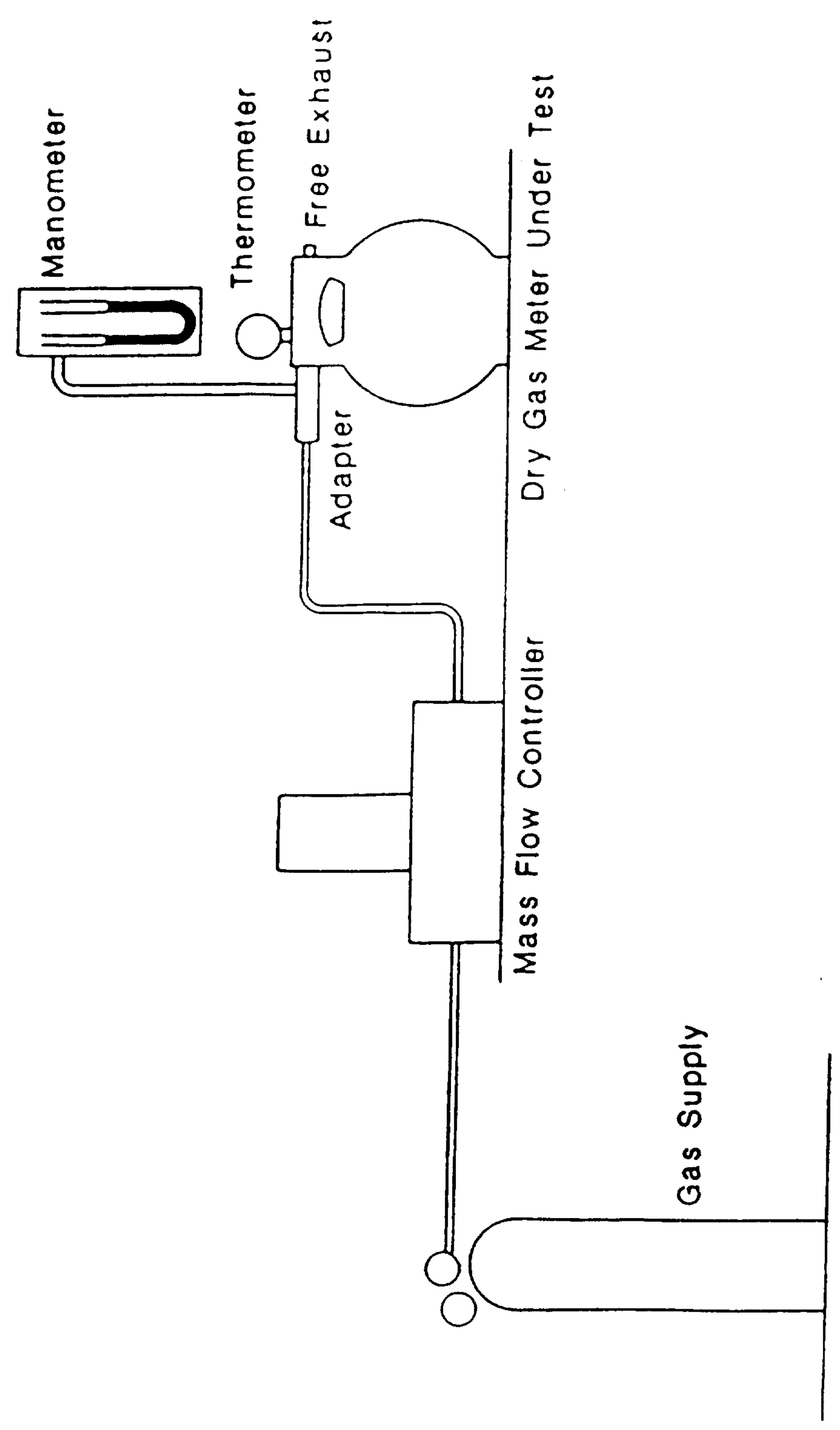


Figure 3-1. Dry Gas Meter Calibration System

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: ____________________

Barometric Pressure: __________

Calibrated By: ______________

Calibration Meter Identification: ______________

Meter Box Identification: ______________

(Q)				ΔH in. H_2O	Cal. Meter V_{ds} ft^3	Box Meter V_d ft^3	Temperature (°F)						Time (θ) min	Meter Box Coefficient (Y_d)				Comments
							Calibration Meter ($\bar{t}_{ds}$)			Box Meter ($\bar{t}_d$)								
Y_{ds}	Ave	Actual	Appr. Flow Rate				in	out	ave	in	out	ave		Y_d	ave	ΔH@	ave	
															▨		▨	
															▨		▨	
															▨		▨	
														▨		▨		

Where: ΔH@ = orifice pressure differential that gives 0.75 cfm of air at 70°F and 29.92 inches of mercury, in. H_2O

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

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

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

• 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)

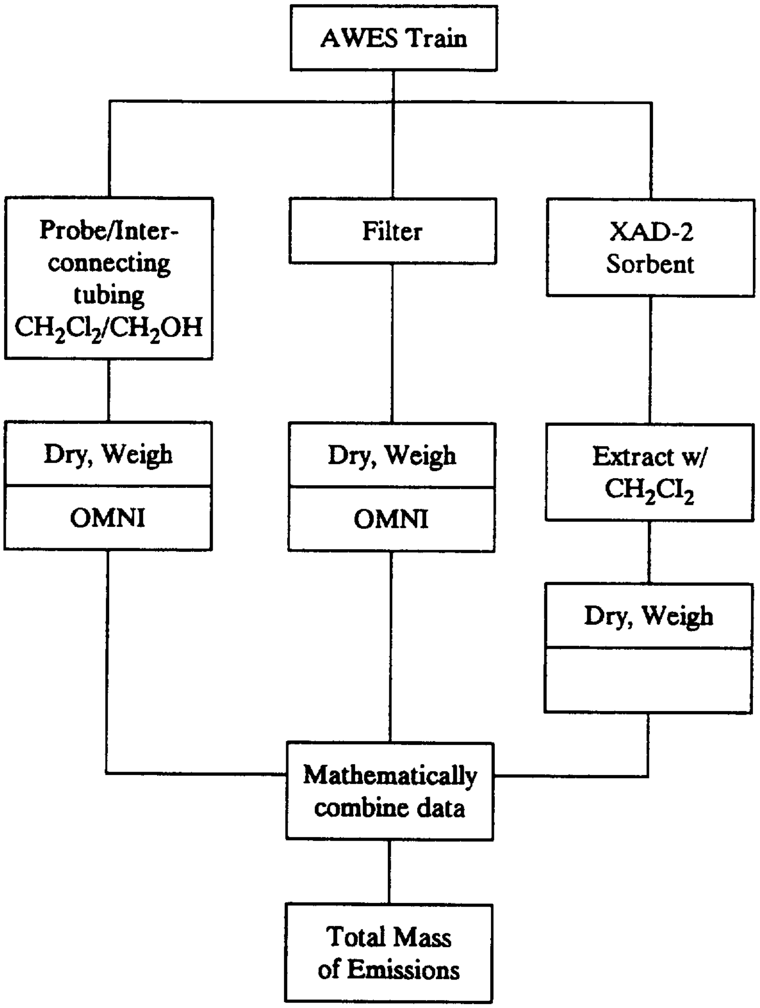
[b] Only for samples with moisture content greater than 30% DWB as determined by Delmhorst moisture meter.

[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

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

where TF = Total flue gas volume during sampling.

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

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
$\%O_2$ = 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 =

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

(3) Mass Particulate Emissions/Time of Stove Operation

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

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.

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

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:

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

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:

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

(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.

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

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.

$$MDC_i = \frac{1}{n} \sum_{j=1}^{n} MC_j$$

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 ith 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

$$T_c = \frac{1}{n} \sum_{i}^{n} (T_c)_i \qquad \text{where}$$

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.

$$TD = \frac{1}{n} \sum_{i}^{n} (T_f)_i - (T_b)_i \qquad \text{where}$$

$(T_b)_i$ = Temperature of combustion products before the catalyst.
n = Number of measurements when $(T_c)_i > 260°C$.

(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 $(T_f)_i > 38°C$ 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.

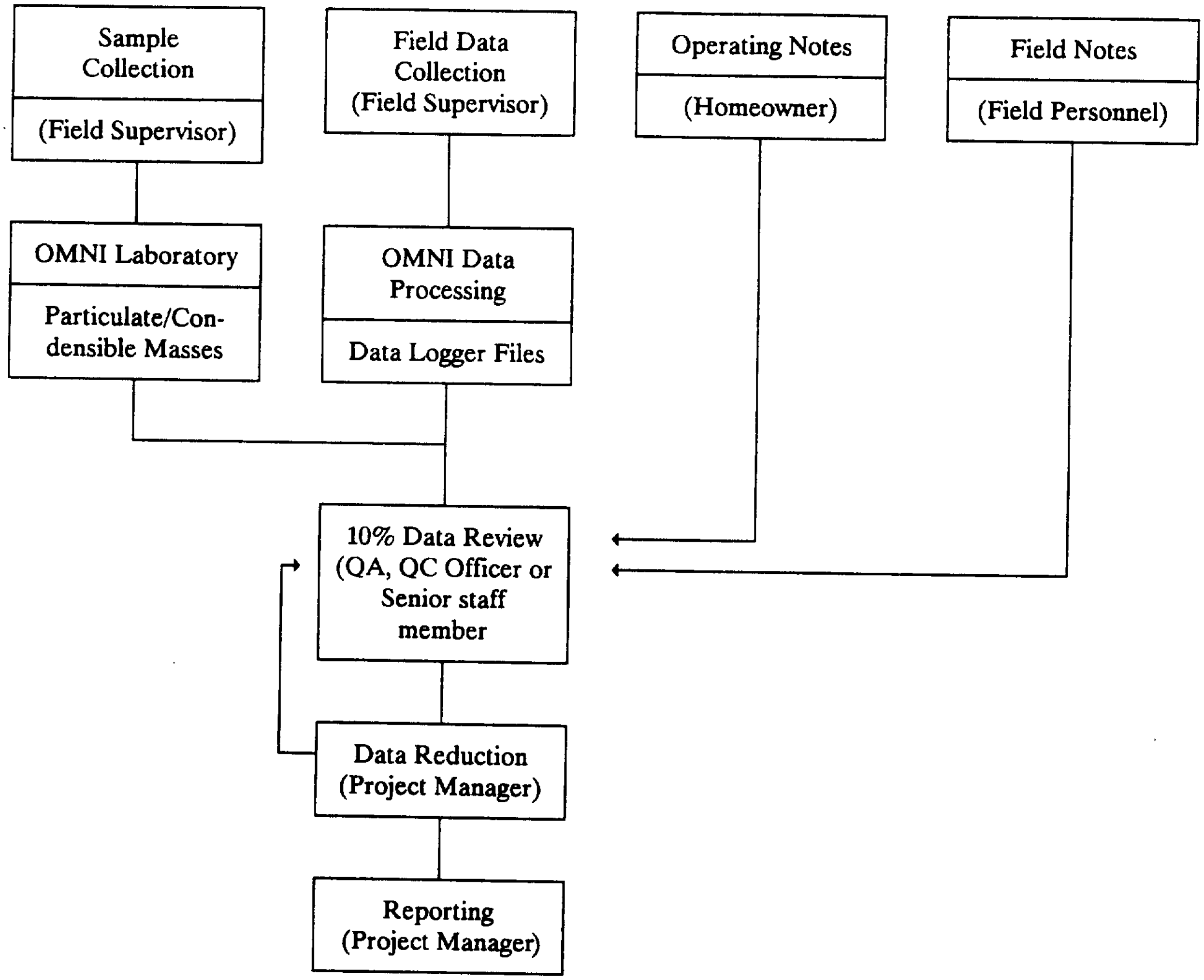
All records of instrument calibrations, sample collection, monitoring, laboratory preparatory work, analyses, and computerized and manual calculations will be stored by OMNI for a minimum of two years after completion of the final report.

