EPA-600/R-98-174a
December 1998

Residential Wood Combustion Technology Review
Volume 1. Technical Report

Prepared by:

James E. Houck and Paul E.Tiegs
OMNI Environmental Services, Inc.
5465 SW Western Avenue, Suite G
Beaverton, OR 97005

EPA Purchase Order 7C-R285-NASX

EPA Project Officer:

Robert C. McCrillis
U.S. Environmental Protection Agency (MD-61)
National Risk Management Research Laboratory
Air Pollution Prevention and Control Division
Research Triangle Park, NC 27711

Prepared for:

U.S. Environmental Protection Agency
Office of Research and Development
Washington, D.C. 20460

Abstract

A review of the current states-of-the-art of residential wood combustion (RWC) was conducted. The key environmental parameter of concern was the air emission of particles. The technological status of all major RWC categories was reviewed. These were cordwood stoves, fireplaces, masonry heaters, pellet stoves, and wood-fired central heating furnaces. Advances in technology achieved since the mid-1980's were the primary focus. These study objectives were accomplished by reviewing the published literature and by interviewing nationally recognized RWC experts.

The key findings of the review included: (1) The NSPS certification procedure only qualitatively predicts the level of emissions from wood heaters under actual use in homes, (2) Wood stove durability varies with model and a method to assess the durability problem is controversial, (3) Nationally the overwhelming majority of RWC air emissions are from non-certified devices (primarily from older non-certified woodstoves), (4) New technology appliances and fuels can reduce emissions significantly, (5) The ISO and EPA NSPS test procedures are quite dissimilar and data generated by the two procedures would not be comparable, and, (6) The effect of wood moisture and wood type on particulate emission appears to be real but to be less than an order of magnitude.

Executive Summary

A review of the current states-of-the-art of residential wood combustion (RWC) was conducted. The key environmental parameter of concern was the air emission of particles. The technological status of all major RWC categories was reviewed. These were cordwood stoves, fireplaces, masonry heaters, pellet stoves, and wood-fired central heating furnaces. Advances in technology achieved since the mid-1980's were the primary focus. In addition to RWC technology, several other related topics were reviewed. These topics included: (1) The evaluation of the U.S. Environmental Protection Agency (EPA) and the International Organization for Standardization (ISO) test methods for wood stoves, (2) The evaluation of in-home, long-term durability and emission performance of certified wood stoves, and, (3) The assessment of the effects of fuel wood types (tree species) and moisture on particulate emission factors. These study objectives were accomplished by reviewing the published literature and by interviewing nationally recognized RWC experts.

Taken as a group, the durability of currently manufactured certified Phase II wood stoves has improved and their particulate emissions are lower than the earliest Phase II models that became available circa 1990. However, there appears to be considerable variation by model within the group and the improvements seen over the earliest models have been described as marginal. Certainly, as a group, Phase II models are better than Phase I models and superior to uncertified models. There has been little incentive for manufacturers to improve durability beyond severe problems that would precipitate warranty claims. (Cordwood stove sales for 1997 were less than one-half of their 1990 level.) The efficacy of a laboratory stress test developed to predict long-term, in-home performance is controversial. The deterioration of catalytic activity often seen in catalytic wood stoves in a three to five year time frame and the identification of viable approaches to ensure catalyst inspection/replacement continue to be unaddressed problems. Wood stoves are designed out of necessity to pass the EPA certification test. It is generally recognized the these tests do not simulate the way that a stove is used in the "real world." Consequently, emission results obtained from certification tests are only roughly predictive of how a wood stove will perform under actual in-home use. However, the general perception is that stoves that show low emissions in the certification testing will also do well in homes. The current status of stove efficiencies is difficult to assess since, while there is an efficiency test method published in the Federal Register, efficiency testing is not required during the certification process.

The EPA certification procedure has been described as an art. Achieving a successful low burn rate condition and coal bed preparation are particularly challenging and they are quite unlike how a stove is usually used in a home.

There are two particulate test methods that can be used as part of the certification procedure, Method 5G and Method 5H. To make the results obtained from these two methods comparable a conversion equation was developed. The data available to develop the conversion equation were limited. The equation has been widely criticized and it is generally believed that after the conversion the 5G method will produce higher emission values than the 5H method. Method 5G is more precise and less difficult (and less costly) than 5H. It is the opinion of many that only the

5G method should be used, but if the two methods are continued to be used, the relationship between 5G and 5H should be re-evaluated.

With regards to the ISO 13336 test standard, at its current status of development, it is too different from the EPA certification methods to have anything but a qualitative correlation (i.e., stoves that show low emissions in the EPA certification will probably also show low emissions using the ISO 13336 test standard). Although the ISO 13336 standard is not final at this time, there is significant work being done in New Zealand, Australia, and in Europe to make the standard compatible or at least correlatable to the U.S. EPA methods and the European Community standards now being developed.

Approximately one quarter of the cordwood burned annually in residences in the United States is in fireplaces. There is no federal certification for fireplaces, although two states (Washington and Colorado) now have a certification program. Some fireplaces are used as significant heat sources and some are used for aesthetic or minor heating purposes. For fireplaces used as significant heat sources there are a number of older technologies (e.g., glass doors, heat convection tubes, and shaped masonry fireboxes) that effectively reduce emissions. In addition, there are certified cordwood and pellet inserts as well as gas inserts that can be installed within the fireplace that reduce effective emissions dramatically. For fireplaces used for aesthetic or minor heating purposes decorative gas logs and wax firelogs can be used to reduce emissions. There has been some research on cleaner burning fireplaces that minimize under-fire air and that utilize secondary combustion to reduce emissions but they are not yet commercially available. There is no significant marketing or, with the possible exception of the two state standards, no regulatory incentives to manufacture low emission fireplaces.

The technological status of three other less common RWC categories was also reviewed. These were: pellet stoves, masonry heaters and wood-fired central heating furnaces. There are about 0.3 million pellet stoves currently in homes. There are certified and exempt units. Modern pellet stoves (both certified and exempt) are very efficient and have very low emissions. Many early models had mechanical and electronic problems. These problems have been largely solved and new units have a good performance record. Pellet fuels have also become standardized which contributes to the success of pellet stoves. Masonry heaters produce low particulate emissions through high-temperature, short-duration combustion of cordwood that transfers heat to a high masonry mass. The masonry mass radiates heat after the fire is out. Masonry heaters are exempt from certification and few are in use due to their high cost. Less than 0.3 million wood-fired central furnaces were in use in 1993. They are exempt from certification. Little research has been conducted on them. The limited emission data that are available show their emission factors to be higher than conventional wood stoves.

The effect of wood type (tree species) and wood moisture on emission factors cannot be accurately quantified with existing data. Due to the physical and chemical differences in hardwoods and softwoods it would be reasonable to expect that their particulate emission factors would be different. However, based on limited data, the effect of wood type and wood moisture on emission factors appears to be smaller than an order of magnitude.

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1. Introduction

Air emissions from residential wood combustion (RWC) became a topical issue in the 1980's. Of most concern were particulate (PM), polycyclic organic matter (POM) and carbon monoxide (CO) emissions. The perceived need to reduce air emissions was the impetus behind the New Source Performance Standard (NSPS)[1] certification requirement for wood heaters and for the considerable RWC design and emissions research conducted in that decade. Manufacturers of wood heaters made major product changes in the late 1980's to meet the July 1, 1990 NSPS deadline that required all heaters manufactured after that date to be certified to Phase II emission limits. Emissions and appliance design research has also been conducted on other RWC appliance types currently exempt from the NSPS certification requirements: i.e., cookstoves, furnaces, appliances with air to fuel ratios greater than 35:1, and appliances weighing more than 800 kilograms.

Two key issues that continue to be of concern are (1) that the emission control performance of wood stoves operated in homes does not match laboratory certification results, and (2) that in-home emission control performance for some stoves becomes poorer over time. Other unresolved issues include how fuel moisture and fuel wood effect emissions, the efficacy of, and relationships between test methodologies, and the effectiveness and feasibility of routine appliance maintenance for reducing emissions. The difficulty in resolving or quantifying cause-and-effect relationships for these issues as well as for other RWC questions is due to the large number of interrelated variables associated with RWC. There are many hundreds of types and models of wood burning devices in use, many dozens of tree species are commonly used for wood fuel, draft characteristics vary (e.g., chimney and temperature conditions), household altitude is variable, there are variations in fuel wood seasoning and storage practices (i.e., wood moisture) and there are wide variations in the operation of wood burning devices (e.g., burn rate, burn duration, damper setting, kindling approach).

To assess the current level of understanding of key issues and to evaluate the overall states-of-the-art of RWC, OMNI Environmental Services. Inc. (OMNI) was contracted by the U.S. Environmental Protection Agency (EPA) to review the published literature and to interview recognized experts in the RWC field. Emphasis was placed on the advances made and knowledge gained since the 1980's. Nine RWC experts were interviewed. The experts interviewed included representatives from the hearth products industry, academia, government researchers and wood stove testing laboratories. An interview briefing package containing a list of topics for discussion was prepared and provided to each interviewee prior to being interviewed. In addition to the nine experts, OMNI staff have provided narrative and organizational input. OMNI is one of the oldest research and testing facilities for RWC. It developed the first certification testing protocol (for the State of Oregon) and has been conducting RWC testing and research since 1979. The Hearth Products Association (HPA) which is a trade organization representing the hearth products and solid fuel industries also provided comments. These comments were unsolicited and outside the scope of this project, however because they represented a synopsis of the opinions of 27 industry experts expressed at an HPA-sponsored technical committee meeting, they were incorporated into this review. OMNI has also prepared a preliminary list of relevant RWC literature which was distributed to each of the interviewees with a request for any additional available literature not contained in the preliminary list. With the references supplied by the expert interviewees included, a total of 417 references were compiled for the review.

A broad spectrum of residential wood burning technology was evaluated. Twelve topics identified by the EPA provided the basis for the interviews, for the HPA comments and for the literature review. These were:

- State-of-the-art of wood stove combustion and emission control technologies
- State-of-the-art of fireplace emission control technology
- State-of-the-art of wood-fired central heating furnace emission control technology
- State-of-the-art of pellet-fired wood stove technology
- Ramifications of the International Organization for Standardization (ISO) draft standard WD 13336[2]
- Correspondence between in-home and laboratory emission test results
- EPA Method 28[3] strengths and weaknesses
- EPA Methods 5G[4] and 5H[5] correlations
- Performance deterioration of EPA-certified wood stoves in the field
- Stress (durability) test pros and cons
- Feasibility of developing separate emission factors for dry and wet wood and for softwood and hardwood species classes
- Routine maintenance of appliances

For many issues, a consensus among the experts was not obtained. In these cases key conflicting viewpoints have been presented. In some cases, minority viewpoints were not discussed in the text because the published literature and the comments from the other experts clearly did not support them. However, for the sake of including all viewpoints, complete review transcripts are contained in Appendix B to this report.

A summary of the findings for each of the twelve topics constitutes the body of the report. The list of published literature is contained in Appendix A. The list of expert interviews, the interview briefing package and the individual interview summaries are provided in Appendix B. A list of the attendees at the HPA technical committee meeting and the synopsis of the attendees opinions provided by the HPA are in Appendix C.

2. Review Topics

2.1 State-of-the-Art of Cordwood Stove Combustion and Emissions Control Technologies

Based on commercial marketing surveys there are an estimated 9.3 million cordwood stoves in use in the United States. From HPA surveys of manufacturers it is estimated that about 0.6 million of these are certified, non-catalytic cordwood stoves and about 0.4 million are certified catalytic cordwood stoves (i.e., there are about 8.3 million old conventional cordwood stoves and about 1.0 million certified cordwood stoves in use in the United States). The term “conventional” is used in this report to indicate non-certified wood burning stoves that were primarily produced before the advent and use of design factors for reducing or controlling wood stove pollutant emissions. All stoves manufactured after July 1, 1988 and sold after July 1, 1990 had to be certified to Phase I particulate emission levels. All stoves manufactured after July 1, 1990 and sold after July 1, 1992 had to be certified to the lower Phase II particulate emission levels. On August 12, 1997, 121 non-catalytic cordwood stove models and 87 catalytic cordwood stove models (including fireplace inserts) were listed as certified to Phase II standards.