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 improvements[1]

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 (O_2) 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'r circuitry changes which caused O_2 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% O_2) 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 O_2 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 O_2 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.,

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

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

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

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

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.,

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

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

$$F = f(x_1, x_2, \ldots, x_n), \tag{12.4}$$

then $$dF = \frac{\partial F}{\partial x_1} dx_1 + \frac{\partial F}{\partial x_2} dx_2 + \ldots + \frac{\partial F}{\partial x_n} dx_n, \tag{12.5}$$

where: $dx_n \equiv$ uncertainty in individual measurement, and

$dF \equiv$ uncertainty in final value, if absolute values are used; i.e.

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

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 theorectial 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 randomners 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	10.67	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 cicle. 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▪x	OM-7▪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 ssystems in stack, n=6
AWES/5H = Mean ration of AWES resutls to Method 5H, both in stack, n=4
AWES$\sqrt{x}$ = Mean ratio of the AWEs results to the mean of the results of the two dilution tunnel OM-7 trains, n=6
AOM-7$\sqrt{x}$ = 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 standards 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 propragated error are discussed in the following sections.

Mass of Particulate Matter

Previous difficultes 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/CO_2 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 ±0.5%. Flows for individual units will be determined with an estimated accuracy of ±3.0% after calibration with this transfer standard. Analysis of the variability of consecutive calibration runs indicate precision to be approximately ±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 ±100cc/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 ±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 equilabration.

In addition, the electronic circuitry of a Data Logger modification which induced a voltage bias in the O_2 cell output has been corrected, eliminating this source of error.

To further verify O_2 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 O_2 cell is functioning properly;
2. Drift in the O_2 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 O_2 concentration approaches that of the atmosphere. Even with the improvement in the precision and accuracy of the O_2 cell output, uncertainty in the correction factor will be high at mean sample O_2 concnetrations greater than 18% O_2. All samples with O_2 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 O_2 values. Calibration values will be used to calculate correction values for O_2 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

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

$\%O_{2c} =$ Corrected O_2 level during sampling

$\%O_{2m} =$ Measured O_2 level during sampling

Table 7-3

O_2 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 O_2 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

$V_{c,i}$ = O_2 cell voltage for calibration gas i

V_o = O_2 cell voltage for air prior to sampling

V_f = O_2 cell voltage for air after sampling

C_i = concentration of O_2 in calibration gas i

B_{if} = B_i as determined after sampling

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

$B_{i,f}$ = Bias of O_2 calibration for cal. gas i measured after sampling
= actual concentration - measured concentration

$B_{i,o}$ = Bias of O_2 calibration for cal. gas i mean before sampling
= actual concentration - measured concentration

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 O_2 concentration values will be calculated for all measured O_2 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 O_2 concentrations where such error will have minimum effect on overall uncertainty.

The effect of O_2 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% O_2 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 O_2 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% O_2. The bias of the mean O_2 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 O_2 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.

$$\frac{d(g/kg)}{g/kg} = \frac{dMP}{MP} + \frac{dSV}{SV} + \frac{dFR}{FR} + \frac{dSD}{SD} + \frac{d\%O_2}{(20.9\text{-}\%0_2)}$$

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.

$\%O_2$ = 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

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

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

$$\frac{d(g/kg)}{g/kg} = \frac{1.1+(0.5)(20.6)+1.4}{163.5} + \frac{500}{4686} + \frac{0.3}{1.14} + \frac{1}{60} + \frac{2.0}{(20.9\text{-}17.5)}$$

$$= 7.83\% + 10.67\% + 26.3\% + 1.67\ \% + 58.82\% \quad = \quad 105.31\%\ \text{or}\ 19.33\ g/kg$$

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% or 7.5 g/kg

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

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

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

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

The precision of the original emissions rate estimate is

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

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

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

The revised precision estimate is

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

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

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

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 Concentration (%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 O_2 levels (which dominate overall error estimate) for this example are very near the 18% O_2 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% O_2 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:

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

SD = 10.3% or 1.9 g/kg

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

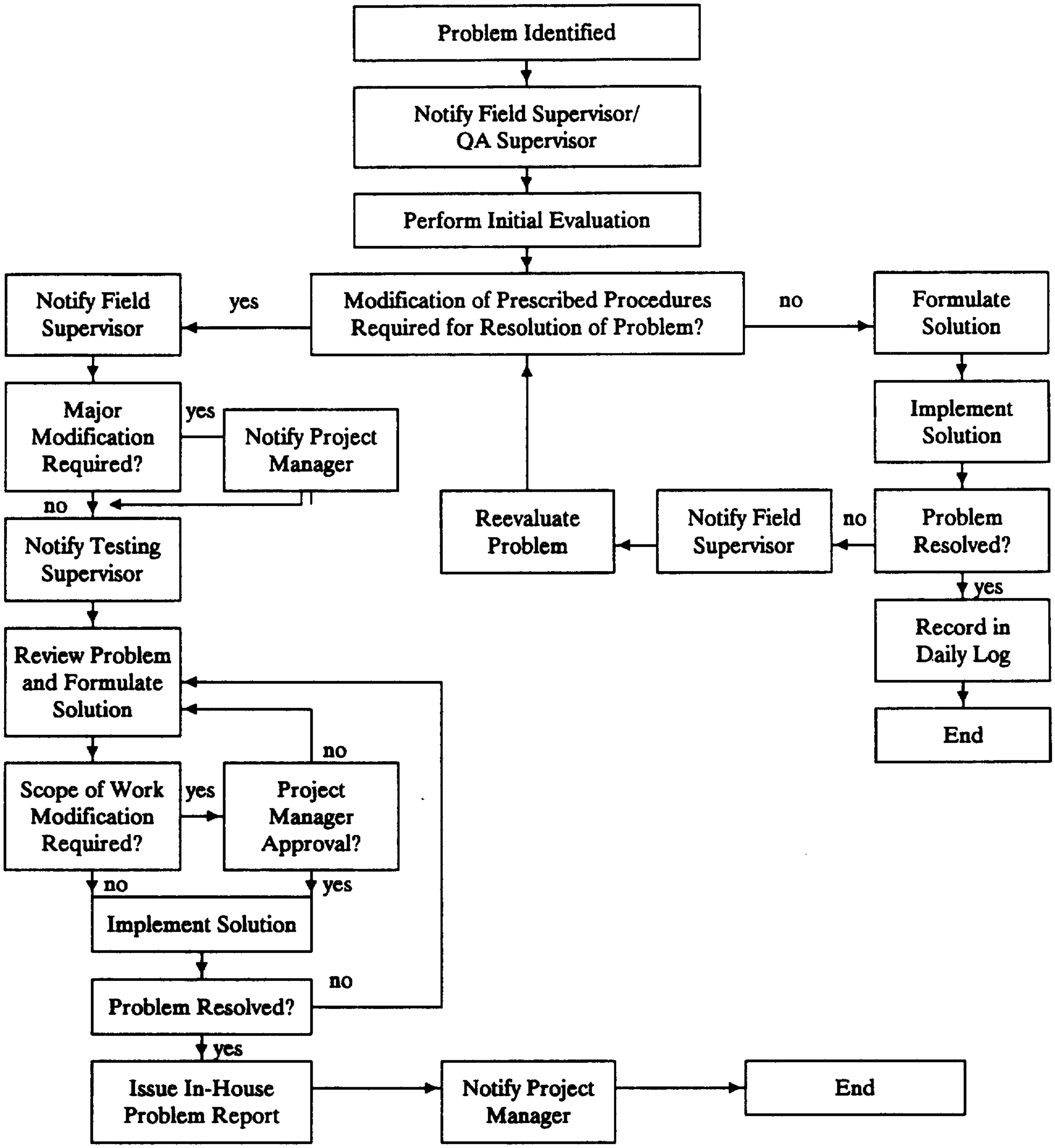
SD = 10.7% or 1.96 g/kg

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	
Blank; 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