Particulate emission factors and efficiencies for conventional and phase II certified cordwood stoves have been tabulated by EPA in AP-42[6]. The general consensus among interviewees is that the emission factor given in AP-42 for conventional wood stoves is lower than the average that would be representative of the United States as a whole and that due to improvements in certified wood stoves, emission factors in AP-42 for Phase II certified cordwood stoves are higher than for newly manufactured appliances. There is persuasive, albeit anecdotal, evidence for both assertions.

The average emission factor for conventional wood stoves is based on studies conducted in homes in Vermont; upstate New York; Portland, Oregon; Whitehorse, Yukon; Klamath Falls, Oregon; and Crested Butte, Colorado. The average value reported in AP-42 is weighted based on the number of tests. The total number of tests that make up the data base is 141. There were 53 tests conducted in Whitehorse and 59 tests conducted in Crested Butte, consequently the average is determined to a large part by the Whitehorse and Crested Butte data. The heating degree day (HDD) value for Whitehorse is 9545 and for Crested Butte it is 11,500, both of which are much higher than most of the wood burning areas of the United States. For example, in 1993 the U.S.

Department of Energy (DOE) reported that 32% of the cordwood consumed in the United States for RWC was consumed in the South census region[7]. It has been well established that higher burn rates (hotter more complete combustion conditions) characteristic of colder climates produce lower emissions. Therefore it is reasonable that the actual national average particulate emission factor for conventional wood stoves is higher than the generally accepted value reported in AP-42. (Several caveats should also be noted in regards to the effect of the Crested Butte data on the calculation of the national average emission factor value. While the effect of a colder climate [i.e., higher burn rate] would be to reduce the magnitude of emission factors, the effect of Crested Butte's unusual 8850 foot [2697 meter] altitude and the effect of the dry wood burned in many of the homes during the studies would tend to increase the emission factor. In addition a different sampling system was used in Crested Butte than in the other studies which may cause the data to be offset with respect to the other data [see Section 2.6].)

In addition, to lower burn rates potentially producing higher emissions in milder climates the fact that the highest emission rates occur during the kindling phase of a burn is also significant. There are some data that suggest that as much as one-half of the total emissions for an individual burn period for non-catalytic stoves occur during the kindling phase (first 17% of a burn) and more than 50% occur for that time period for catalytic stoves[8]. In warmer climates fires tend to be started and allowed to burn out more frequently than in colder climates hence the kindling phase portion of the burn period will contribute relatively more to the overall emissions in warmer climates than in colder ones. Another related observation was that stoves purchased in the Western United States tend to have larger fireboxes than those purchased elsewhere, hence if all else is equal stoves in the Western United States will have higher emissions since emissions tend to be higher for larger firebox appliances for a given burn rate because combustion temperatures are not as high in a larger firebox.

The emission factors for Phase II certified stoves in AP-42 are also based on studies conducted in homes. The data set is also over represented by stoves located in colder climates although not as much so as for the conventional stove data set. The key issue for emission factors given in AP-42 for Phase II certified stoves is the fact that they are based on studies conducted in homes during the 1989/90 heating season or earlier. Consequently, only the earliest Phase II certified models or models that eventually became Phase II certified, were included in the averages for AP-42. Manufacturer representatives commented that improvements have been made on many of the certified models in regard to the durability of construction materials, there have been many new models introduced and certified since July 1, 1990 and many models that had durability issues or that were manufactured by smaller less established companies are no longer available. This is supported by the observation that more than one third of the wood stove models listed in the EPA August 12, 1997 certified stove list are no longer offered. The key motivation for improved durability has been financial due to the cost of repairing or replacing stoves under warranty.

Using AP-42 data as a starting point, Table 2.1-1 was prepared. It represents the AP-42 data qualitatively adjusted based on "best professional judgment" to take into consideration climate and model improvement factors. This table was provided to the nine experts and to the HPA technical committee for comment. While a spectrum of comments was received, the overall consensus appeared to be that the values shown in Table 2.1-1 were reasonable. Table 2.1-1 also shows the percent reduction in emission factors achievable with the replacement of conventional cordwood stoves with certified catalytic and non-catalytic models.

The efficiency of a wood heater is an important factor in assessing emissions and in comparing emission reductions offered by new technology appliances since a more efficient device will use less wood to provide the same heat which produces an effective emissions reduction. Efficiencies of cordwood stoves have been tabulated in AP-42 based on field studies. The interviewees noted, as with emission factors, there is a range of efficiency values for a given technology type but in general agreed that the average values shown in AP-42 are more-or-less reasonable with the exception of the value for catalytic cordwood stoves which should be slightly higher to reflect newer or well maintained units. The catalytic cordwood stove value shown in AP-42 is 68%. The default efficiency value used for U.S. EPA NSPS certification is 72%. The latter value was felt to be more representative of new or well-maintained catalytic stoves. Efficiency values are given in Table 2.1-2 along with particulate emissions in units of mass particles per amount of heat delivered. Table 2.1-2 also shows the percent reduction in emissions when a conventional cordwood stove is replaced with a certified catalytic or non-catalytic cordwood stove. One very relevant comment was that for non-catalytic stoves, some less efficient units may produce less emissions (if all else is equal) since higher temperature gases which produce a greater sensible heat loss may also promote tertiary combustion downstream of the baffle. Unfortunately, the relationship between efficiency and emission factors cannot be determined since efficiency testing is not required during the certification process and default values are usually used.

There is currently no strong impetus to improve or test wood stove efficiency. There is a well documented efficiency test method published as a proposed method by the U.S. EPA[9]. Opinions among experts were split regarding the appropriateness of testing efficiency. Some felt that a requirement to test efficiency would add additional and unacceptable costs for appliances that have a small market, plus many of the manufacturers feel they are already over regulated. Others felt that adding efficiency to the emission testing would only add a very small incremental cost to certification testing since most of the information needed for efficiency calculations is already obtained during the NSPS certification process as it now stands.

Related to the determination of efficiency is the use of emissions per unit of heat delivered to rank the performance of stoves since efficiency is needed to calculate emissions in this fashion. Some felt that since emissions in the units of mass of particles per mass of fuel burned (g/kg) and mass of particles per hour of stove operation (g/hr) are already in common use, that another unit (g/MJ or lb/MBtu) may cause confusion and may require additional education of the public and regulators. Others felt it was the most appropriate way to assess emissions since the emissions per amount of heat delivered is the environmental “bottom line” for a heating appliance.

Table 2.1-1

“Best Professional Judgement” Particulate Emissions Factors and Their

Reduction by the Use of Alternatives to Conventional Stoves and Cordwood

	Particulate Emissions Factor		
Appliance	Pounds/Ton	Grams/Kilogram	Reduction (%)
Conventional Stove	37	18.5	--
Non-Catalytic Stove	12	6	68
Catalytic Stove *	13	6.2	65
Pellet Stove	4	2	89
Masonry Heater	6	3	84
Conventional Stove with Densified Fuel	25	14	24

* With a well maintained catalyst after normal use, on the average a newer catalyst will produce lower emissions and an older catalyst higher emissions.

The general perception is that the emission reduction performance of Phase II wood stoves has improved marginally over the earliest certified models. They have become more reliable and durable. For example, most manufacturers originally offered only one-year warranties, now prorated five-year warranties are common. The major incentive for the improvements has been the cost of warranty replacements and marketplace competition.

Laboratory and in-home research has shown that exposure to high temperature during very high burn rates and under high draft conditions accelerates the degradation process. For non-catalytic stoves, warping and cracking of the baffles and secondary air tubes are the most common form of degradation seen and can cause higher emissions due to their adverse effects on secondary combustion characteristics. The two most common degradation effects seen in catalytic stoves are damage to the catalyst bypass and the deterioration of the catalyst itself either through physical breaking, pealing or plugging or through the loss of catalytic activity. Under normal use the emissions of particles from most catalytic wood stoves will increase, in some cases reaching conventional stove levels within five years of use due to the loss of catalytic activity.

It should be noted that the routine replacement of a catalyst is a simple procedure for many models. The catalyst bypass is susceptible to damage due to the fact that it is a moving part. If it does not seal properly a fraction of the emissions bypasses the catalyst and enters the atmosphere

Table 2.1-2

“Best Professional Judgement” Efficiencies, Particulate Emission per

Unit of Heat Delivered, and Effective Pollutant Reduction by the Use of Alternatives to Conventional Stoves and Cordwood

Appliances	Efficiency (%)	Mass Particulate Emissions/Delivered Heat		
		lb/MBtu	g/MJ	Reduction (%)
Conventional	54	3.89	1.68	-
Non-cat. Stove	68	1.14	0.49	71
Catalytic Stove*	72	1.02	0.44	74
Pellet Stove	78	0.31	0.13	92
Masonry Heater	58	0.59	0.25	85
Conv. with Densified Fuel	57	2.79	1.20	27

*With a well maintained catalyst after normal use, on the average a newer catalyst will produce lower emissions and an older catalyst higher emissions.

untreated. In most cases the repair of a catalyst bypass system needs to be performed at the manufacturer's facility. Another minor problem common to both catalytic and non-catalytic stoves, is the deterioration of the fuel loading door gasket material causing leaks and commensurate excess combustion air. Faulty door gaskets are typically noticeable to casual observers and easily replaceable.

As discussed previously, most interviewees felt that performance and durability improvements have occurred since the advent of Phase II of the U.S. EPA NSPS but they have been marginal. They also felt that further improvements are possible but there is little incentive at this time for the improvement of fundamental catalyst technology applied to RWC since the current technology meets NSPS requirements and because there are so few catalytic wood stoves currently being sold. It should be noted however, that some early models of catalysts failed due to substrate disintegration and this problem was addressed and is not seen in current models. There is also little incentive for a wood stove manufacturer to change the design of a wood stove even slightly to improve performance because all new, updated safety and emissions testing would need to be performed for the "new model."

An interesting observation was made by one interviewee. If a catalyst were used that would withstand temperatures just a few hundred degrees higher than those currently generated in a wood stove catalyst, even if it cost 50% more than currently used catalysts, there would be a dramatic improvement in performance and durability. The current cost of a catalyst represents less than 10% of the costs of a catalyst stove.

Beyond the issue of catalysts, the overall opinion regarding future wood stove performance improvements was relatively consistent: they can be made but there is little incentive to do so. Stoves are designed to pass safety and EPA certification tests and to garner a market share primarily through cost and appearance. The reduction of emissions under in-home use conditions and post warranty durability are not important market factors. With the exception of addressing gross durability issues which cause warranty problems it is unlikely that significant improvements will be made in wood stove durability.

One additional point is worth noting. State and local air quality authorities can require wood stove emission limits lower than those required by the EPA which, of course, can provide impetus for improvements in wood stove designs. The State of Washington's regulation (Washington Administrative Code 150-31-200) is an example of a more stringent regulation. Once stoves are designed to meet more stringent state or local regulations, they will be sold in other jurisdictions as well.

Non-catalytic stoves obtain their emission reduction with the use of geometry, secondary air, heat retaining refractory material and insulation. These factors are "tuned" to optimize lower emissions from the burn cycle requirements specified in the U.S. EPA NSPS Method 28 certification procedure. Most challenging is combining these factors to produce low emissions at the low burn rate conditions and within the constraints of the five-minute test period start-up procedures specified in Method 28. It is generally felt that the low burn rate and five-minute start-up procedure specified in Method 28 are "artificial" in that stoves are not used in homes in a manner that approximates the Method 28 low burn rate and start up procedure. The other major comment is that stoves are designed to produce low emissions while burning dimensional lumber with fixed spacing, not cordwood loaded in a stove in the "normal" fashion.