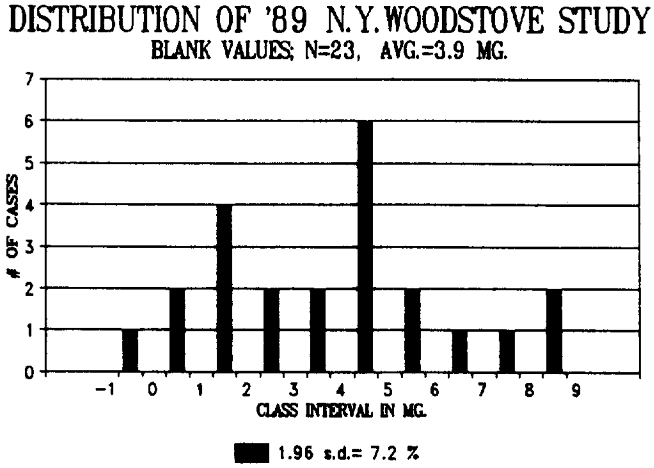


Figure 9.2

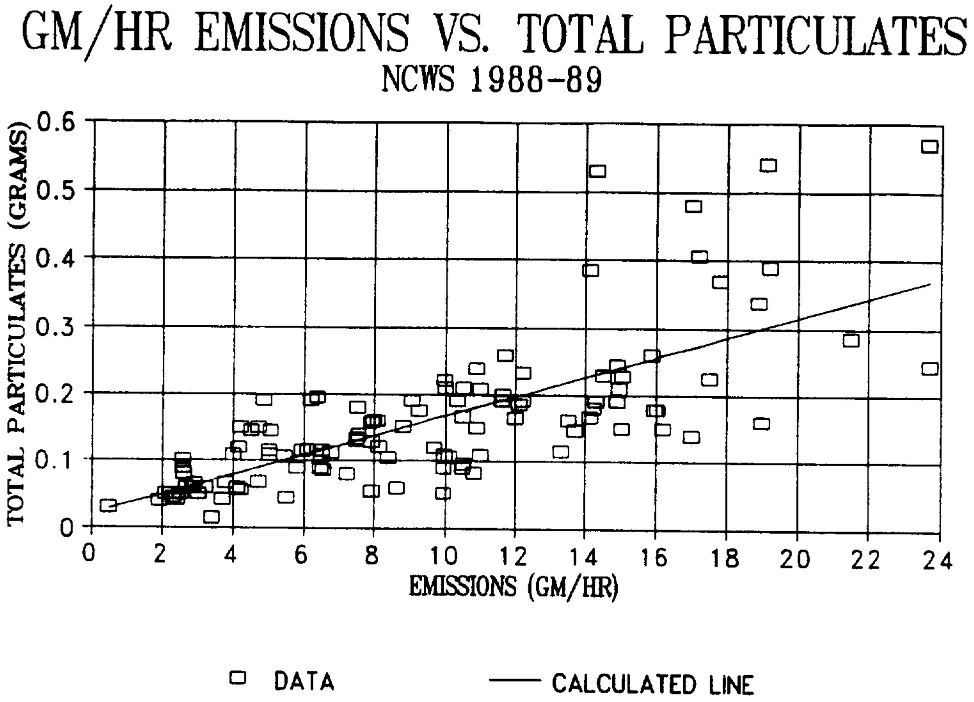
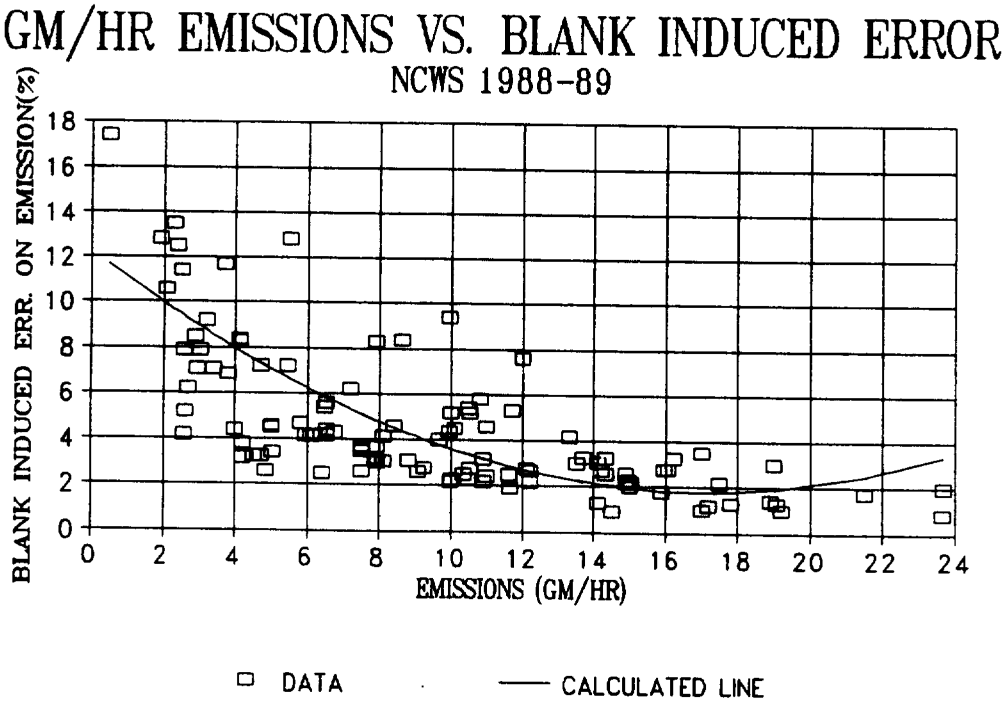


Figure 9.3



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 ±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 ±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 ±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

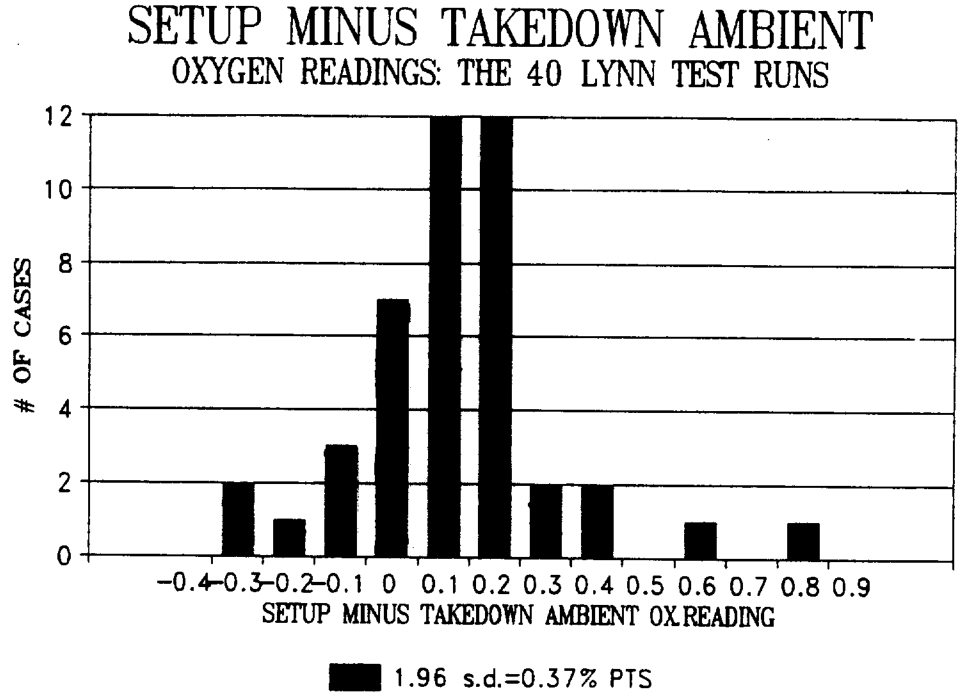
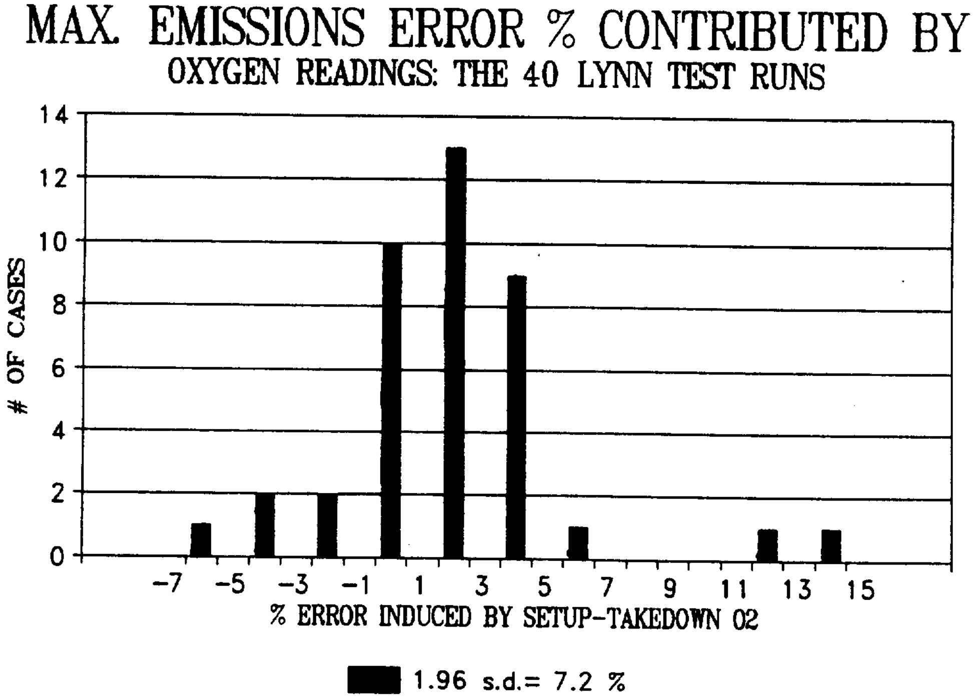


Figure 9.5



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 ±2.14%. This is very close to the ±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 ±2.14%. This verifies that the ±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 O_2 cell block must be approximately ±10°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 <u>programmed</u> 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 rotometer scale is cc/min x 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 ±10°F of ambient temperature and have held its temperature for at least five minutes.** Follow the O_2 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.

10.2

NCWS FIELD LABORATORY
STANDARD OPERATING PROCEDURE
OMNI ENVIRONMENTAL SERVICES, INC.

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 filer 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.

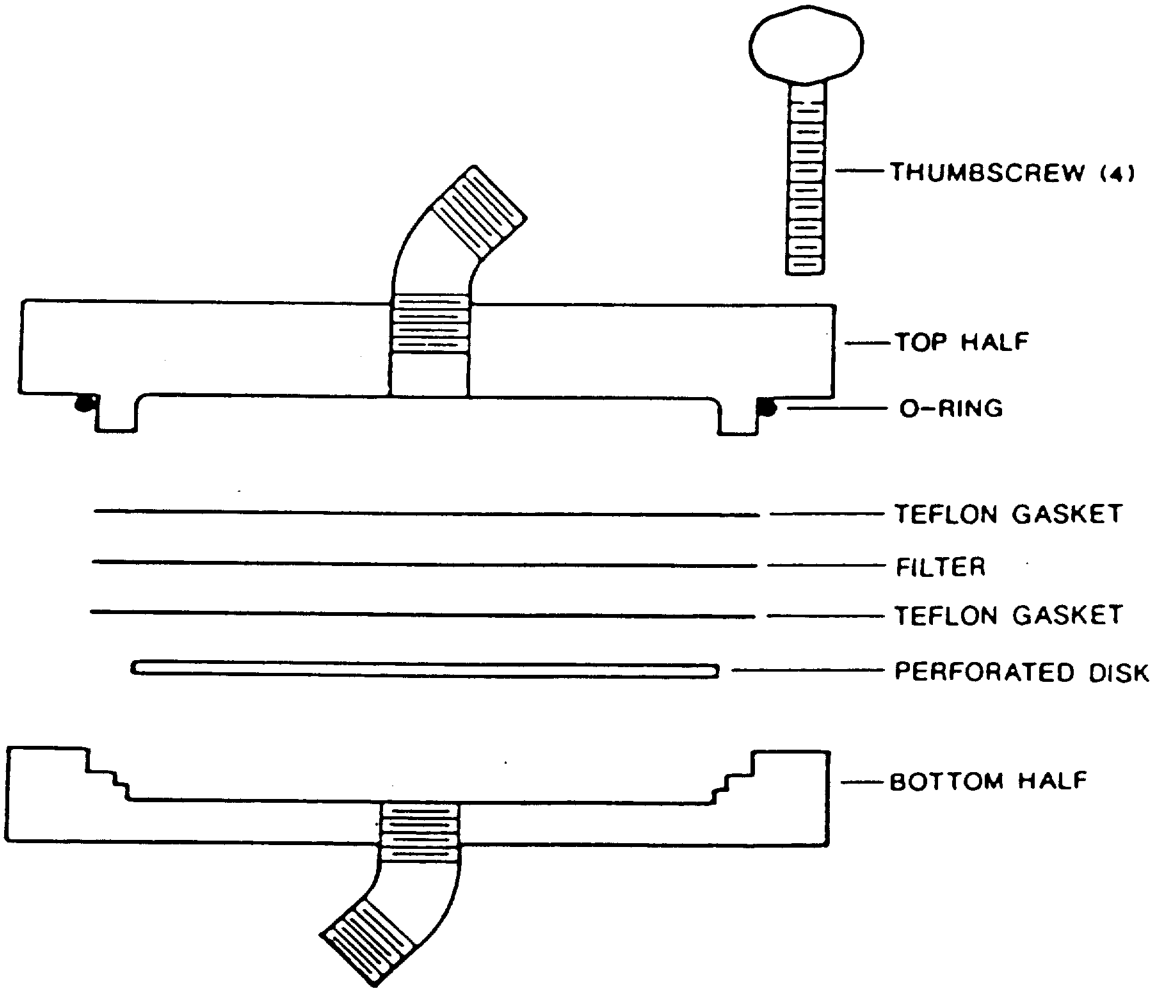
10. **The sample jar should now be tightly capped.** Wrap joint between lid and jar with Teflon tape. Verify that labels are on the jar and the lid and that data are correct. The level of solvent shoul dbe marked on the jar using a Sharpie permanent marker or a strip of marking tape turned sideways, with the straight upper edge of the tape at miniscus (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