Catalytic stoves are less sensitive to burn rates and patterns than non-catalytic stoves since once the catalyst is "ignited" emission reduction is controlled by the catalyst. Similarly, the internal design of a catalytic stove, other than designing the unit to avoid direct flame impingement on the catalyst surfaces and optimizing its temperature exposure, requires less engineering than a non-catalytic stove. As a consequence of catalyst being less sensitive to stove design, catalytic stoves with larger fireboxes than non-catalytic stoves can achieve low enough emissions to be certified.

As previously discussed, in home use, a large fraction of the particulate emissions from wood stoves occurs during the kindling phase before the stove reaches its optimum operating temperatures and in the case of catalytic stoves, before the catalyst is ignited. Also as previously discussed, the problem of high emissions during the kindling phase is relatively more important in warmer climates or in the spring and fall when the stoves are allowed to burn out between fuel loads and there are more cold starts. The use of high heat content starter wax logs or the use of natural gas to rapidly bring temperatures up to the point at which secondary combustion occurs or to reach the ignition temperature of the catalyst, have the potential of reducing emissions significantly. Preheating the catalyst with an electric heater has also been suggested. However, again, there are no significant incentives for advancing current technologies.

The use of densified fuel logs as a fuel has been shown to reduce particulate emissions in the 20% to 30% range as compared to cordwood (Tables 2.1-1 and 2.1-2). Densified fuel is most readily available in the Western United States. For the purposes of this discussion, the term "densified fuel" is used to describe those manufactured fuel logs which contain only compressed wood materials (e.g., chips, sawdust, etc.) in contrast to wax fire logs which contain about 60% petroleum wax and are burned in fireplaces. Densified fuel is clean, uniform in size, and convenient, however it costs about 70% more than cordwood. Some interviewees felt densified fuel offered a viable option for reducing emissions, others felt that it did not since many wood stove users are low income and either cut their own fuel wood or could not afford the additional cost of densified fuel. In urban or suburban areas where air quality is more often an issue the use of densified fuel may be more viable than in rural areas. Not only is wood cutting less of an option in urban and suburban areas but the distribution of a commercial product such as densified fuel is easier there. It is also the opinion of some interviewees that wood stove users in urban and suburban areas are on the average more affluent than in rural areas, hence the added cost of purchasing fuel is less of an issue for suburban and urban wood users. In any case, it was expressed that densified fuel does offer the potential to significantly reduce emissions during short-term episodic air pollution events when burned as a cordwood replacement in existing certified or conventional wood stoves.

The discussion on masonry heaters has been included in this section along with wood stoves because masonry heaters are more closely allied to wood stoves in their use than to fireplaces. Like wood stoves, they burn cordwood primarily for heating whereas fireplaces are more often used for aesthetic, recreational, or only for minor heating purposes. The emission factors and efficiencies given in AP-42 and shown in Tables 2.1-1 and 2.1-2 for masonry heaters are based on in-home studies conducted in the early 1990's. Most interviewees were in agreement that the values are reasonable for the emission factor and efficiency of the current state-of-the-art masonry heater, although it was noted that there is a range of values for different models and operation conditions. Masonry heaters achieve their low emissions by burning wood at a high rate (i.e., high temperature complete-combustion conditions) during a short time period. A large mass of masonry material is heated rapidly by the high-temperature fast-burning fuel load. The "stored heat" is then radiated from the masonry materials into the space being heated after the fire is out. Efficient heat transfer is achieved by a folded flue system which runs through the masonry material. In contrast to fireplaces, which are most often located along the outside wall of a home, masonry heaters are generally located toward the center of a home to facilitate heat transfer and also in contrast to fireplaces, masonry heaters typically have combustion air controls.

Because masonry heaters weigh in excess of 800 kg, they are exempt from EPA NSPS certification requirements. However, both the State of Colorado's Regulation 4 and Canada's R-2000 high-efficiency home program have certification procedures for masonry heaters. Some interviewees felt that there should be no EPA certification required for masonry heaters because there are so few in use.

The majority felt that they should be certified to provide them with a level of credibility and acceptance, however, those who felt that they should be certified agreed that the certification protocol would need to be conceptually and practically quite unlike that used for wood stoves due to the typical single, high burn rate and large mass of masonry heaters. Emissions expressed in g/hr units are meaningless for masonry heaters due to the fact that their heat release is not contemporaneous with their fuel burn cycle. Emissions expressed in g/kg or g/MJ are more meaningful.

Because masonry heaters and masonry fireplaces can be similar in appearance and construction, conceptually there could be units that would fall between those that are clearly masonry heaters and those that are clearly fireplaces. It was felt important that a definition be established distinguishing the two appliance types. One suggestion for delineating the two appliance types was an efficiency threshold in the 40% to 50% range, another was to develop a narrative description of the flue and air control systems. The Masonry Heater Association of North America (MHA) has developed a definition based on construction materials, techniques, and specifications along with surface temperature performance requirements.

2.2 State-of-the-Art of Fireplace Emissions Control Technology

There are 27 million fireplaces currently in U.S. homes. Some fireplaces are used as supplemental heat sources, some are used for only aesthetic or minor heating purposes and some are even used as a primary heat source. There are two structural types of fireplaces ─ manufactured metal fireplaces (referred to as zero-clearance or factory-built fireplaces) and site-built masonry fireplaces. Industry experts estimate that about 20% of existing fireplaces are masonry and 80% are factory-built. There were approximately 0.4 million factory-built fireplaces sold in 1997. Factory-built fireplaces are designed to last 40 years or more. Masonry fireplaces can last indefinitely. Consequently, the 27 million fireplaces currently in homes will be available for use well into the future.

The emission factor for fireplaces given in AP-42 is 17.3 g/kg. This value was estimated by the EPA using limited field and laboratory data. Estimates from more recent (albeit also limited) data, produces a value of about 12.5 g/kg. The typical burn rate of a fireplace is 3 kg/hr. The emission rates corresponding to an emission factors of 12.5 g/kg and 17.3 g/kg with a burn rate of 3 kg/hr are 37.5 g/hr and 51.9 g/hr. There has been some data suggesting that 60 g/hr is a more representative fireplace emission rate. Clearly, the particulate emission rate from a fireplace is dependent on what the “typical” burn rate is. There was no consensus of opinions among the interviewees on how reasonable these emission values were for fireplaces. Some thought they were too low, some thought were too high and some thought they were reasonable. It is recognized that the data base is very small and emissions are very variable.
A large number (albeit the minority) of fireplaces are used as significant supplemental heat sources. Fireplace inserts are designed for increased efficiency, and based on national surveys there are 7.1 million fireplaces with inserts in them. (The term “insert” as used in the survey is not what is often thought of as an insert. It most likely encompassed a variety of older fireplace

designs and accessories, such as double-shell convection designs, convection tubes, blowers, etc. Some of the survey respondents also may have confused a zero-clearance fireplace unit with the term “insert.”) Some fireplaces are even used as primary heat sources. In 1993, 0.4 million households used wood burning fireplaces as their main source of heat.

Fireplaces utilizing older technology may be able to reach efficiency levels in the 40% range. Older technologies that increase efficiencies and effectively reduce emissions by requiring less wood to provide the same heat include double-shell convection designs, convection tubes, the use of blowers to transfer heat, glass doors, and masonry fireplaces with contoured fire chambers (e.g., Rosin and Rumford designs). The open radiant fireplace, with an efficiency potential of approximately 7% is the simplest and most common fundamental unit. Efficiencies, emissions in units of mass particles per unit of heat delivered and effective emission reductions obtained with these older technologies as compared to simple open radiant fireplaces are shown in Table 2.2-1. In reviewing the data in Table 2.2-1 it should be noted that the effective efficiency of a given fireplace varies with outside temperature and chimney draft.

Certified non-catalytic, certified catalytic, and pellet inserts can be installed into and used in existing factory-built and masonry fireplaces. They are essentially wood stoves designed to be installed into fireplace firebox/hearth cavities. If properly installed, their performance is similar to that of their stove counterparts, albeit their efficiencies are slightly lower since convection and radiation of heat is more restricted by their fireplace cavity surroundings and fireplaces are often located along an outer wall. There are an estimated 0.5 million certified cordwood inserts and 0.2 million pellet inserts in use. The EPA lists four catalytic and six non-catalytic insert models as certified. Efficiencies, emission factors in units of mass particles per unit of heat delivered and effective emission reductions obtained with certified cordwood and pellet inserts as compared to simple open radiant fireplaces are shown in Table 2.2-1.

Over the last 10 years, the use of natural gas and liquified petroleum gas (LPG) in place of cordwood has become widespread in fireplaces used for primary and supplemental heating purposes. Three types of gas units have the “fireplace-look.” They are gas fireplace inserts, decorative gas fireplaces, and gas fireplace heaters. All have negligible particulate emissions, compared with cordwood fireplaces. Therefore, particulate reductions are near 100%. The environmental “downside” of the nearly 100% particulate reduction is that both natural gas and LPG are, of course, fossil fuels, not renewable biomass fuels. Gas fireplace inserts, like certified cordwood and pellet inserts, can be put into existing fireplaces. Decorative gas fireplaces and gas fireplace heaters are generally designed for new construction. Gas fireplace heaters are more sophisticated than decorative gas fireplaces, as they are designed more for efficiency whereas decorative gas fireplaces are designed more for flame presentation aesthetics.

Table 2.2-1

“Best Professional Judgement” Efficiencies, Particulate Emissions per Unit of Heat Delivered, and Effective Pollutant Reduction by the Use of Alternatives to Open Radiant

Fireplaces and Cordwood

Appliance/ Fuel	Thermal Efficiency (%)	Mass of Particulate Emissions/Delivered Heat (g/MJ)	Reduction (%)
Conventional Open Radiant Fireplace	7	8.6	-
Double-Shell Convection, Natural Draft	13	4.6	46
Convection Tubes, “C” Shaped, Glass Doors	15	4.0	53
Double Shell Convection, Blower, Glass Doors	32	1.9	78
EPA Certified Non-Catalytic Insert	66	0.50	94
Certified Catalytic Insert*	70	0.45	95
Pellet Stove Insert	76	0.13	98
Gas-Fired Insert	75	Negligible	~100
Gas-Fired Fireplace	50	Negligible	~100
Certified Catalytic “Fireplace-Like” Wood Stove	70	0.45	95
Masonry Fireplace With Shaped Fire Chambers and Glass Doors	42	1.2	86

*With a well maintained catalyst after normal use, on the average a newer catalyst will produce lower emissions and an older catalyst higher emissions.

Some certified wood stoves are designed to have the appearance of fireplaces, to be “zero-clearance” units, and capable of being installed at the time of construction. The effective emission reduction they can offer over simple open radiant fireplaces is on the order of 95%. These units are sometimes called EPA certified fireplaces but, in fact, meet all of the EPA NSPS definition specifications for an "affected facility" wood stove (i.e., one that is subject to the NSPS regulation).

In addition to the large number of fireplaces used for supplemental heating purposes, even more fireplaces are used for aesthetic or minor heating purposes. During the 1994-1995 heating season, 17% of surveyed fireplace owners reported burning wood once or twice a season, 13% reported burning wood once or twice a month, and 18% reported burning once or twice a week. The sum of these three categories corresponds to about 13 million fireplaces in the United States. Even though these statistics do not provide an exact number of fireplaces used for aesthetic and minor heating purposes, they do illustrate the relative magnitude of use. As these data indicate, many fireplaces are used very infrequently. Of the 27 million total fireplaces in the United States, survey data suggest that only 16 million of them were used to burn wood in any given 12-month period.

As with wood stoves which are designed and used for the utility of residential space heating, it is important to use the most appropriate reporting units for providing a means for comparison between fireplaces. Unlike wood stoves however, fireplaces can be used partially or totally as space heaters or they can be used partially or totally for aesthetic or recreational purposes. In the case of appliances used as sources of heat (i.e., wood stoves and "heating fireplaces"), the use of emissions mass per unit of heat delivered (i.e., grams/MegaJoule), is appropriate. In this sense, masonry heaters can be considered a special case of a "heating fireplace." In the case of appliances used strictly for aesthetic or recreational purposes however, emissions rates (grams/hour) or emissions factors (grams/kilogram of fuel burned) provide for better comparisons. For emissions inventory purposes, having g/hr information for a population of fireplaces would only require the determination of population usage hours for calculating an estimated total airshed impact. On the other hand having g/kg information for a population of fireplaces would only require the determination of total wood usage by the population for calculating an estimated total airshed impact.

The burn rate of a fireplace used only for aesthetic purposes is mostly related to the size of a typical sustained "warm" aesthetic fire, typically about 3 kg of cordwood per hour. The amount of wood burned and the resulting emissions are not directly related to heat demand, but are more or less constant for a given appliance. Wax fire logs typically have a fixed burn rate associated with them. Manufacturers of wax logs generally recommend a one-at-a-time usage rate with each log having a specified burn duration. Since most wax fire logs burn in the range of 0.7 to 1.3 kg/hour, it more appropriate to use the mass of emissions per hour (i.e., g/hr) reporting units when a fireplace burning cordwood for aesthetic purposes is compared to a fireplace burning wax fire logs.

Manufactured wax fire logs are widely used in fireplaces nationwide. One hundred million manufactured logs are burned each year. Manufactured logs were burned some of the time in 30% of the fireplaces and exclusively in 12% of the fireplaces during the 1994-1995 heating season. Typical wax fire logs are composed of approximately 60% wax and 40% sawdust. Paraffin or microcrystalline waxes are used. The heat content of wax logs is much higher than that of wood, and their moisture content is much lower. They are exclusively for use in fireplaces (not wood stoves), they typically require no kindling, and, as previously noted, are typically designed for one-at-a-time use. Particulate emissions rates from fireplaces burning wax fire logs in the prescribed manner is about 68% lower than when burning cordwood.

There have been improvements in the design of cordwood fireplaces that minimize the underfire air supply and maximize combustion conditions with the introduction of secondary air. At least one such unit not currently in commercial production reportedly had very low emissions. Therefore, some new fireplaces may have emission rates lower than currently manufactured units. However, little data are available.

There is no federal certification requirements for fireplaces. They are exempt from EPA certification because their air-to-fuel ratios are in excess of the 35:1. The states of Washington (WAC 150-31-200) and Colorado (Regulation 4) have fireplace standards and currently provide the only regulatory impetus for the manufacture of fireplaces with low emissions. Two local air quality authorities in California (i.e., Northern Sonoma County and San Louis Obispo County) are in the process of developing fireplace emissions standards.

An alternative to burning cordwood in fireplaces for aesthetic or recreational purposes is decorative gas log systems. They are known to have negligible particulate emissions at all heat input levels and therefore, as with wax fire logs, the emission rate (g/hr) reporting units may be appropriate when comparing emissions from fireplaces burning cordwood and used for aesthetic or recreational purposes with those using gas logs.

The use of decorative gas logs has become very popular. During the 1994-1995 heating season, 17% of fireplaces used gas as fuel mostly for decorative gas logs. Decorative gas logs are designed to be used in masonry or factory-built fireplaces. Gas log sets consist of a control valve and burner assembly, a grate, and imitation logs made of cast refractory or cement. Their functions are primarily for aesthetics with flame appearance being the primary design criterion. Decorative gas logs have negligible particulate emissions, compared with cordwood-burning fireplaces. Therefore, particulate reductions are nearly 100%, compared with fireplaces burning cordwood. As with gas fireplaces and inserts, either natural gas or LPG can be used with decorative gas logs.

2.3 State-of-the-Art of Wood-Fired Central Heating Furnace Emission Control Technology

There are less than 10 manufacturers of wood furnaces and less than 20 models available. In 1993 less than 0.3 million were used in the U.S. No data were found that provided estimates to be made on annual sales. They are most popular in the upper Midwest. Some models burn cordwood, some wood chips, some sawdust and some pellets. They are used more widely in Europe and in Canada than in the U.S.

Wood-fired furnaces most commonly heat water, which is circulated into the home, either through a heat exchanger coil in the cental air duct or directly into the living space through baseboard radiators. Since many homes do not have the space or the type of flue system needed for in-home installation, many current furnaces are designed to be standalone units located adjacent to the house enclosed to look like a small utility building. Most current wood-fired furnaces consist of a combustion chamber in the front and a boiler in the back of the unit. Hot gases generated in the combustion chamber pass around horizontal boiler tubes. In single-pass designs, the gases then exit through the stack, while in double pass designs the gases flow horizontally back to the front into a separate compartment above the combustion chamber and then out the stack. The latter designs should be more energy efficient, although no data were found to substantiate this supposition. There are some who also think the double pass design burns cleaner due to the longer flame path, but, again no data were found on this subject. Since the temperature of the gases exiting the boiler after the first pass are only in the range of 250-400°C, it seems unlikely that there would be any additional combustion after the first pass.

The furnace control system regulates the draft as needed to maintain boiler water temperature. When water temperature drops below the set point the draft opens which, in most designs, means the forced-draft fan is turned on. When the water temperature rises above the upper set point, the fans shuts off, reducing the draft to the low fire setting. A manually operated shutter on the fan inlet provides a means of fine tuning the unit to local weather conditions, stack height, house size, etc. When properly sized to the heating need, these furnaces need to be stoked 1-2 times per day. The smaller units will accept a fuel load of 18-25 kg of wood. On the basis of two fuel loadings per day such a unit is rated at 120 MJ/hour heat output. Recent testing of units showed that their typical efficiencies were in the 50% range.

A search of the literature for emission data turned up few references. A recent review article covering some limited work done in Canada and Sweden, a very recent EPA emission test report for two furnace models and two papers presented at conferences in the early 1980's were the only relevant literature found. The particulate emission factor for furnaces operated in their typical intermittent firing mode (draft controlled) are roughly a factor of two higher than for conventional stoves. Furnaces burning wood chips and pellets have much lower emission factors.

Wood-fired central heating furnaces are exempt devices, i.e., there is no U.S. certification for them. There is however an applicable draft Canadian emissions standard (CSAB415.2). The opinions of the interviewees were split as to the appropriateness of certifying them. Some felt that since so few were in use and those were predominately in rural areas where air quality is typically not an issue that it made little sense to go through the considerable effort and expense to developed a certification procedure and require new models to be tested. Others felt that to provide an even playing field for all RWC appliances that they should be certified and that being certifiable may enhance their marketability. It was noted by several interviewees that some outside residential wood-fired boilers have very high emissions and have created some localized concerns.

2.4 State-of-the-Art of Pellet-Fired Wood Stove Technology

There are an estimated 0.3 million pellet stoves currently in use. During the 1995-1996 heating season, 654,000 tons of pellets were sold. Nearly all pellet stoves have been sold since 1989. Many pellet stoves manufactured during the first several years of their availability had serious durability issues with electronic and moving parts that failed. The RWC experts that were interviewed agreed that these issues were addressed and that new units are dramatically improved. Some early pellet stove manufacturers went out of business because of these durability issues. To the experts' knowledge none of the early models are currently available. There are two categories of pellet stoves ─ EPA-certified and exempt. There are five models listed as certified by the U.S. EPA as of August 12, 1997. Appliances with a greater than a 35 to 1 air-to-fuel ratio are exempt from certification. Early models with the high air-to-fuel ratio had lower efficiencies than certified models due to sensible heat loss out the exhaust. This is not the case with newer models, since the high air-to-fuel ratio needs to be demonstrated only at low burn rates to obtain the exemption. At more normal burn rates, the air-to-fuel ratio is much lower for exempt models.

Efficiency values for pellet stoves shown in AP-42 (i.e., 68% for certified and 56% for exempt) were based on field studies conducted during the 1989/1990 heating season for certified pellet stoves and during the 1990/1991 heating season for exempt pellet stoves. (The data in AP-42 are erroneously listed as for Phase II certified pellet stoves, the stoves used to derive the values were certified as Phase I units.) The default efficiency value used in the certification process is 78%. Based on the interviews with RWC experts, the 78% efficiency is probably closer to the efficiency of newly manufactured units and is shown in Table 2.1-2 here. The emission factors shown in AP-42 for certified and exempt pellet stoves (2.1 g/kg and 4.4 g/kg, respectively) are also based on the 1989/1990 and 1990/1991 field studies and the certified values are erroneously listed as for Phase II units.

It was generally agreed that the 2 g/kg emission factor value shown in Table 2.1-1 is applicable to both currently manufactured certified and exempt pellet stoves and that most units produce lower emissions than even 2 g/kg. This observation is supported by certification test data of Phase II units. Unlike for cordwood stoves, realistic fuel and reasonably realistic fueling practices are prescribed by the Method 28 certification procedure for pellet stoves. The five pellet stove models that have been certified as Phase II units have certified emission rates ranging from 1.3 g/hr to 2.7 g/hr. The typical in-home burn rate of a pellet stove is approximately 3 lbs/hr (1.36 kg/hr). Based on this burn rate, the corresponding emission factors for the certified stoves would range from 0.96 g/kg to 1.98 g/kg.

The opinions among the interviewees regarding certification were split. Some felt that the 35:1 air-to-fuel ratio should be dropped and that all pellet stoves should be required to be certified since certification gives the units credibility and since emissions levels are listed for certified units it provides an incentive to improve them further. Others felt that since "their emissions are so low and they apparently have lower $PM_{2.5}$ and PM_{10} to total particulate ratios, as compared to cordwood stoves (see following discussion), certification would serve no purpose. Another suggestion was that a very simplified certification testing procedure would be appropriate for pellet-fired stoves. The simple test method would verify that air-to-fuel ratios are below a specified level at all burn rates and that carbon monoxide is below a certain percentage of the total flue gas carbon compound content.

Some early models of pellet stoves had problems with clinker formation in their fire pot. This problem was mitigated by both improved stove design and improved pellet fuel. The Pellet Fuel Institute (PFI) has provided inorganic ash content standards for residential pellet fuels. Most major pellet fuel manufacturers guarantee their product to these standards (<1% ash for premium grade and <3% ash for standard grade). The reduced ash content lessens fire pot clinker formation. The PFI also recommended that the pellets have less than a 300 ppm water-soluble sodium content. Sodium salts cause corrosion to the firebox. The PFI requests manufacturers to proved a guaranteed analysis listing ash and sodium content.

The $PM_{2.5}$ fraction of pellet stove particulate emissions is believed to be smaller than for cordwood stoves. Cordwood stove emissions are composed primarily of condensed organic compounds that are mostly submicron in size, whereas pellet stove emissions due to the more complete combustion characteristic of a pellet stove are believed to contain a higher fraction of entrained inorganic ash that is typically composed of larger particles. This perception is supported by some very limited data that shows that the ratio of the mass of particles collected on the back half (ice water impingers) to the front half (heated filter) of EPA Method 5 sampling trains is lower for pellet stoves than for cordwood stoves.