[illegible]
P O BOX 2219 COLUMBUS, OHIO 43216 • (614) 889-3333
24-HOUR EMERGENCY TELEPHONE (606) 324-1133

Ashland

004208 METHYLENE CHLORIDE SEMI CONSIG PAGE 1

ACCEPTED BY O.S.H.A. AS ESSENTIALLY SIMILAR TO O.S.H.A. FORM 20

****

ASHLAND PRODUCT NAME: METHYLENE CHLORIDE SEMI CONSIG
CAS NUMBER: 75-09-2

CHEMONICS
P O BOX 17376
PORTLAND, OR 97217
ATTN: JEFF NICOUD

06 -78 -
DATA SHEET NO 0170647-001
LATEST REVISION DATE: 03/86-86086
PRODUCT 7340140
INVOICE ACCLOC
INVOICE DATE: 03/11/86
TO:

**** INTERCOMPANY MAIL ****

SECTION I-PRODUCT IDENTIFICATION

GENERAL OR GENERIC ID: CHLORINATED HYDROCARBON

HAZARD CLASSIFICATION: (14) 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
NITIAL BOILING POINT	FOR PRODUCT	104.00 DEG F (40.00 DEG C) @ 760.00 MMHG
APOR PRESSURE	FOR PRODUCT	340.00 MMHG @ 68.00 DEG F (20.00 DEG C)
APOR DENSITY	AIR = 1	2.9
PECIFIC GRAVITY		1.318 @ 77.00 DEG F (25.00 DEG C)
RCENT VOLATILES		100.00%
VAPORATION RATE	(ETHYL ETHER = 1)	1.80

SECTION IV-FIRE AND EXPLOSION DATA

ASH POINT NOT APPLICABLE

PLOSIVE LIMIT NOT APPLICABLE

TINGUISHING MEDIA: WATER FOG OR CARBON DIOXIDE OR DRY CHEMICAL

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

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

USUAL FIRE & EXPLOSION HAZARDS: NOT APPLICABLE

9

SECTION V-HEALTH HAZARD DATA

MISSIBLE EXPOSURE LEVEL 500 PPM

ESHOLD LIMIT VALUE 100 PPM

SEE SECTION II

ECTS OF OVEREXPOSURE: FOR PRODUCT

E - CAN CAUSE IRRITATION
N - CAN CAUSE IRRITATION
ATHING - EXCESSIVE INHALATION OF VAPORS CAN CAUSE NASAL AND RESPIRATORY IRRITATION, DIZZINESS, WEAKNESS, FATIGUE, NAUSEA, HEADACHE, POSSIBLE UNCONSCIOUSNESS, AND EVEN ASPHYXIATION
LLOWING - CAN CAUSE GASTROINTESTINAL IRRITATION, NAUSEA, VOMITING, AND DIARRHEA

ST AID:

[illegible] METHYLENE CHLORIDE SEMI CONXIG

SECTION V-HEALTH 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

INCOMPATABILITY: 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 SALVAGE 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 CLEAR 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 SPECIFIED CONDITIONS (SEE YOUR SAFETY EQUIPMENT SUPPLIER). ENGINEERING OR ADMINISTRATIVE CONTROLS SHOULD BE IMPLEMENTED TO REDUCE EXPOSURE.

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

ROTECTIVE GLOVES: WEAR RESISTANT GLOVES SUCH AS:, POLYVINYL ALCOHOL

YE 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)

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

SECTION IX-SPECIAL PRECAUTIONS OR OTHER COMMENTS

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

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

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

E INFORMATION ACCUMULATED HEREIN IS BELIEVED TO BE ACCURATE BUT IS NOT WARRANTED TO BE WHETHER ORIGINATING WITH ASHLAND 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 6018, 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

mical Name:
ethanol

Catalog Number:
MX0475, MX0483, MX0485, MX0487, MX0488, MX0490

de Name & Synonyms:
ethyl Alcohol, Wood Alcohol

Chemical Family:
Alcohols

nula:
H_3OH

CA #67-56-1

Formula Weight:
32.04

SECTION 2 PHYSICAL DATA

ng Point, 760 mm Hg (°C)	64.5°C	Specific Gravity (H_2O = 1)	0.79
ing Point (°C)	-144°F	Solubility in H_2O, % by wt. at 20°C	Soluble
r Pressure at 20°C	96 mm Hg	Appearance and Odor	colorless liquid slight alcoholic odor
r Density (air = 1)	1.1		
ent Volatiles by Volume	100	Evaporation Rate (Butyl Acetate = 1)	5.91

SECTION 3 FIRE AND EXPLOSION HAZARD DATA

Point (test method) 52°F . (tcc)	Flammable Limits	Lel 6.7%	Uel 35%

uishing Media CO_2, dry chemical, foam
Water spray to cool fire-exposed containers
Water spray to disperse vapors

al Hazards and Procedures Wear self-contained breathing apparatus

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

SECTION 4 REACTIVITY DATA

X	Conditions to Avoid heat, sparks, open flame
le	

ls to Avoid
Oxidizers

ous Decomposition Products CO_x

SECTION 5 SPILL OR LEAK PROCEDURES AND DISPOSAL

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

Disposal Method To be performed in compliance with all current

MX0483, 0485, 0487, 0488, 0490

SECTION 6 HEALTH HAZARD DATA

eshold Limit Value

OSHA std-air: TWA 200 ppm TXDS: orl-hmn LDLo: 340 mg/kg

ects 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.

t 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

ilation, 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

eep container tightly closed
o smoking or flares
tore in a well-ventilated area, away from sources of ignition
void prolonged or repeated contact with skin
f ingested, can cause blindness; cannot be made non-poisonous

SECTION 9 HAZARDOUS INGREDIENTS

(refer to section 3 through 8)

T - FLAMMABLE LIQUID

SECTION 10 OTHER INFORMATION

PA 704:	1	3	0
	Health	Flammability	Reactivity

DAS-5 Data Acquisition System/Data Logger Field Operating Instructions

rev. 1/89

(Use Only Black Ink in Log Books)

Background

The OMNI Data Acquisition System (DAS) is a programmable data logger and controller. The DAS-5 is currently being used in several in-home woodstove 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), which collects particles and hydrocarbons and measures the oxygen content of sampled stove gases.

The DAS-5 consists of a small grey box with removable sensors and control wires. The DAS-5 is controlled by a program which resides in a non-volatile memory (EPROM). Actual sampling parameters are entered by the field technician using a host computer connected to the DAS-5 by a communications cable using a standard RS-232 serial port. Access to the RS-232 port is via a program called DASR5.1. Data collected by the DAS-5 is stored in a non-volatile 32 KB memory cartridge, which is locked inside the DAS-5 unit to avoid tampering. The DAS-5 has battery backup capabilities and will continue to record while AC power is not available. Error conditions are indicated by a red LED on the outside of the box and by a beeper tone.

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.

Operation

There are two operational modes for the DAS-5:

1. Maintenance mode.
2. Data collection mode.

Each operational mode is used for certain calibration procedures as described in this SOP. Detailed descriptions of each mode follow.

Two conditions may exist in which the operator desires to enter the maintenance mode. The first is when the DAS-5 is installed and AC power is applied for the first time. The second is waking the DAS-5 from its data collection mode. The procedures for each are different and are described here.

A. Installation and Initial Calibration Procedures

1. Connect all wires (AC power, TCs, S.S. Sensors, AWES cable, groundwire) to be used to the external filter board located on the outside of the DAS-5. (These should already be attached. Refer to the wiring diagram in Figure 1 and the Section entitled "Temperature Sensor Installation" if guidance is needed.) The scale is attached by plugging the 25-pin connector to the matching connector on the outside of the DAS-5. NOTE: Do not plug in the AC/DC transformer unless the two leads from the transformer have been attached to the DAS-5; if the two

leads are allowed to contact one another while the adapter is plugged into AC power, the adapter will be ruined. Record the locations of all temperature sensors on the data sheet entitled "Temperature Sensor Location Form".

2. Connect the communications cable to the RS-232 port of the host computer. (Do not plug into the Data Logger!) Any IBM-compatible portable computer with PC-DOS or MS-DOS, at least one floppy drive, and a serial port may be used as the host computer. Compaq, Sperry portables, and IBM machines have been used successfully by OMNI.

3. Turn on the computer and run DASR5.1 after the computer has booted. (Boot the computer by installing the "program" disk in drive A [left drive] and turning on the computer.) **CAUTION: Do not turn the host computer on or off while the communications cable is connected to the DAS-5.** This may affect the DAS-5 such that it must be completely powered down and restarted in order to work properly. This is true whether or not the DASR5.1 program is running at the time.

4. Connect the ten-pin connector to the pins on the top circuit board inside the DAS-5 with the black strand of the communications cable oriented toward the black plastic clip at the end of the rainbow harness on the top circuit board.

5. Apply power to the DAS-5 by plugging in the AC adapter. NOTE: on first time power application, remove the data cartridge from the DAS-5. **Carefully** replace the memory cartridge with the label facing in.

6. Plug in the battery pack and slip inside the DAS-5, taking **extreme care** that none of the wires inside the DAS-5 are disturbed or pinched.

7. Random graphics characters may appear on the computer screen (a string of Fs, or the words "time" or "scale"). These conditions occur because the DAS-5 memory locations contain random values when first powered up, and should no cause for concern. If the maintenance menu (similar to Figure 2) appears, skip to step 9.

8. Press the small black button located on the top circuit board. After a 2-3 second delay the maintenance menu should appear on the screen. If not, try pressing the button again. If this does not work, unplug both the battery pack and the AC power adapter and return to step 5.

9. The sampling parameters may now be set by selecting items from the menu and answering the questions which result. Begin filling out the Maintenance Log Form (Figures 4 and 5) by completing **Sections A and B**.

10. The Maintenance Menu

The following menu items will appear on the computer screen along with a listing of current values for a number of parameters and sensors **(Figure 2)**.

> NOTE: when the unit is first powered up with no data cartridge in place, the parameters will be random values; otherwise old parameters may be loaded into the DAS-5 from the data cartridge.
>
> NOTE: During the time that the DAS-5 is in the maintenance mode, the DAS-5 will begin chirping and the red LED will flash regularly after 2-5 minutes. This should not be cause for concern, and may be turned off for another 2-5 minutes by hitting the black reset button at any time that the DAS-5 is in the maintenance mode.
>
> NOTE: If a data entry error or any other procedural error causes the DAS-5 program to abort, a colon (":") will appear on the screen. This simply means that the program has aborted and may be restarted by typing **"goto 600"** followed by pressing the return key.
>
> NOTE: If the maintenance menu appears on the screen but typing is not echoed on the computer screen, try

pressing Ctrl-Z once. If the communications program aborts, restart DASR51. If communications still do not appear to work properly, refer to the troubleshooting Section of this SOP.

It is mandatory that you to go through all items **in order** 1 through 12. Setting up the various functions of the DAS-5 out of order may cause it to malfunction. Calibration values may also be improperly set if the DAS-5 is not set up in the order specified in this SOP.

A description of each of the menu items follows:

#1. Set the clock

The requested format < YYMMDDhhmmss > means:

YY - two-digit year
MM - two-digit month
DD - two-digit day
hh - two-digit hour, in military time (00 - 24)
mm - two-digit minutes
ss - two-digit seconds

Example:

```
              -----OPTIONS-----
1.Set clock  4.Alt trip  7.# TC's   10.Scale cal  13.Done
2.Init cart  5.Pmp times  8.# O2's   11.Scale rdg
3.Rst batt   6.ES on/off  9.O2 cal   12.Sys stat

YOUR CHOICE:? 1
SET DATE/TIME <YYMMDDhhmmss> 881104100230
```

If an **entry error** is made, use the **backspace key** to move back to the point of error and continue on from there. **Do not use** the left **cursor control key**. Only the first 12 digits of the entry are used in setting the clock.

#2. Initialize the data cartridge. The date must be set properly before this option is called. The initialization will fail and the DAS-5 will beep if the data cartridge is installed backwards (the Dallas Semiconductor label should be facing the circuit boards), if the data cartridge is not installed, if the cartridge is not fully seated in the socket, if the data cartridge is faulty, or if the write-protect switch is in the "on" position. If the unit beeps and the red LED blinks, correct the problem and select option 2 again. If the cause of the problem cannot be determined, try another data cartridge. If the problem persists, refer to the troubleshooting Section. If the initialization is successful, the DAS-5 will write to the cartridge the unit serial number and the current date and time in hexidecimal form, similar to:

```
YOUR CHOICE:? 2
00 00 7F FF 55 29 31
00 03 7F FC
10 62 02
00 06 7F F9
04 62 11
00 09 7F F6
```

Make sure that **six lines** of hexidecimal data appear on the screen. Also, select option 12 and check that 3 blocks of the cartridge have been used (fourth line of status screen). If the cartridge has not been initialized correctly, try option 2 again. If necessary, try another cartridge or refer to the troubleshooting Section.

#3. Reset the battery used time. No response is needed to this item.

#4. Set alternate heat trip point. The solid state sensor in the #4 position is used to detect whether an auxiliary heat source has come on or not. The field technician should make an estimation of a trip point (in degrees F) which will be a true indication of whether the heat source is on. A trip point of 95°F is typically used. Too low of a setting will cause the DAS-5 to over-record auxiliary heat use; too high of a setting will cause under-recording of auxiliary heat use. If the sensor will not be used, enter 200.

Example:

```
YOUR CHOICE:? 4
Set trip point <95..200>: ?
```

#5. Pump times. This allows selection of the AWES operating frequency and duration. The following items will be input:

Month (0-12) - The month on which sampling is to start. NOTE: if the AWES unit is not connected or not to be used, a "0" MUST be entered in response to this item. When this is done, the program will automatically clear all the other parameters to zero and return to the maintenance menu. If this is not done, the DAS-5 may try to activate AWES sampling at an unpredictable date and time, resulting in meaningless data being stored on the data cartridge.

Day (1-31) - input the **dates** on which sampling is desired. Don't be concerned if a month change occurs in the middle of the sampling sequence. As long as the start month is entered correctly above, the AWES will sample properly. A 7-day sampling sequence should always be used.

On Minutes - this is the time that the sampler will be on during each sampling sequence. Normally this will be 1.

Off Minutes - this is the time between sampling sequences. Normally this will be 29.

Start Hour - input the hour (0-23) at which sampling should start. In most cases this will be 0.

Stop Hour - input the hour (0-23) at which sampling should stop. In most cases this will be 23. Note that sampling will stop AFTER the completion of the hour designated; for example, if 15 is designated as the stop hour, the sampler will sample through the 15th hour and shut off at 16:00.

Example:

```
YOUR CHOICE:? 5
Start month <0..12>: ? 11
day1 <1..31>: ? 5
day2 <1..31>: ? 6
day3 <1..31>: ? 7
day4 <1..31>: ? 8
day5 <1..31>: ? 9
day6 <1..31>: ? 10
day7 <1..31>: ? 11
On mins <1..255>: ? 1
Off mins <1..255>: ? 29
Start hr <1..23>: ? 0
Stop hr <1..23>: ? 23
```

#6. Emission Sampler on/off. This is to test that the AWES unit is correctly wired and that the pump is operating properly. This option is an on/off switch for the pump; that is, calling option 6 the first time will turn the pump on, and calling it the second time will turn the pump off. NOTE: When the DAS-5 is first powered up, the DAS-5 may already be running the AWES pump. The pump may be turned off by selecting option 6 twice (the first time option 6 is selected simply sets a variable in the DAS-5 to agree with the fact that the pump is on; the second time option 6 is selected turns the pump off). The pump should be off at the completion of this step.

#7. Number of thermocouples used. This will differ according to the specific installation and stove. The DAS-5 automatically records values for TC#1 through TC#[max]. That is, the number of TC channels may be varied from 1 to 4. **Thermocouple 1 is always installed in the stack**, through the compression fitting immediately above the AWES probe. For non-catalytic stove, this will be the only thermocouple used. For catalytic stoves, **thermocouple 2 is always in the catalyst.** Place TC#2 **halfway** into a cell in the center of the combustor (round or rectangular). This must be done consistently for all installations. **Thermocouple #3 is always installed 1 inch away from the inlet to the combustor (precatalyst position.)** It should be directly in line with TC#2 and should always be exactly 1 inch from the combustor. Photograph all combustor TC installations. If more TCs are specified than are actually attached, no harm is done, but unnecessary space is taken up in the Data Logger. If fewer TCs are specified than are actually used, the Data Logger will not record values from positions above the specified number of TCs.

When the number of TCs to be used has been entered, you will be prompted to enter the number TCs written to the Data Logger every 5 minutes. This entry affects the resolution, or averaging time, of all the TCs. It also affects the maximum data collection time of the Data Logger. For example, if 3 TCs are written to the DAS-5 every 5 minutes, total collection time will be only nine days before the memory is full. All 3 TCs would be recorded with a 5 minute averaging time. Conversely, if 1 TC was written every 5 minutes, the averaging time for each thermocouple would be 15 minutes, giving lower resolution, but the total data collection time could be extended to about 30 days. Table 1 contains a more complete description of the averaging and writing times.

Averaging times are derived from time required to write TC1 . . . (active TCs) to data cartridge at the rate of (#TCs Written/5 min.) That is, with three active TCs written at 2 per five minutes requires 10 minutes (two written during the first five minutes, the third TC written during the second five minutes.

Note that all the TCs are read and averaged over the **same** ten minutes. The averages are calculated and stored in a temporary memory location. The temporarily stored values are then written to the data cartridge at the rate described in the previous paragraph. During the time it takes to write out these temporarily stored values (the next ten minute block of time), another set of averages is being collected. At any given time, then, the temperatures being written to the data cartridge are actually averages collected during the previous ten minute averaging time. Moreover, even though the TCs may be written to the data cartridge at different five minute intervals, they were all averaged together at the same time.

For this project, specify one TC every 5 minutes for the non-catalytic stoves (your only choice) and two TCs every 5 minutes for the catalytic stoves.

Example:

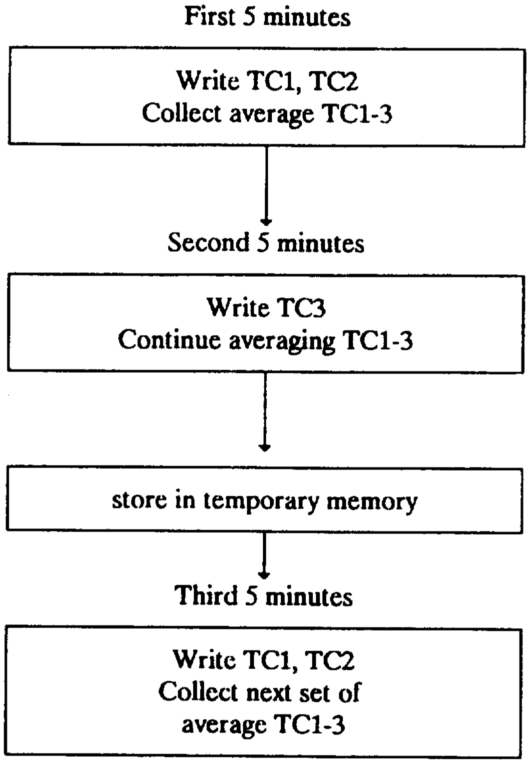
```
YOUR CHOICE:? 7
# TCs <1..4>: ?
# TCs written/5 minutes <1..4>: ?
```

Table 1

Thermocouple Averaging and Writing Periods

# Active TCs	# TCs Written per 5 minutes	Averaging Time	TCs Stored to Data Cartridge		
			1st 5 min	2nd 5 min	3rd 5 min
1	1	5 min.	TC1	TC1	TC1
2	1	10 min.	TC1	TC2	TC1
2	2	5 min.	TC1, TC2	TC2	TC1, TC2
3	1	15 min.	TC1	TC2	TC3
3	2	10 min.	TC1, TC2	TC3	TC1, TC2
3	3	5 min.	TC1, TC2, TC3	TC1, TC2, TC3	TC1, TC2, TC3
4	1	20 min.	TC1	TC2	TC3
4	2	10 min.	TC1, TC2	TC3, TC4	TC1, TC2
4	3	10 min.	TC1, TC2, TC3	TC4	TC1, TC2, TC3
4	4	5 min.	TC1-4	TC1-4	TC1-4

Flow Chart Showing Example Thermocouple Averaging and Writing Sequence



#8. Number of O_2 sensors to be used. Two AWES units may be controlled simultaneously from a single DAS-5, with the possibility of two O_2 sensors being recorded. Sensor #1 position is always read if the AWES is sampling; sensor #2 is optional. **Connect the O_2 wires to the sensor #1 position only when 1 AWES is used.** (If the response to this item is 2 and a sensor is not connected to the second position, no harm is done, but unnecessary space will be consumed in the data cartridge and the readings will be meaningless.)