2.5 Ramifications of the International Organization for Standardization (ISO) Draft Standard WD 13336

Since approximately 1990, significant efforts have been made by hearth products industry members, primarily from New Zealand and Australia, to develop International Organization for Standardization (ISO, Geneva, Switzerland) test standards for measuring pollutant emissions and thermal efficiency, and for determining performance margins for safe wood stove operations. All of these test standards are currently in active development and classified in "draft" status. The last full meeting of ISO Technical Committee (TC) 116, Subcommittee 3 for individual heating appliances was held in Langenbruck, Switzerland on November 18-20, 1998.
Interviews conducted for this technology review project indicate that the current draft ISO test standards for measuring pollutant emissions and thermal efficiency have not been widely distributed and read by hearth products industry members in North America. In addition, since the draft ISO standards have not been adopted, nor are they expected to be adopted by any jurisdictions in any of the major markets serviced by most of the hearth products manufacturers in

North America, there has been no compelling reason for North American hearth products manufacturers to become involved or to contribute to the further development of the standards.

Most interviewees felt that having one international test standard that was recognized in all, or at least the major markets of the world, is a good idea and some effort should be made by representatives from each of the major market areas to develop the ISO standards with this goal in mind. It was also expressed that if no final ISO standards could be developed that were acceptable to all jurisdictions in the major market areas of the world, the goal should be to develop standards that are compatible with other widely used test standards (i.e., where only one test is required with the application of possibly different calculation procedures or different pass/no-pass criteria being required by different jurisdictions). If it is not possible to make the test methods compatible, the ISO test standards should be developed so that they are at least correlatable (i.e., where there is a consistency between the results of the non-ISO methods that can be expressed consistently with a mathematical formula). One interviewee felt that because there has been such extensive use and knowledge gained with the U.S. EPA NSPS methods over the last 12 years, with some minor improvements or “corrections,” they could serve as the basis for an international emissions test standard. Another pertinent point should be made that if further development is undertaken on the ISO draft standards or the U.S. EPA NSPS test standards are revisited for the purposes of developing improvements or making corrections, the Canadian Standards Association (CSA) test standard B-415 and the proposed European Community (Comit’e Europ’een de Normalisation [CEN] Technical Committee [TC]295 Working Group [WG] 5, Brussels, Belgium) test standards should also be reviewed for their relevance to an international, worldwide set of standards.

For the purposes of this review, Table 2.5-1 was prepared for presenting a first-level comparison of the primary differences between the present ISO draft WD 13336 standard and the U.S. EPA NSPS standards for operating wood stoves and for sampling particulate emissions from wood stoves during test periods. It should be noted that there are many additional differences between these standards but only those which are considered to have the most potential to produce major differences in test results between the methods are presented in Table 2.5-1.

All interviewed North American market manufacturers indicated that the current U.S. EPA methods should not be replaced by an ISO standard at this time. Until there is more familiarity with the draft ISO standards, it not expected that this sentiment will change any time soon.

Table 2.5-1

Comparison of the Draft ISO 13336 Test Standards and the U.S. EPA NSPS Test-Standard Methods 5G, 5H, and 28 for Wood Stoves

Test Standard/ Method	Emissions Sampling Technique	Fuel Spacing	Fuel Species	Thermal Efficiency	Burn Rate Requirements	Units
ISO 13336: Wood Stove Operation and Emissions Sampling	Dilution Tunnel	0.75 Inches	Many Including Coal	Calorimeter Room	Low, Medium, High Based on Percentage of Maximum	g/kg
U.S. EPA 28 Wood Stove Operation	NA	1.5 Inches	Douglas Fir	NR	Specified Burn Rate Categories: <1, 1-1.25, 1.26-1.5, and Maximum kg/hr	NA
U.S. EPA 5G Emissions Sampling	Dilution Tunnel	NA	NA	NR	NA	g/hr
U.S. EPA 5H Emissions Sampling	Direct Flue-Gas	NA	NA	NR	NA	g/hr

NA = Not Applicable, NR = None Required

2.6 Correspondence Between In-Home and Laboratory Emissions Test Results

The overwhelming majority of laboratory emission tests have been for the certification of wood stoves. There has also been some research testing of wood stoves or other RWC appliances in the laboratory, most of which has been done in the 1980's. In-home studies of stove emissions have been conducted in the Glens Falls, New York area; the Waterbury, Vermont area; Whitehorse, Yukon; Klamath Falls, Oregon; Medford, Oregon; Portland, Oregon; and Crested Butte, Colorado. In-home studies of fireplaces and masonry heaters have been conducted at various locations in western Oregon and Washington.

The data for the certification tests are based on testing with Method 5G or Method 5H following the Method 28 stove operating procedures (40 CFR Part 60, Appendix A). The data for the field studies are based on tests conducted with a sampler referred to as the Automated Woodstove Emissions Sampler (AWES) except for data for Crested Butte, Colorado which was based on tests conducted with a sampler referred to as the Virginia Polytechnic Institute (VPI) sampler. Most research laboratory tests have utilized Method 5 samplers or samplers developed from EPA’s Method 5 train. These include Method 5 itself, Method 5H, Modified Method 5 (i.e., Method 23) and Oregon's Method 7. Some laboratory testing utilized a dilution tunnel prior to sampling with a Method 5-based sampling train. Some utilized a research dilution sampler developed by the Southern Research Institute (SRI) referred to as the Woodstove Sampling System (WSS).

In the development of emission factors for AP-42, data obtained from the two in-home samplers were converted to their equivalent Method 5G values first, then the 5G values were converted to equivalent Method 5H values. For the AWES sampler the equation used to convert results to Method 5G values was:

For the VPI sampler the equation used was:

These equations were developed by performing linear regression on data taken form simultaneous AWES-M5G and VPI-M5G tests. The 5G equivalent data were then converted to method 5H equivalent values by the equation:

While the correlation between the methods is reasonable there will be some bias between using data generated by the different sampling methods. This is particularly important when comparing in-home data and laboratory data, because laboratory certification data are all either based on Method 5G or 5H and research laboratory data are mostly based on method 5-type samplers whereas all in-home data are based either on the AWES or VPI sampler.

The issue of correspondence between in-home and laboratory emissions usually refers to the correspondence between in-home wood stove data and wood stove certification data (not research laboratory testing or the testing of appliances other than wood stoves) since the purpose of the certification process was to reduce air quality impacts from wood stoves. The interviewees were in general agreement that emission values obtained from certification tests only roughly predict in-home performance. While, as discussed, there may be some bias due to the sampling method, the key issue is the burning conditions and fuel characteristics prescribed by Method 28. Method 28 requires that Douglas fir 2 x 4's and 4 x 4's with a 19% to 25% (dry basis) moisture content made into cribs with fixed spacings be burned, that a coal bed be established before the testing is started (no kindling phase emissions), that fixed burn rates are used, that a 15-foot stack that freely communicates with non-pressurized indoor air is used, and that unrealistic air control settings be used. The air control prescribed by Method 28 is unrealistic for several reasons. First, the air control setting cannot be changed after the initial five minutes of the Method 28 test regardless of the state of the burning conditions. Second, there are no stops for the air settings for the medium-low and medium-high burn rates prescribed by the Method 28 protocol, consequently they are not generally reproduced by the in-home operator. Third, the in-home operator often loads the stove and “dampers-down” the unit at the same time for an “all night” burn at the end of the day — a condition which is not simulated by the Method 28 protocol. In addition to the actual testing procedures, data reduction prescribed by Method 28 produces unrealistic values because emissions rates are burn-rate weighted. The weighting factors were designed to be representative of the distribution of wood stove burn rates of the nation as a whole. The geographical distribution of in-home burn rate data is very limited.

In summary, burning cordwood in-home under real-world conditions is unlike that conducted following Method 28. The certification process should be viewed as a licensing process and it needs to be emphasized that emission rates obtained from it are not closely correlatable to emissions from actual in-home use.

2.7 EPA Method 28 Strengths and Weaknesses

The U.S. EPA NSPS Method 28 (40 CFR Part 60, Appendix A) which specifies wood stove operating and fueling requirements during wood stove test periods, has, since its promulgation in 1987, been a target for criticism by EPA-accredited wood stove testing laboratories and hearth product industry research and development departments. Complaints range from the method being too flexible, allowing or generating large and misleading variability in test results, to the method being too restrictive, not allowing enough flexibility to demonstrate the true clean and efficient burning capabilities of many wood burning stove models.

Specifically, some interviewees felt that there is no need to measure emissions from a full series of four separate burn rates or burn-rate categories as required by Method 28. Since intermediate burn rates (i.e., medium-low and medium-high) results always fall within the results obtained at the low and the high settings, they felt that it is only necessary to test for emissions at these low and high settings. Related to this was the comment that the Method 28 low burn rate requirements should not be expressed in absolute values but should be expressed as a percentage of the fuel load burned per hour. For example, instead of the present requirement for the low burn rate to be below 1.0 kg/hour, the low burn requirement could be expressed as a percentage (e.g., less than 20%) of the test fuel load weight calculated as described in Method 28 based on the firebox volume of the individual stove.

It is also generally recognized that with the current Method 28, there are many ways to affect burn cycle patterns and results while staying within the required Method 28 operating and fueling specifications. These include:

- Using higher or lower average moisture content fuel loads ranging from 19% to 25% (dry basis) to increase or decrease burn rates and/or emissions rates,

- Placing higher or lower moisture content fuel pieces at different locations within the firebox (e.g., bottom/top or back/front) to control the timing, location, and temperature regimes of pyrolysis products and volatile gas releases into secondary combustion zones,

- Placing higher or lower fuel density pieces at different locations within the firebox to control the timing, location, and temperature regimes of pyrolysis products and volatile gas releases into secondary combustion zones. There are no Method 28 fuel density specifications and Douglas fir wood densities vary up to 60% from low to high density fuel pieces,

- Starting the test at the high or low end of the allowed coal-bed size range (i.e., 20% to 25% of the test fuel load weight) to affect the start-up pattern and the ultimate average burn rate and emissions characteristics for the fuel load,

- Starting the test at high or low average firebox/stove temperatures which also affects the start-up pattern and ultimately the average burn rate for the fuel load. The desired relative firebox/stove temperature can be obtained by both managing how much of the coal bed is present at test start-up and managing how the stove is operated before the required one-hour, no-adjustment pre-burn period is started, and,

- Using fuel load weights at the high or low end of the Method-28-allowed fuel weight limits (i.e., 7 pounds per cubic foot of firebox volume, plus or minus 10%). Fuel load weight differences of 10% can affect burn rates and measured emissions rates. It is well known that smaller fuel loads produce lower emissions rates at any burn rate.

Although the effects of these factors have not been quantified, the overall concern is that EPA NSPS testing can be manipulated and a practiced technician can prepare custom results.

In addition to the pragmatic concerns about the conduct of Method 28 (and associated methods 28A and 5H) and the perception that the methods are in part an art, there are also controversial mathematical/conceptual issues associated with them as well.

For example, many interviewees believed that the weighting scheme used for calculating average wood stove emissions rates is flawed in that for any geographic location, even one that represents an “average” U.S. heating climate, there will be a very wide range of use patterns: from fall to winter to spring, between large and small homes and between low versus high indoor temperature preferences. Taking into consideration that there are many geographic locations within the U.S., with very different heating requirements and patterns, it was suggested that a simple arithmetic average of emissions measured at different heat output rates be used rather than the complex weighting scheme currently required by the method. It was theorized by one interviewee that a survey of current wood stove use in the U.S. would most likely show a shift from their use as primary heating sources more characteristic of the time when the NSPS was being developed, to currently a higher percentage of use as secondary heating sources. If this shift is real, it gives added rationale for changing the current weighting scheme.

Another mathematical/conceptual issue is that the equations used to calculate the air-to-fuel ratios (A/Fs) in Method 28A and to determine flue gas flow rates in Method 5H do not adequately take into account volatile organic compound emissions. The results of calculations with the equations are used both for determining the exempt/nonexempt status of wood burning appliances under the NSPS A/F exemption specification (i.e., being more or less than 35:1) and in the determination of particulate emission rates using Method 5H.

For the calculation of A/F the following equation is used.

,

where, M_d is the dry molecular weight of the wood stove flue gases,

N_T is the total moles of dry exhaust gas per unit mass of wood burned. N_T in both methods 5G and 28A is defined by the equation,

,

where, Y_{CO2} is the mole fraction of carbon dioxide measured in the dry wood stove flue gases,

Y_{CO} is the mole fraction of carbon monoxide measured in the dry wood stove flue gases,

Y_{HC} is the mole fraction of gaseous hydrocarbon compounds in the dry wood stove flue gases. Method 28A and Method 5H specify Y_{HC} as a constant. The value for catalytic wood stoves is 0.0088, for non-catalytic wood stoves it is 0.0132, and for pellet-fired stoves it is 0.0080.

A problem occurs when the Y_{HC} constant is used in the equation to calculate the N_T value. Methods 28A and 5H define the hydrocarbon mole fraction (Y_{HC}) as a constant regardless of how efficient the combustion process or how concentrated the other flue gas combustion byproducts (i.e., CO_2 and CO). The problem this can cause can be illustrated by performing some simple calculations using a non-catalytic wood stove as an example. Mathematically if the value of 0.0132 is used for Y_{HC}(the constant value of Y_{HC} for a non-catalytic wood stove) and the A/F of of the unit is 35:1 or more, the sum of CO_2 plus CO mole fractions in the wood stove flue gases must be equal to or less than 0.0214. (This CO_2 plus CO mole fraction value of 0.0214 was obtained by first estimating M_d as 28.95 g/g-mole, setting the A/F equation equal to 35, and solving for N_T. The corresponding N_T value is equal to 1226.598 g-mole of dry exhaust gas per kilogram of wood burned. By putting the Method-28A-specified hydrocarbon mole fraction value of 0.0132 into the N_T equation, setting the N_T equation equal to 1226.598 g-mole/kg, and solving for Y_{CO2} plus Y_{CO}, the value of 0.0214 was obtained.)

The 0.0214 value means that the assumed (or more correctly defined) Y_{HC} value of 0.0132 is a very substantial 38.2% of the total carbon mass flow in the non-catalytic wood stove when the A/F is at 35:1; i.e.,

If the combustion process being tested is efficient with the corresponding actual flue gas Y_{HC} negligible, there would be an additional 61.8% of excess unneeded air flowing through the wood stove before it would be calculated to exceed the 35:1 A/F required for the EPA NSPS A/F exemption. (Another way to intuitively understand this effect is to considered that if hydrocarbons artificially account for 38.2% of the concentration of carbon containing gases, the value for the sum of CO_2 and CO mole fractions will have to be in practice reduced by the same amount. Because the number of atoms of CO_2 and CO cannot be changed, the only way this can be accomplished is to increase the total flow by 61.8%.) A primary implication of this Y_{HC}-generated need for additional excess air to meet the 35:1 A/F exemption, is the fact that any and all excess air above the optimal level for efficient combustion in wood stoves only serves to carry additional combustion generated heat out of the stove and into the atmosphere ultimately resulting in significantly reduced wood stove thermal efficiencies. This, of course, results directly in the need for users to burn more wood and an effective higher emissions factor.

In a similar fashion and perhaps more importantly, the same Method-28A-specified Y_{HC} values that cause excess flue gas flow rates to be needed to obtain calculated A/Fs greater than 35:1, also cause the flue gas flow rates calculated by Method 5H to be up to about 61.8% lower than the flow rates would be if actual flue gas Y_{HC} values were negligible. Since Method 5H emissions rate results are the product of the measured flue gas emissions concentrations and the calculated flue gas flow rates, the Method 5H emissions-rate values could also be lower than actual value depending on the A/F and the real concentration of Y_{HC} in the flue gases.

Two other related points are relevant to make. First, the term hydrocarbons (generally abbreviated "HC") is a misnomer in that many oxygenated organic compounds will be present along with hydrocarbons in the vapor phase particularly at typical flue gas temperatures and second, while a large fraction of the organic compounds in flue gas vapors will be single carbon compounds (e.g., methane, methanol, formaldehyde), some will have two or more carbon atoms which further complicates the effects of using fixed Y_{HC} values.

Because there has not been any widespread recognition of these volatile organic compound problems, there were no strong opinions among interviewees on how best to correct the problem. Two suggestions were:

- Measure or approximate total wood stove flue gas volatile organic compounds during tests using a heated sample line with a flame ionization detector calibrated to a surrogate compound such as methane, butane, propane, or

- Determine if there is a relationship between another indicator of incomplete combustion in wood stoves (i.e., carbon monoxide) and use that relationship in the N_T equations.

Another mathematical/conceptual issue regards the Method 28A calculation of fuel factor (F_o) values using measured flue gas concentrations. This calculation is performed using the equation:

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The F_o values obtained with the equation are used as a check of the proper operation of test equipment. In practice, the F_o values are usually calculated and reviewed for each ten minute average CO_2 and O_2 data set. (If carbon monoxide levels are measurable the CO_2 and O_2 values are adjusted.) Method 28A states that F_o values "calculated beyond the acceptable range of 1.000 and 1.120, should be investigated before the results can be accepted" [by EPA]. Accredited wood stove test laboratories as well as research and development laboratories operated by hearth products manufacturers have often found F_o values below 1.000 and above 1.120 levels with testing equipment operating properly and within specifications. Based on extensive calibration and retest work which has been done, it appears the primary reason for the frequent occurrence of apparent flue gas chemical imbalances (i.e., F_o values outside the 1.000 to 1.120 range) is the fact that fuel combustion in wood stoves is a batch process. Different fuel characteristics and burning conditions which occur over the course of the batch process change the relative O_2 and CO_2 (and CO) flue gas concentrations.

For example, at the beginning of a burn cycle when the fuel load heats up, wood tends to burn more volatile compounds which contain most of the hydrogen and oxygen in the fuel ("fuel oxygen"). At the end of a burn cycle, wood tends to burn mostly high carbon content charcoal-like materials. To add further complication, at the very start of the burn cycle proportionately more of the starting coal bed (containing a high carbon content) specified by Method 28 burns than the fuel load, especially at the Method 28 low burn condition.

Two other factors which can change with combustion conditions over the course a wood stove batch burn cycle that can affect the F_o values are (1) the relative proportion of fuel oxygen versus atmospheric oxygen consumed to produce combustion gases and (2) the amount of hydrogen combining with oxygen to produce water.

When carbon uses predominately fuel oxygen for burning, there is a greater than one to one replacement of atmospheric oxygen with CO_2. Under normal circumstances fuel oxygen would not be exclusively used as compared to atmospheric oxygen during any portion of the batch process but this phenomenon occurs with varying degrees during different parts of a burn cycle.

The water produced by combustion of hydrogen will not be measured as a component of the volume in the flue gases (flue gas percentages are measured against total dry flue gas) and, therefore, the CO_2 produced by combustion will become effectively a larger percentage of the total dry flue gases when more hydrogen is converted to water. Another way of conceptually understanding this effect is to consider that hydrogen would be using up atmospheric oxygen with no measurable replacement to take up the volume like there is when carbon burns with atmospheric oxygen; i.e., one carbon atom uses one O_2 molecule from the atmosphere to make one CO_2 molecule which replaces, on a one-to-one volume-per-volume basis, the one atmospheric O_2 molecule. Therefore, when carbon burns with atomospheric oxygen, the sum of the remaining atmospheric oxygen present in flue gas and the carbon dioxide produced will be 20.9% (with a small correction for CO and volatile organic compounds).

If flue gas results from pellet stoves, wood chip or sawdust-fired boilers that operate on virtually a steady-state basis were being analyzed then short-term F_o factors of 1.000 to 1.120 may be appropriate. However, for the batch combustion processes of a wood stove, the F_o method using 10 minute averages over the course of the burn cycle does not provide a valid quality assurance check since not only does the chemistry of the fuel change from the beginning of a burn to the end but the combustion conditions at the beginning and end of a test change as well. Only average F_o values should be calculated for the burning of a complete fuel load, not for any single test segment.

In conclusion of the Method 28 issues it was expressed by several interviewees that the Random Compliance Audits (RCAs) described in 40 CFR Part 60, Subpart AAA should be conducted on a regular or consistent basis. It is felt by many manufacturers in the hearth products industry that there has been some abuse of the NSPS test methods and the NSPS-specified exemptions. It is a widespread belief that “policing” by the use of RCAs would be of benefit to the industry.

2.8 EPA Methods 5G and 5H Correlations

The general perception among interviewees was that although the performance of Method 5H generally results in lower measured emissions rates, it is a very complicated and difficult method to perform. Its multi-step and multi-component sample train complexities are compounded by the use of a tracer gas flow measurement procedure making the overall method fraught with many points of potential error and it is not surprising that the Method-5G-to-Method-5H conversion equation does not reflect industry experience with the two methods. There is no question among most interviewees that Method 5G is more precise than Method 5H and that it probably reflects actual wood stove emissions more consistently than Method 5H.

Several interviewees also stated that if the EPA ever eliminates Method 5H, the relationship between Methods 5G and 5H should first be established with much greater certainty than is obtained using the Method 5G conversion equation. It was the experience of several interviewees that the present Method 5G to Method 5H conversion equation penalizes the use of Method 5G especially at lower measured emissions rates. All interviewees felt a concern that any change in the Method 5G conversion equation not increase the current stringency of the NSPS. Some concern was also expressed that because the regulators dealing with wood stove emissions control strategies, industry research and sales people, and consumers are now familiar with the current emissions rates, there should be no drastic change from the present use of Method 5H emissions equivalents.

Another reason there are observed differences between Method 5G and 5H results may be that in paragraph 5.2.2.2 of Method 5H it is stated that the average of the flue gas CO_2 and CO mole fractions should be used in the carbon balance calculations for total test average flue gas flow rates. To be correct, the method should first calculate the carbon balance flue gas flow rate for each test interval (i.e., 5- or 10-minute period). Then an average of the individual test interval flow rates should be calculated.

An example of the mathematically correct procedure for obtaining average flue gas flow rates is used in the EPA Method 2 Equation 2-9 (40 CFR Part 60, Appendix A). In Method 2, the velocity for each traverse point and test interval must be calculated before an average of traverse points or test intervals is calculated. Or more correctly in the case of Equation 2-9, the square root of the pitot velocity pressure for each individual sample point or test interval must be calculated before a total test period average is calculated.

When performing multiple arithmetic functions, the proper order of adding and multiplying or multiplying and adding must be followed or incorrect results are generated. In the case of the Method 5H carbon balance flue gas flow rates, if Equation 5H-7 is not carried out for each test interval before an average flow rate is calculated, the correct amount of weighting is not provided for the CO_2 + CO measurements made for each test period time interval. Experience indicates that the errors generated by following the instructions in Method 5H paragraph 5.2.2.2 are generally small (i.e., less than 5%), but not insignificant.

2.9 Performance Deterioration of EPA-Certified Wood Stoves in the Field

Performance deterioration (particulate emission increase) has been monitored in the field in four communities by retesting stoves after one or more heating seasons of use. Most of the stoves that were part of the in-field performance studies were Phase I, not Phase II stoves. One stove that was studied was a research stove developed by the Oregon Department of Environmental Quality (the "BEST" stove) and has never been available commercially. The studies have been conducted in Glens Falls, New York; Crested Butte, Colorado; Klamath Falls, Oregon; and Medford, Oregon. The stoves in the Glens Falls study were originally tested in the 1988-89 heating season and retested and inspected in the 1989-1990 heating season. They were all phase I units. The stoves in the Crested Butte study were originally tested in the 1988-89 heating season. Some stoves were retested after one or more heating seasons during the 1989-90, 1991-92 and 1995-1996 heating seasons. Some stoves were Phase I and some were Phase II. Also, as part of the Crested Butte study, some old certified stoves were only tested once but because of the fact that they had been in use for some years, information on degradation was obtained from a single testing and inspection. The stoves in Klamath Falls study were originally tested in the 1989-90 heating season and retested in the 1991-92 heating season. They were Phase II stoves. The stoves tested in Medford were all the Oregon Department of Environmental Quality BEST stove model and were first tested in the 1988-89 heating season and subsequently retested in the 1989-90 heating season. It should be noted that among all the studies a total of only six Phase II certified stoves were emission tested in more than one heating season (five in Klamath Falls and one in Crested Butte). There has been concern about both the Glens Falls and Crested Butte stove usage being on the extreme end of the spectrum of in-home stove use. Many homes in Glens Falls were multiple stories with high draft conditions plus, while not extreme, the heating degree day value for Glens Falls (7500 HDD) is on the higher end of the spectrum typical of the United States. In the case of Crested Butte, the heating degree day value is extremely high (11,500 HDD) as compared to most of the continental United States.