Example:

```
YOUR CHOICE:? 8
# O2s <1..2>: ?
```

#9. Calibration of the O_2 sensors. The O_2 μV output is calibrated to ambient oxygen levels, which is assumed to be 20.9%. The oxygen sensors should be allowed to reach normal operating temperature before the calibration is run, as these sensors are sensitive to temperature. The #1 sensor is always calibrated; the #2 sensor will be calibrated if the response to menu item #8 is 2. The AWES **pump** must be allowed to run for **only one minute** prior to selecting option 9 to allow "fresh air" to reach the O_2 cell. The μV readings will be displayed for each sensor calibrated; these readings should range from 6500 to 10000 μV. Turn pump off for three minutes using option #6, and then turn pump on again for one minute. At the end of one minute note on the back side or in the margins of the data sheet the μV reading. Reprot this procedure until you achieve three readings which are ± 10 μV of each other.

Example:

```
YOUR CHOICE:? 9
#1 Rdng = 9060uV
```

Record the last μV readings for each oxygen sensor in **Section** C of the Maintenance Log Form. Note: if two sensors are used, the μV readings from the two sensors may vary from each other. This should not be cause for concern, so long as both sensors are within the 6500 to 10,000 μV range.

#10. Scale calibration. The scale is calibrated using a 10.0 pound calibration weight. Simply follow the directions which appear on the screen. After the weight has been loaded onto the scale, press one of the grey buttons on the scale keypad. After the green light on the keypad appears, remove the weight and press the red button. The red light will be illuminated momentarily when the calibration procedure is completed. Only a single calibration factor is stored, so which coal bed status button is pressed during the calibration procedure is unimportant. Care should be taken during the calibration procedure that the scale is level, on a hard surface, and that nothing besides the calibration weight is contacting the pan during the weighing process.

Example:

```
YOUR CHOICE:? 10
Put wt on scale
remove wt
CBS = 1
```

#11. Scale reading. A reading may be obtained from the scale using this option. Normally this is used with the 10 pound calibration weight to verify that the calibration procedure was done correctly. Follow the same procedure as outlined for option #10. The scale weight will appear on the screen when the process is complete. Calibration weight values should be ±0.1 pounds of 10.0 pounds; if not, the calibration procedure should be done again. (Note that no decimal point is shown; 100 is 10.0, 98 is 9.8.)

Example:

```
YOUR CHOICE:? 11
Put wt on scale
Remove wt
CBS = 1 wt = 100
```

When the first valid reading is obtained, repeat this option (Do not repeat option 10) for each of the four coal bed states, recording the readings obtained in **Section** C of the "Maintenance Log Form".

#12. System status. This updates the screen with new real time TC, solid state sensor, time, and O2 values in a form similar to **Figure** 2. In addition, the current sampling parameters are displayed. Verify at this time that all input channels are operating properly and that all sampling parameters are correct.

Check the O_2 cell with calibration gases. Open the compression cap on the "T" fitting on the right side of the pump. Attach the fitting from the high concentration ("15%") O_2 bottle. Close the toggle valve. Open the regulator valve on the gas bottle (clockwise) until the pressure gauge reads 25 psi. (**Warning!** Do not exceed approximately 25 psi!) Gas will begin flowing when the regulator valve is opened. Allow the gas to flow for 1 minute. Use option 12 to bring up the updated Maintenance screen and record the O_2 value in **Section** D on the data sheet.

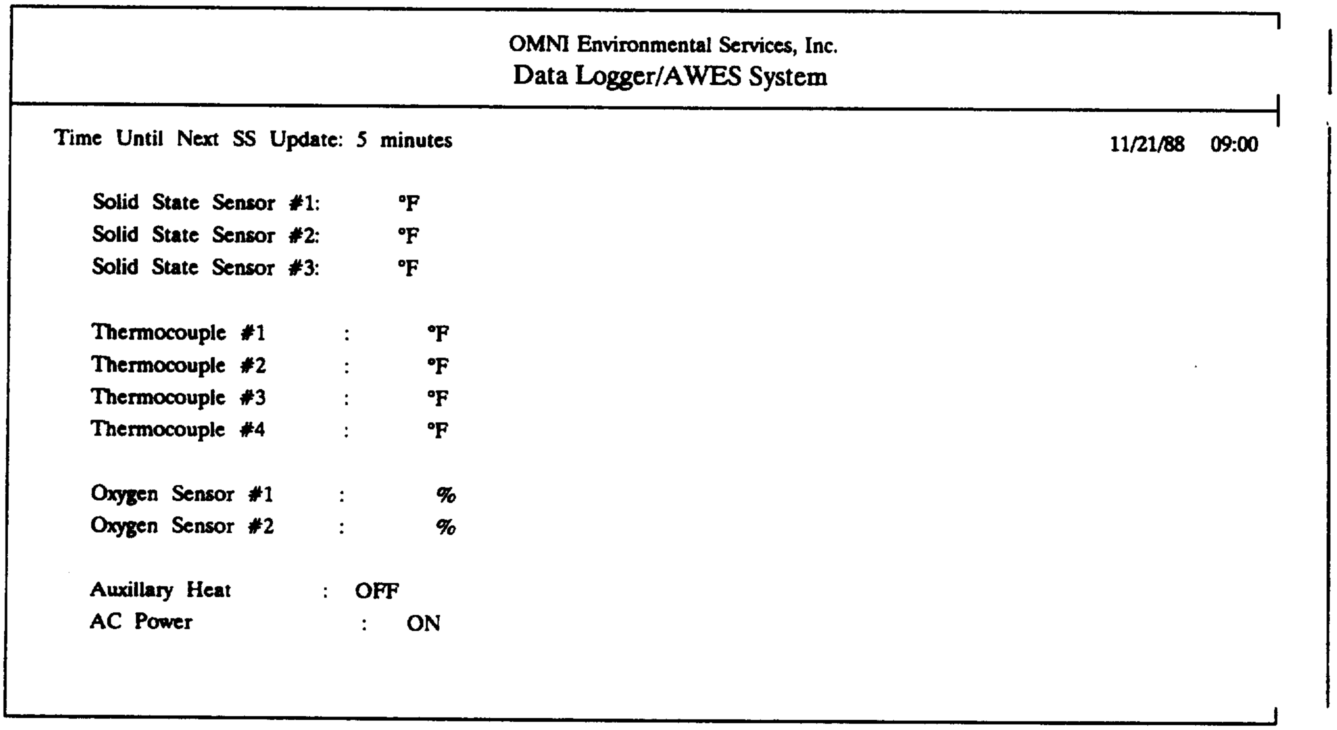
Close the regulator valve and the main valve on the gas tank of the 15% O_2 bottle. Disconnect the fitting from the 15% O_2 bottle and attach the fitting from the low concentration ("8%") O_2 bottle. Turn the gas on. Allow gas to flow for 1 minute. Bring up the maintenance screen with option 12 and record the O_2 value on the data sheet. Open the toggle valve. Turn the pump on using option 6. Flush out the span gas with ambient air for approximately one minute. Check O_2 % with option 12. Using option 6, turn off pump. Record the cumulative time count value in the AWES in **Section D** of the data sheet. **Do not turn the pump on after this value has been recorded!**

Close the regulator valve (counterclockwise), and the main valve on the 8% O_2 gas tank. Disconnect the hose fitting and replace and tighten the compression cap. With the main valves on the gas tanks closed, open the regulators on both tanks to release the pressure in the regulators. Do not travel with the regulators under pressure.

Connect a TC calibrator to the 3 TC channels and set the calibrator for 400°F. Record all the millivolt values on the screen on **Section E**. Verify that all values are reasonable! Use option 12 to bring up the Maintenance Screen again. Record all values from the maintenance screen in **Section E**.

#13. The black button on the Data Logger should be pressed immediately before option 13 is selected. Option 13 puts the DAS-5 into the data collection mode after all parameters have been entered and verified.

Within several seconds a screen should appear with the words "waiting for next minute marker. . ." After one minute, the monitoring screen will appear, as shown below. **The Data Logger is now asleep, and all inputs (TC, SS Sensor, Scale and O_2 readings, etc.) will be recorded on the memory cartridge.**



```
                         OMNI Environmental Services, Inc.
                            Data Logger/AWES System

Time Until Next SS Update: 5 minutes                              11/21/88   09:00

     Solid State Sensor #1:      °F
     Solid State Sensor #2:      °F
     Solid State Sensor #3:      °F

     Thermocouple #1      :        °F
     Thermocouple #2      :        °F
     Thermocouple #3      :        °F
     Thermocouple #4      :        °F

     Oxygen Sensor #1     :         %
     Oxygen Sensor #2     :         %

     Auxillary Heat       :  OFF
     AC Power               :   ON
```

The monitoring screen will not show TC values for another minute, and one SS sensor is updated every 5 minutes. Oxygen values will be updated at the end of a pump cycle. Scale weighing values will appear when the keypad is used.

Plug the TC calibrator into the TC channel(s), and set to 100°F. Wait for the one minute update, and record the values on the data sheet. Repeat for 1000°, and 2000°F. Enter the values on the data sheet in **Section F**.

Wait until the first five-minute marker has been reached (one of the SS sensor values will appear) before using the keypad. Use the 10 lb weight on each of the four coal bed status buttons, and enter the values on the data sheet in **Section F**.

Verify date and time shown in the upper right hand corner. Verify (after the first five-minute marker) that AC power is on.

Watch the monitoring screen for at least 10 minutes (2 SS sensors showing) to verify that the Data Logger is working properly. Disconnect the rainbow communication cable and lock the Data Logger box. Exit the DASR5.1 program by hitting Ctrl-Z twice.

B. Downloading and End-of-file Calibration Procedures

Entering the Maintenance Mode From the Data Collection Mode

1. Turn the computer on, boot it, and run DASR5.1. Do not do this with the computer connected to the Data Logger. Connect the computer to the Data Logger using rainbow communication cable. Fill out **Section** G.

2. The screen may fill with characters which represent data being sent to the data cartridge. These characters will appear at least every minute. These characters are in hexadecimal form and need not be heeded by the operator.

3. While the DAS-5 is still in the data collection mode, hit 13 and return. The monitoring screen will appear after one minute. Weigh the calibration weight for all four coal bed states, recording the weights that appear on the screen in **Section** H of the Maintenance Log Form. Connect the thermocouple calibrator to the thermocouple channels used and record the readings which appear on the screen at the next minute marker. **Record the AWES cumulative time counter value now.**

4. Press the black button on the top circuit board. After a 2-3 second delay the status screen and maintenance menu should appear. If the black button is pressed when the program is in the progress of writing characters to the screen, wait until the characters are finished and press the button again.

Check the O_2 cell with calibration gas. Open the compression cap on the "T" fitting on the right side of the pump. Attach the fitting from the 15% O_2 bottle. Close the toggle valve. Open the regulator valve (clockwise) until the pressure gauge reads 25 psi. **Warning! Do not exceed approximately 25 psi.** Gas will begin flowing when the regulator valve is opened. Allow the gas to flow for one minute. Use option 12 to bring up the updated Maintenance screen and record the O_2 value in **Section** I of the data sheet.

Disconnect the fitting from the 15% O_2 bottle and attach the fitting from the 8% O_2 bottle. Turn the gas on. Allow gas to flow for one minute. Bring up the Maintenance screen with option 12 and record the O_2 value on the data sheet.

Close the regulator valve (counterclockwise). Disconnect the hose fitting and replace and tighten the compression cap. Open the toggle valve. Make sure the main valves on both O_2 bottles are closed and that the pressure between the main valve and the regulator is released before traveling with the bottles.

5. Record the values that appear on the status screen in **Section** J of the Maintenance Log Form. Pull the AWES sample probe from the flue, and select option 6 to turn the sampler on for one minute to allow ambient air to reach the oxygen sensor. At the end of one minute, note O_2 % by using option 12 and record the value on the back of the data sheet or in its margins. Turn off the pump (option 6) for three minutes. Turn the pump on for one minute and note record O_2 %. Repeat this procedure for a total of five times and record the final O_2 % in section J of the maintenance log form. At the end of the fifth cycle, also use option 9 to record the μV reading in section J of the maintenance log form. Complete final leak check of AWES according to the AWES SOP.

6. It is now time to download the Data Logger onto a floppy disk. The downloading can take place with the data cartridge write lock in the "on" position; in fact, switching this on before beginning downloading will insure that something adverse does not happen to the data on the cartridge before it is totally sent to the host computer. The

cartridge may be removed temporarily from the DAS-5 if reaching the write-protect switch while the cartridge is in place is difficult. If the cartridge is removed temporarily, MAKE SURE the cartridge is placed back correctly into the DAS-5 (with the Dallas Semiconductor label facing the circuit boards).

7. Place a formatted floppy with at least 77 KB of space empty in drive B. The downloading option is activated by pressing the F1 key. The program will ask for a file name to which the data will be saved (prefix the filename with "B:" if data is to be saved to a floppy in the B drive); the uploading will begin automatically when this name is entered. File names should follow the convention established for the particular project in progress. Refer to Figure 7.

8. The operator should see a string of Ys appear on the screen as data is downloaded. When the process is complete, the string of Ys will end with an S and the menu will again appear. The downloading process takes five to ten minutes.

9. Record the data file name, date, and technician's initials on **Section K** of the Maintenance Log Form.

10. All data disks should be backed up (copied) as soon as possible.

11. The DAS-5 may now be reprogrammed following the procedures above, starting with option 1. It is mandatory that all menu items be selected in order to ensure that all calibrations and sampling parameters are updated. Check the battery voltage and replace the batteries if necessary. If the batteries have been used for more than five days, replace the batteries regardless of the tested voltage.

Temperature Sensor and Thermocouple Installation

The following narrative and Figure 1 should be used as a guide for solid state temperature sensor and thermocouple installation. **These must be installed following the presented conventions.** In preparation to connecting the sensors, remove the cover from the external filter board on the DAS-5 by removing the three nuts holding it in place. Two terminal strips will be exposed to which the sensors and AWES wiring (if used) will be connected. After wiring the sensors, replace the filter board cover, ensuring that all wires feed neatly through the hole in the side of the cover.

Solid State Sensors

1. Data Logger temperature sensor—this sensor is mounted on the filter board as a thermocouple cold junction reference. This sensor should already be in place and, barring failure of the sensor, should not be removed. If the sensor must be replaced, the negative lead is the one to which a resister has been soldered (i.e., the one with the solder blob should be oriented to the left). Alternatively, the orientation of the sensor should be such that the flat side of the sensor is facing the terminal strip.

2. Indoor temperature sensor—this sensor 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.

3. Outdoor temperature sensor—**Do not connect**—(Outdoor temperatures will be measured only at selected homes. The outdoor sensor will be located a foot or so from the outside wall and sheltered from direct sun. An ideal location is near the leading edge of the roof overhang and on the north or east side of the home.)

4. 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 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.

Thermocouples

1. Woodstove emissions thermocouple—this thermocouple will measure the temperature of the flue gases. The TC1 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.

2. Catalyst thermocouple—this thermocouple will only be used in catalyst-equipped woodstoves. The TC2 probe is inserted into a combustor cell in the middle of the combustor and is positioned so that the tip is one-half the way through 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 TC is positioned one inch in front of the inlet face of the combustor. It should be directly in line with TC #2 and should always be exactly one inch from the combustor. Photograph all TC installations.

Troubleshooting

Because of the complexity of the DAS-5 and the number of sensors attached to it, occasional problems are likely. Experience has shown that the most common cause of problems with the DAS-5 is operator carelessness resulting in broken wires or poor connections. Plan on taking time to be careful any time that wires are handled or disturbed. The second most common cause of problems is a lack of understanding of the procedures to be followed in installing the DAS-5. If problems are experienced, read over the instructions a second time to ensure that the correct procedures were followed.

Most problems may be located with the use of a volt-ohm meter. The discussion below assumes that such a meter is available.

Problems which are not covered in the discussion below should resolved by calling OMNI at 503/643-3755, or Lyle Pritchett at (702) 677–3183 (work) or (702) 246–1625 (home). OMNI is three hours **behind** EST; Lyle is two hours behind EST.

Problem: Cannot establish communications.

Check that the green LED is lit, indicating AC power is being supplied to the DAS-5. Check that the host computer is running "DASR5.1", that the communications cable is securely attached at both the host computer and the DAS-5, and that the connection at the DAS-5 is oriented properly (brown stripe in ribbon cable should be next to the terminal strip). If pressing the black reset button several times does not result in the appearance of the status screen, trying pressing the return key several times. If a question mark appears, the DAS-5 is already into the maintenance menu; simply type option 12 to produce a status screen and continue. If a colon appears, the program has aborted itself; type "goto 600" followed by the return key. This will start the program at the level of the maintenance menu; type option 12 to produce a status screen. If pressing the return key has no effect, press the Esc key several times; if the colon appears then type "goto 600" <return> to start the program.

If the DAS-5 still does not respond, try completely removing power (both AC and battery) from the DAS-5, waiting about 15 seconds, and reapplying power.

If the DAS-5 does not respond on the second application of power, test the communications cable by removing the 10-pin connector from the DAS-5, inserting a small diameter wire between the two pins adjacent to the brown wire in the ribbon cable, and try typing on the host computer. If the characters are echoed to the screen, the communications cable is working properly. If not, probably a break has occurred in the communications cable: contact OMNI for a replacement cable.

If the cable tests okay, try another DAS-5 unit. If communications can be established with the second unit, return the first unit to OMNI for repair.

Two items should be noted which will affect the communications between the host computer and the DAS-5. First, if this is a host computer which has not been used before successfully with the data loggers, the communications cable may be configured improperly for the serial port in the host computer. Switch the two wires on pins 2 and 3 in the 25-pin end of the communications cable and try communications again. Second, the host computer must be grounded properly in order for the serial port to work reliably with the DAS-5. If an adapter has been used to convert the 3-prong power cord on the computer to a 2-prong wall outlet or extension wire, that adapter must be grounded by connecting the ground loop on the adapter to the wall socket screw or some other reliable ground such as a water pipe.

Problem: Data cartridge will not initialize.

Failure of the data cartridge to initialize is manifested in three ways: the red LED may blink and five beeps will be produced; the six lines of hex data normally written to the cartridge after initialization do not appear on the screen; or after initialization the status screen indicates that more than 3 blocks of the cartridge have been used.

Check that the write-protect switch is in the "off" position. Check that the data cartridge is properly oriented with the "Dallas Semiconductor" label facing the circuit boards and that the cartridge is firmly seated in the socket. If the cartridge still does not work, try another cartridge. If the second cartridge does not work either, contact OMNI for assistance. If the second cartridge does work, probably the contacts on the bottom of the first cartridge are dirty. These contacts may be cleaned by gently wiping both sides of the data cartridge connectors with a paper towel moistened with alcohol or contact cleaner. Take care that excess solvent does not enter the cartridge. Try the cartridge again. If the cartridge fails after cleaning the contacts, return the defective cartridge to OMNI.

Problem: AC power is not being supplied to the DAS-5.

Check the green LED to see if AC power is indeed being supplied to the DAS-5. If the LED is not lit, insure that AC power is available at the wall socket, that the adapter is securely plugged in, that the two wires supplying power to the DAS-5 unit are securely fastened to the appropriate terminals on the filter board, and that the wire with the white stripe is at terminal #16. If the cause is not yet found, test across terminals 15 and 16 of the top terminal strip on the filter board. A proper reading is between 9 and 13 VDC. A lack of proper voltage at these terminals indicates that the power adapter is probably bad; replace the adapter with a different one.

If proper DC voltage is being supplied to the DAS-5 and the green LED is still not lit, check that the two wires to the LED are intact. Broken wires to the LEDs will affect the performance of the DAS-5 and should be repaired before the unit is used. Carefully solder the wires to the LED, or return to OMNI for service.

If the AC power problem has not been found by the above checks, contact OMNI for assistance.

Problem: the AC power indicator in the status menu indicates that AC power is off.

If the green LED is lit and the status menu still indicates that the AC power is off, check that the battery pack is attached securely to its clip; if the battery pack is not present or if poor connections are present, the circuit which switches between AC and battery power will not operate properly. If the problem cannot be located, contact OMNI for assistance. Note: if the problem cannot be located and the DAS-5 is operated in data collection mode, data may be lost.

Problem: unusually high or low oxygen sensor voltages.

Readings obtained from the O2 calibration option from the maintenance menu which are very large ($>1500\ \mu V$) or small ($<600\ \mu V$) are usually indications of poor connections somewhere. Recheck the connections from the O2 sensor to the filter board using Figure 2 for reference. Ensure that the connector to the AWES unit is tight. Check also that the wires to terminals 11-14 on the lower inside terminal board are tight. Negative μV readings are an indication that the O2 sensor wires are reversed.

Problem: high negative TC readings.

Highly negative (>-200 mV) TC readings indicate either that the leads to the filter board have been reversed or that the connecting wire or thermocouple probe itself has a problem. Try swapping a different thermocouple into the same channel to see if the problem persists. If the problem is not resolved, check that all connections at terminals 3,4,5,7, and 9 on the lower inside terminal strip are intact.

Problem: no thermocouple response when calibrator is attached.

A poor connection exists somewhere. Check the connections at the filter board, at terminals 3,4,5,7, and 9 on the lower inside terminal strip, and at the calibrator itself. Check also that the battery in the calibrator is fresh.

Problem: AWES pump will not run after toggling option 6.

Check that the connections to the filter board are intact and connected with the proper polarity. Check also the connection at the AWES unit. Finally, check that the AWES unit is plugged in. If no problems can be found, verify that the AWES pump should work by using the manual override switch inside the AWES. Check that all connections on the lower inside terminal strip of the DAS-5 are intact. If no problems can be found, contact OMNI for assistance.

Problem: scale keypad lights not working.