In general, the field studies showed that emissions increased with time and that some stoves showed physical deterioration. The level of deterioration appeared to be related to how "hard" the stoves were used. Those that were burned at high burning rates with high draft chimney conditions showed the most wear. Some models appeared to have less deterioration then others. Catalytic stoves were more susceptible to deterioration than non-catalytic stoves due to damage to the catalyst itself and the catalyst bypass which is a sealing/moving part. Damage to non-catalytic stove was primarily to the baffle/secondary air system.

Several interviewees pointed out that wood stove design has improved since the early Phase I and even Phase II models. Warranty claims, as noted previously, have been the primary driving force for the improvements. Also as previously noted, more than one third of the certified stoves listed by EPA are not currently available. Not surprisingly some of these stoves had durability issues and are not commercially available for that reason. A representative of one manufacturer noted that he attended the 1993 "Manufacturers Seminar on Woodstove Stress Testing" which was based on EPA-sponsored research[10] and improved the quality of the materials they used in manufacturing their stove models based on the information presented. Two concrete improvements cited by interviewees were that in their stoves catalysts are positioned vertically rather than horizontally now to allow ash to fall out and to prevent plugging and that catalyst bypass systems are now made more "robust."

Some interviewees felt that catalyst could last longer than five years if properly maintained. Others noted that under extended high temperature use a catalyst could fail very rapidly. Once a catalyst fails, the emissions for some models would be close to those from a conventional uncertified stove, particularly if the stove is designed in such a fashion that the catalyst removes virtually all the organic emissions. Other better engineered catalyst stoves with improved combustion design (secondary combustion, heat retaining refractory, etc.), with a failed catalyst, would have emission levels closer to that of certified non-catalytic stoves. Some interviewees noted, that while catalytic stoves were most susceptible to deterioration, non-catalytic stove also can be damaged by high temperature, over drafting conditions.

Most interviewees felt that some type of home owner training on the use and maintenance of wood stoves was appropriate and that it might best be accomplished at the time of purchase. An instructional video as part of the purchase package was mentioned. Most interviewees felt that it was inappropriate to include the costs of an inspection and catalyst replacement program in the purchase cost of a new unit, particularly since sales are declining.

2.10 Stress (Durability) Test Pros and Cons

As discussed in Section 2.9, wood stove field studies have shown that some newer technology wood stoves designed to have low particulate emissions have degraded in performance and have shown physical deterioration after as little as one season of use. It is generally believed that most damage to the wood stoves occurs during those occasional times when the wood stove is operated at exceptionally high temperatures. A method to test the long-term durability of wood stove models in the laboratory in a one to two week time frame has been developed and has come to be referred to as a "stress test"[10].

At the time of its development the most valuable aspect of the stress test was felt to be its ability to simulate in-home wood stove aging and degradation over a short time period in the laboratory. The short-time required for the test would permit modifications to be made in stove design and manufacturing during the period when a given stove model was in development, rather than having to wait for one or more seasons of use for degradation to be discovered. The biggest environmental "plus" of the stress test would be to increase the probability that low particulate emission provided by new technology stoves are realized in actual long-term in-home use.

The opinions of the interviewees seemed to be split as to the applicability of a stress test. One faction felt that a stress test would improve wood stove performance and that it might even be appropriate to include it as part of the certification process. Although some of these interviewees that felt that a stress test was appropriate had caveats on its use. These included the concern that the stress test as developed might have been too severe, with the related observation that there is a difference between acute and chronic stress which is not addressed in the stress test, and the point that because draft conditions strongly influence the combustion rate and temperature, draft should be taken into consideration in the testing. One interviewee felt that some form of stress testing may be appropriate for certification but that the NSPS should not be "piece mealed" but completely redone. As part of such a new NSPS testing protocol, it was suggested that a range of draft conditions should be defined to which the model is certified. It was noted that the stress test is important since some of failure mechanisms such as the loss of catalytic activity or damage to secondary air tubes may go unnoticed by a homeowner and hence it is critical to minimize the occurrence of these failures by stove design.

A number of interviewees felt that the stress test was inappropriate and that it should not be part of the certification process. It was felt that the economic disincentives of warranty claims provides enough impetus to manufacturers to build quality long-lasting appliances. However as previously noted, some degradation which can cause increased emissions may go unnoticed by the home operator and its repair will not be initiated by a warranty claim. It was also noted that the stress test only evaluates damage caused by high temperatures and, as with other products designed for in-home use, there are other factors besides temperature that could cause damage to wood stoves under real-world consumer use. Some interviewees were against the stress test because it would add a cost to wood stoves which already have a poor market.

2.11 Feasibility of Developing Separate Emission Factors for Dry and Wet Wood and for Softwood and Hardwood Species

A review of the RWC literature and the responses of the interviewees revealed that there is little data to quantify either the effect of fuel tree species or of moisture on particulate emissions of wood burned in home heating appliances. Most interviewees believed that fuel moisture has a larger effect on emissions than tree species. Part of the concern regarding the effect of fuel tree species and wood moisture on particulate emission rates stems from the fact that the certification Method 28 specifies that only Douglas fir 2 x 4's and 4 x4's with a moisture content of 19% to 25% (dry basis) can be used in the certification of wood stoves. Discounting the issue of dimensional lumber, clearly wood from many other tree species with different moisture contents are burned nationally in homes. For example, the U.S. Department of Agriculture, in cooperation with the Oregon State University Extension Service, listed the fuel wood characteristics of 47 tree species in a recent RWC guidance circular[11] and an in-home emission study[12] of 28 homes in upstate New York and Vermont showed that the average moisture content of wood in the home woodpiles ranged from 17% to 41% (dry basis). Even from the limited number of homes included in the in-home studies from which AP-42 emission factors were derived and from which wood stove durability was assessed there were over 31 descriptions of wood types. These were: ash, aspen, apple, alder, beech, birch, black cherry, cedar, unspecified cherry, Douglas fir, elm, fir, unspecified hardwoods, hornbeam, juniper, lodgepole pine, laurel, unspecified maple, madrone, unspecified oak, unspecified pine, pinion pine, poplar, red fir, red oak, unspecified spruce, unspecified soft wood, white fir, white oak, white pine, and yellow pine. Most of the unspecified categories were mixtures of different tree species and in some cases the same generic term (e.g., oak) was used in different parts of the country which suggests that different tree species made up the cordwood even within the same category.

There are physical and chemical differences in softwoods (conifers) and hardwoods (deciduous trees) that may influence particulate emission rates. The average heat content and density of softwoods and hardwoods are distinct although there is considerable overlap. The reported[13] average higher heat content of 10 hardwood tree species is 8100 Btu/lb dry wood (18.8 MJ/kg) with a standard deviation of 215 Btu/lb (0.5 MJ/kg) and for eight softwood species it is 8746 Btu/lb (20.3 MJ/kg) with a standard deviation of 861 Btu/lb (2.0 MJ/kg). The average heat content of softwood is higher than for hardwood because the resin content is on the average higher in wood from conifers than from deciduous trees. The resin content in conifers is reported to range form 0.8% to 25%, whereas its content in deciduous trees is from 0.7% to 3%. The higher heat content of resin is 17,400 Btu/lb (40.4 MJ/kg) as compared to about 8000 Btu/lb (20.0 MJ/kg) for dry wood without resin. Softwood also has on the average a slightly higher heat content because it usually contains more lignin than hardwood. Lignin has a higher heat content than cellulose. The average density of wood from 22 deciduous tree species is 2689 lbs/dry cord (1.222 metric tons/cord) and for wood from 14 conifer tree species it is 2007 lbs/dry cord (0.912 metric tons/cord)[11].

There has been some limited data from laboratory studies suggesting that pine may produce lower emissions than oak in RWC appliances. The average difference in emission factors from changing from pine to oak shown in two of these studies was in the 30 to 40% range, however, in both cases the effect was below the 90% confidence limit (bound) probably due to the complicating effect of the large number of variables. Results from other laboratory studies suggest that emissions from oak are lower than from pine or fir. Most laboratory studies did not reach any conclusions on the effect of wood type. A number of the interviewees felt that oak produced lower emission than softwood. $PM_{2.5}$ (particles with aerodynamic diameters less than 2.5 microns) emission data compiled by the U.S. Forest Service[14] for slash and brush burning revealed that there is little inherent differences in particulate emission factors from the combustion of wood from various wood species under these conditions. The standard deviation around the mean emission factor of 21.1 g/kg of fuel consumed based on a total of 45 tests on a variety of species was only 3.2 g/kg or 15% of the mean. Species and mixtures tested by the U.S. Forest Service were Douglas fir/hemlock, hardwoods, ponderosa pine/lodgepole pine, mixed conifer, juniper sagebrush and chaparral. The probable small effect of tree species on emission rates was anecdotally noted by one interviewee who pointed out that a well-designed wood stove seems to burn either hardwood or softwood equally as well.

In regards to the effect of wood moisture on particulate emission factors, the general consensus is that the lowest emissions occur with wood moisture in the 15% to 25% range (dry basis). High moisture reduces combustion temperature and hence combustion is more incomplete. Alternatively, low moisture produces high temperatures which allows volatile organic compounds to be vaporized and escape without being combusted, some which condense to form particles after leaving the stack. One laboratory study examined the effect of burning cured cordwood (15.0% and 12.3% moisture content on a dry basis) versus uncured cordwood (31.8% and 34.9% moisture content on a dry basis). The average particulate emission factor for the drier wood was about 13% lower at a 90% confidence limit. While the magnitude of the effect was small, the moisture levels of both the cured and uncured wood were not far from the apparent optimal moisture levels and hence do not represent the extremes. Interestingly, even though the moisture range in cordwood studied did not represent the entire range of cordwood moisture, the magnitude of the effect seems to be small which is contrary to the opinion of many interviewees.

The difficulty in retrospectively using existing field and laboratory data to isolate and quantify the effect of moisture or tree species is due to the fact that there are so many interrelated variables (appliance type, fuel tree species, altitude, burn rate, fuel moisture, fuel size, kindling characteristics, etc.) that were not controlled in the studies. Technically the feasibility of developing emission factors for moisture or wood type is straight forward if an experiment is designed to do so. This was noted by one interviewee who stated that the fuel type and moisture effect has not been quantified simply because there has been not been an adequate study funded to specifically do it. One pragmatic suggestion regarding the certification was that instead of burning one fuel type at four different burn rates as it is done now that it would make more sense to burn different fuels with different moisture contents from which an average is calculated or to burn a mixture of fuel types with different moisture contents at each burn rate.