Ensure that the 25-pin connector to the scale/keypad cable is tight.
Note that if scale weights are attempted from the maintenance mode, option 10 or 11 must be selected BEFORE the coal bed state button is depressed. If the coal bed state has already been selected before selecting option 10 or 11, simply press the red button on the keypad to restore the scale to its resting state, then select option 10 or 11. If no obvious causes can be found for the failure of the keypad lights to work, most likely the cause is a break in an internal wire. Contact OMNI for assistance. DO NOT unnecessarily disturb the wires inside the DAS-5 looking for the break.

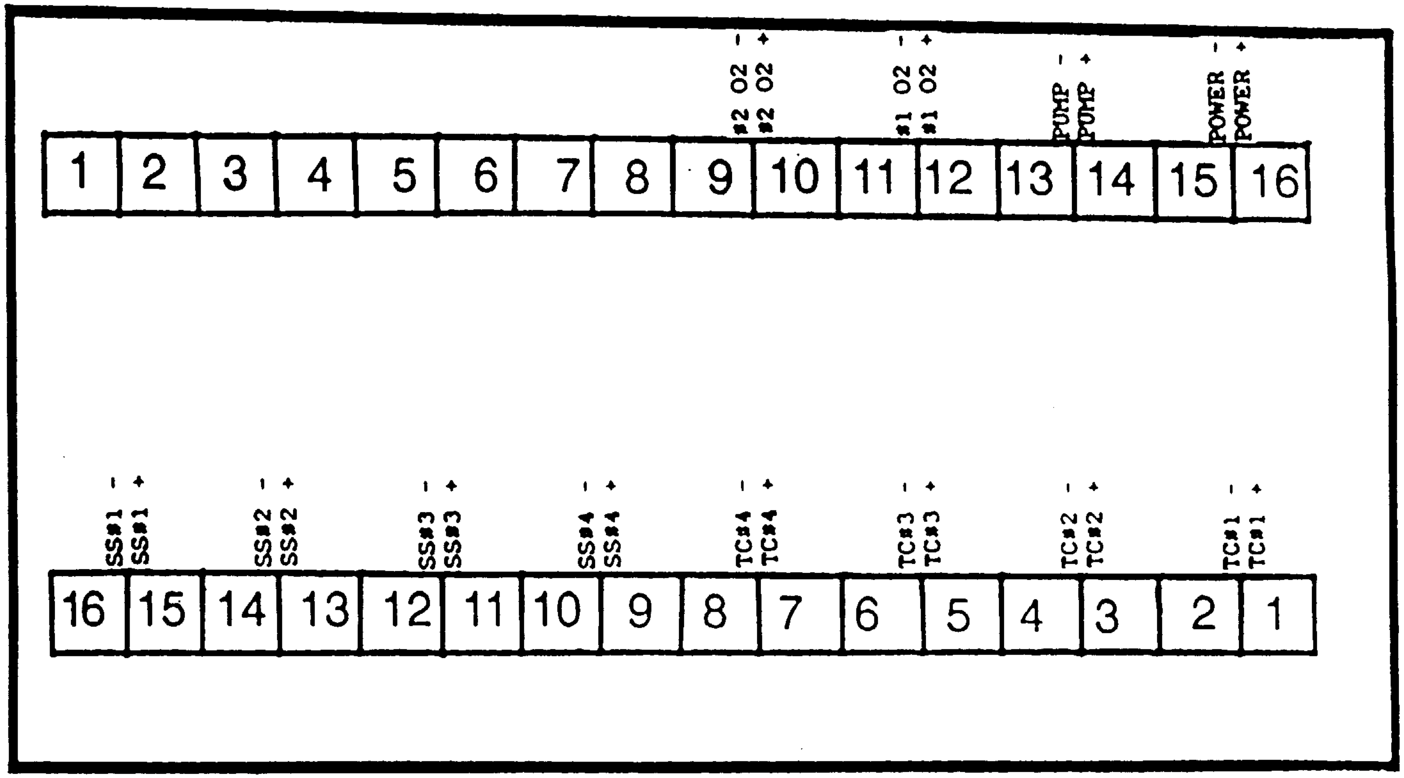
Problem: "Bad Calib." appears during scale calibration.

The calibration procedure has found an inadequate difference between the expected 10.0 pound weight and no weight at all. The weight should be placed on the scale before the coal bed state is selected, and the weight should be removed after the green light at the top of the keypad is lit. Note: during the time that the weight is being read from the scale, the scale should not be disturbed, against any object which would interfere with its weighing, or touched by the keypad cable, or inaccurate weights will be recorded.

Problem: one or more "Ns" appear during download of the data cartridge.

The appearance of the "Ns" during download indicates that the host computer did not receive a line of data from the data cartridge correctly. Normally, when the DAS-5 receives an "N", it simply re-sends the line. As long as multiple lines of "Ys" (with an occasional "N" possible) are on the screen when the downloading is complete, there is no cause for concern. If "Ns" are frequent or if the downloading program appears to "hang", or if fewer than normal lines of characters appear on the screen, make sure the cartridge is inserted correctly and refer to the discussion on communications problems earlier in this section. DO NOT erase the data cartridge until a complete and proper download can be verified.

Figure 1.
Filter Board/Sensor Wiring Diagram



NOTES: All multistrand leads to terminal block should be tinned.
Positive lead on power transformer has white stripe on wire.
Positive lead on O2 cell is white wire.
On 4-wire cable from AWES, positive O2 lead is yellow.
Negative leads on O2 cell are both the green and grey wires.
On 4-wire cable from AWES, negative O2 lead is green.
Positive lead on thermocouple is yellow.
Negative lead on thermocouple is red.
Positive lead on solid state sensor is red.
Negative lead on solid state sensor is green.

Figure 2
Sample Status Screen

```
          -----SYSTEM STATUS-----                    1003 Hrs 11/4/86

Serial #: 8541-49                            Vers: 3.1

Power:         ON          Bty used:         0 mins
Cartrage:      73 used                       10821 free
Trip point:    100 degF

Start month:   11
days:          1=5         2=6               3=7          4=8          5=9          6=10         7=1
start hour:    0           stop hour:        23
min. on:                   1                 min. off:    29

SSS:           1=65        2=-431            3=-459       4=-459
TC:            1=-9        2=-9              3=-8         4=-9
O2:            1= -110%                      2= 267%

          -----OPTIONS-----
1.Set clock    4.Alt trip 7.# TC's               10.Scale cal        13.Done
2.Init cart    5.Pmp times                       8.# O2's            11.Scale rdg
3.Rst batt     6.ES on/off                       9.O2 cal            12.Sys stat

YOUR CHOICE:?
F1 = Dump data cartrage data to a disk file.  :  <Cntrl-Z> = Exit
```

Figure 3

Data Logger

Temperature Sensor Location Form

Location Code ____________________

Stove Model ____________________

A. Initial Setup:

Sensor	Location
Thermocouple #1	
Thermocouple #2	
Thermocouple #3	
Indoor Ambient Temp. Sensor	
Aux. Heat Sensor	

____________________________________ ____________________

Service Technician Date

B. Location Changes: (Note any changes in temp. sensor locations during the heating season.)

Date	Comments	Technician

Figure 4

Location Code _____ Page ____

OMNI Data Logger Rotation Maintenance Log Form

AWES Setup

Run Number _____

A

1. Data Logger # ___________ 2. Scale # _____________ 3. Cartridge # ___________

B

Service Call Information

1. Check one: Initial Installation ___ Planned Maintenance ___ Unplanned* Maintenance ___

*If unplanned maintenance, state reasons in Part L.

2. Service Call Date: ___/___/___. Military Time ________:_________

C

Maintenance Mode Calibrations

1. O_2 Sensor span reading (with ambient going through all of AWES, 1 min. apart)
1 = _____ μV 1 = _____ μV 1 = _____ μV
2. Scale calibration with 10 lb. wt.: CBS 1=____ 2=____ 3=____ 4=____ ave.=____ (lbs)

D

O_2 cell calibration ________% O_2 Tank = ________% ________% O_2 Tank = ________%
________% O_2 Tank = ________% ________% O_2 Tank = ________%

E

Maintenance Screen

System Status **Just Prior** to Data Collection Period

Time________________ Date ________________

Power ____________________ Battery Used ______________ Min.

Cartridge: _____________ blocks used ______________ blocks free __________

Alt. Ht. Trip Point: ___________ F° (should be 95°)

Pump Mon = _____ Days 1=_____ 2=_____ 3=_____ 4=_____ 5=_____ 6=_____ 7=_____

Start Hr:________ Stop Hr:______ Min on:_____ Min off:_________

Sensors: (°F) ________ 1=_______ 2=_______ 3=______ 4=_______

Thermocouples (mV): 1=_______ 2=_______ 3=_______ (Calibrator set @ 400°F)

O_2%: 1=_________ (Pump must be on)

AWES Cumulative Time Counter ____________________ (Pump off)

Note: Fill out Part F **after** placing Data Logger into the Data Collection Mode.

F

Start of File Calibrations

Calibrator:	100°F	1000°F	2000°F
TC1	________	________	________
TC2	________	________	________
TC3	________	________	________

Scale calibrations: CBS A= ______ B= ________ C= ________ D= _______

Figure 5
AWES Takedown — Run Number __________

Note: Fill out Part G **prior** to switching Data Logger to Maintenance Mode.

Service Call Information

G
1. Check one: Initial Installation ___ Planned Maintenance ___ Unplanned* Maintenance ___
*If unplanned maintenance, state reasons in Part L.
2. Service Call Date: ___/___/___. Military Time ________:_________

H
Start of File Calibrations

Calibrator:	100°F	1000°F	2000°F
TC1	________	________	________
TC2	________	________	________
TC3	________	________	________

Scale calibrations: CBS A = ______ B = ________ C = ________ D = _______

AWES Cumulative Time Counter ________

I
O_2 span ________% O_2 Tank = ________% ________% O_2 Tank = ________%
________% O_2 Tank = ________% ________% O_2 Tank = ________%

Maintenance Screen

J
1. System Status **Just After** Data Collection Period
Time________________ Date ________________
Power ________________________ Battery Used ______________ Min.
Cartridge: ______________ blocks used _______________ blocks free ___________
Alt. Ht. Trip Point: ____________ °F
Pump Mon = _____ Days 1 = _____ 2 = _____ 3 = _____ 4 = _____ 5 = _____ 6 = _____ 7 = _____
Start Hr:________ Stop Hr:______ Min on:______ Min off:__________
Sensors: _________ 1 = _______ 2 = _______ 3 = ______ 4 = ________
Thermocouples (mV): 1 = _______ 2 = _______ 3 = _______ (Calibrator set @ 400°F)
O_2%: 1 = __________ (Pump must be on)
2. End of emission sampling period O_2 sensor reading after sufficient amount of ambient air is pulled through AWES: (using options 8 and 9) #1 _________ μV #2 _________ μV
3. Service Technician: ______________________________

Disk File Information

K
File Names
Data File ______________________________
AWES Sample ______________________________
Disk File Created
Date _____/_____/______
Time ________________

Field Service Notes

L
Planned and Unplanned Maintenance Record (note any changes to system parameters or hardware)

Date	Comments	Technician

Figure 6

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, e.g., 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, e.g., 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 catalyst 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

11.0 References

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