2.12 Routine Maintenance of Appliances

There was agreement among the interviewees that it would be a sound practice for maintenance training and/or a manual to be provided to homeowners at the time of purchase of a wood stove. The use of a video format was suggested. Some manufacturers and retailers are already providing manuals, video and/or training. Several interviewees did point out that the cost of a service contract added to the purchase price of the unit would not be appropriate. Wood stoves already have a small market share as compared to other home heating options. In addition, service contracts traditionally are optional not mandatory. In the case of catalyst stoves particularly, they did not feel the added cost, at the time of purchase, of catalyst replacement (that would probably be needed in a three to five year time frame) would work since it would make catalyst units more unpopular than they already are. Alternatively, some interviewees felt that for catalyst stoves, such a program may be the only way to increase the probability that reduced particulate emissions would be long-term.

There was general agreement that routine maintenance was a good idea, as it is for nearly all appliances. It was noted that it is less critical for pellet stoves in terms of emissions since generally if there is a malfunction they do not operate. Routine maintenance/inspection for cordwood stoves should consist of checking and replacing if necessary door, bypass and window seal gaskets; moving parts (e.g., the catalyst bypass system); baffles; air tubes; and bypass seals. Baffles should be checked for warps and cracks, air tubes for leaks and plugging. The replacement of baffles and air tubes can be done in the home for some models. The replacement of baffles and air tubes for other models would require returning the unit to the factory or to a metal repair shop. For catalyst stoves, the inspection and replacement, as necessary, of the catalyst is, of course, a key element of the maintenance program. The inspection should include a visual determination that there is no physical damage or no plugging and if possible the catalyst should be observed during operation to determine if it has the typical glowing appearance of a properly functioning catalyst. Also stove cleaning should be part of the maintenance program, including removing any accumulated ash from the catalyst and air tubes. It was noted that since chimney sweeping is generally recommended once a year that utilizing chimney sweeps for routine maintenance would be a good approach.

3. Conclusions

Residential wood combustion is unlike many other sources of particulate matter. The effect that technologies, fuel properties and combustion conditions have on particulate emissions are characteristic of point sources, but since there are an estimated 25 million RWC appliances dispersed over wide geographic areas and in use nationwide, emission inventories and most regulatory controls treat them as area sources. Residential wood combustion appliances, as emission sources, are extremely heterogeneous. There are many hundreds of types and models of wood burning devices currently in use in the U.S. They are so durable that the manufacturers of many are no longer in business. Many dozens of tree species as well as various manufactured fuels are burned in them; home settings vary dramatically in terms of climate, altitude, and chimney characteristics; and homeowner burning practices also vary widely (e.g., fuel seasoning, burning patterns, burning rates, kindling approaches). Because there are so many models and home settings and so many different ways that RWC appliances can be used, combined with the fact that they are in private homes where personal preferences and behavior are not controllable, it is very difficult to quantify generic wood-burning emissions cause and effect relationships. Further, since many manufacturers compete for market share, there is understandably, much relevant technical and sales information which is considered confidential.

Based on the review of existing literature and interviews with recognized RWC experts, a number of conclusions regarding the states-of-the-art of RWC and allied subjects have been reached. These are as follows:

- The particulate emission factor published in AP-42[6] for conventional wood stoves is most likely lower than the actual national average.

- Taken as a group, the durability of currently manufactured certified Phase II wood stoves has improved and their particulate emissions are lower than the earliest Phase II models that became available circa 1990. However, there appears to be considerable variation by model within the group and the improvements seen over the earliest models have been described as marginal. Certainly, as a group, Phase II models are better than Phase I and superior to uncertified models.

- There has been little incentive for manufacturers to improve durability beyond severe problems that would precipitate warranty claims or to improve durability to make units last without deterioration beyond the typical prorated warranty period of five years.

- The efficacy of the laboratory durability "stress" test developed to predict long-term, in-home performance of wood stoves, is controversial.

- The significant deterioration of catalytic activity often seen in catalytic wood stoves in a three- to five-year time frame and the identification of viable approaches to ensure catalyst inspection/replacement continues to be an unaddressed problem.

- In addition to deterioration of the catalyst, damage to catalyst bypass dampers and seals has been noted under in-home use of certified catalyst stoves. Long-term degradation has also be seen in certified non-catalytic stoves. Deterioration in non-catalytic stoves is mostly restricted to baffles and secondary air tubes. Door gaskets also appear to commonly wear out in all stoves. High temperature conditions accelerate the degradation of stove components. High draft conditions (mostly caused by unusually tall chimneys) tend to increase the probably of high burn rates and commensurate high-temperature damage.

- The EPA NSPS wood stove operating procedure (i.e., Method 28) does not represent the"real world" use of wood stoves. Wood stoves are designed, out of necessity, to pass the certification test and consequently, their design is not necessarily optimal for low emission performance under actual in-home use. Similarly, the emissions values obtained from EPA NSPS certification is only roughly predictive of emissions under in-home use.

- There has been little incentive to increase the thermal efficiency of wood stoves. Increased thermal efficiency, in effect, reduces emissions since less fuel is consumed to produce the same amount of heat. There is an efficiency test method published in the Federal Register, but efficiency testing is not required in the EPA NSPS certification process.

- The improvement in wood stove technology has not progressed rapidly in part due to economic considerations. The primary indicator of this conclusion is that the market for wood stoves has been declining. Cordwood stove sales for 1997 were less than one-half of their 1990 level.

- Performance of the EPA NSPS wood stove operating procedures has been described as an art. A technician, skillful in manipulating parameters within the specifications of Method 28, can influence test results significantly. In addition, the Method-28A-specified values of flue gas hydrocarbon compounds (i.e., Y_{HC}) used in calculating air-to-fuel ratios, effectively requires additional excess air to be needed in order to attain calculated air-to-fuel ratios of 35:1. This is significant for affected facilities in that any unneeded excess air reduces thermal efficiency.

- There are two particulate sampling methods used in the EPA NSPS certification process, Method 5G and Method 5H. To make the results obtained from these two methods comparable, a conversion equation is used. The data available at the time the conversion equation was developed, were limited. The equation has been widely criticized and it is generally believed that after conversion, Method 5G results produce higher "equivalent" emission values than if Method 5H had been used for emissions sampling. Method 5G is more precise and less difficult (and less costly) than Method 5H. It is the opinion of many that only Method 5G should be used. However, if the two methods continue to be used, the relationship between Methods 5G and 5H should be re-evaluated.

- There are two issues that may account for some of the perceived differences observed between Method 5G and 5H results. The first is the use of assumed values for flue gas hydrocarbon compounds (i.e., Y_{HC}). The assumed values, when used in Method 5H calculations, can reduce flue gas flow and emissions rate results. The second is the improper calculation of flue gas flow rate averages in Method 5H. The Method 5H carbon-balance calculation of flue gas flow rate averages is carried out by first averaging the 5- or 10-minute test interval concentration values for CO and CO_2 separately and then calculating the average flow rate for the test period from those constituent averages. To be mathematically correct, flue gas flow rates should be calculated from the CO and CO_2 concentrations for each 5- or 10-minute test interval and then those calculated test interval flow rates should be averaged.

- The EPA NSPS certification test methods and the draft International Standards Organization (ISO) test methods are quite different at this time. The relationship of values generated by the two standards are expected to be only qualitative at best. A major revision in the NSPS protocols or a major revision to the draft ISO method would be necessary to make the two testing procedures compatible.

- Many interviewees would like to see the NSPS protocols completely revised. Related to this, many would like to see some type of certification procedure required for all wood burning appliances, including masonry heaters, furnaces, all pellet stoves, fireplaces, and cookstoves. It is felt that this would provide "an even playing field," provide incentives to improve their performance and provide credibility for the appliances which may actually improve their marketability.

- Manufactured densified fuel logs burned in wood stoves has been shown to reduce emissions in the 20% to 30% range. Manufactured densified fuel logs are more expensive than cordwood and are more available in the Western United States.

- Masonry heaters have relatively low emission factors and presumably low mass of emissions per unit of useful heat delivered as compared to cordwood stoves. They are exempt from EPA NSPS certification and there are few in use due to their high cost.

- Wood-burning fireplaces are used as primary or supplemental heat sources and for aesthetic purposes. For fireplaces used as supplemental heat sources there are both old technologies (e.g., glass doors, heat convection tubes and contoured masonry fireboxes) and new technologies (pellet, certified cordwood, and gas inserts) that can increase the useful heat and reduce effective emissions. For fireplaces used for aesthetic purposes, wax fire logs and decorative gas log inserts can be used to reduce emissions. There has been research showing that lower emissions can be produced in fireplaces by minimizing under-fire air and by enhancing secondary combustion. Other than the certification requirements of two states, there is little impetus to develop and manufacture fireplaces that produce low emissions.

- Particulate emissions from pellet stoves are very low and efficiencies are high as compared to cordwood stoves. Some pellet stoves currently on the market are EPA NSPS certified and some are exempt from certification due to having air-to-fuel ratios greater than 35:1 (usually at the lowest burn rate). There is most likely little difference in performance between exempt and certified models for currently manufactured pellet stoves. Many early models sold in the 1988/90 time period had mechanical and electronic problems. These problems have been largely solved and new units have a good performance record. Pellet fuels have also become standardized which contributes to the growing success of pellet stoves.

- Wood-fired central heating furnaces are not widely used. They are more commonly used in Canada and Europe than in the U.S. In the U.S. they are most widely used in the upper Midwest. There has been little research on their emission performance. Based on limited data cordwood furnace emissions appear to be higher than emissions from conventional wood stoves. Furnaces burning wood chips or pellets have much lower emission factors than those utilizing cordwood.

- The effect of wood type (tree species) and wood moisture on emission factors cannot be accurately quantified with existing data. The effect of wood type and moisture content appear to be relatively small. In both cases the effect appears to be less than an order of magnitude.

- It was a general consensus among interviewees that routine maintenance programs could improve the long-term performance of EPA NSPS certified stoves and that some type of maintenance training should be provided to the home owner at the time of purchase.

4. References

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2. Draft International Standard ISO/DIS 13336, "Solid fuel burning appliances - Determination of power output, efficiency and flue gas emissions," International Organization for Standardization, Geneva, Switzerland, May 22, 1997.

3. 40 CFR Part 60, Appendix A, pp. 988-1069, July 1, 1997.

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5. 40 CFR Part 60, Appendix A, pp. 672-684, July 1, 1997.

6. Compilation of Air Pollutant Emission Factors, Fifth Edition. Volume I: Stationary Point and Area Sources, AP-42 Supplement B, GPO S/N 055-000-00565-6, November 1996. (Can be accessed through the web site http://www.epa.gov/ttn/chief/ap42etc.html)

7. Energy Information Administration, Housing Energy Consumption and Expenditures 1990; Supplement: Regional, DOE/EIA-0321(90)/S, 1993.

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10. Bighouse, R.D., S.G. Barnett, J.E. Houck, and P.E. Tiegs, Woodstove Durability Testing Protocol, EPA-600/R-94-193 (NTIS PB95-136164), November 1994.

11. "Fuelwood Facts," Extension Circular 1023, Oregon State University Extension Service, Corvallis, OR, September 1980.

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EPA-600/R-98-174b
December 1998

Residential Wood Combustion Technology Review
Volume 2. Appendices

Prepared by:

James E. Houck and Paul E.Tiegs
OMNI Environmental Services, Inc.
5465 SW Western Avenue, Suite G
Beaverton, OR 97005

EPA Purchase Order 7C-R285-NASX

EPA Project Officer:

Robert C. McCrillis
U.S. Environmental Protection Agency (MD-61)
National Risk Management Research Laboratory
Air Pollution Prevention and Control Division
Research Triangle Park, NC 27711

Prepared for:

U.S. Environmental Protection Agency
Office of Research and Development
Washington, D.C. 20460

Abstract

A review of the current states-of-the-art of residential wood combustion (RWC) was conducted. The key environmental parameter of concern was the air emission of particles. The technological status of all major RWC categories was reviewed. These were cordwood stoves, fireplaces, masonry heaters, pellet stoves, and wood-fired central heating furnaces. Advances in technology achieved since the mid-1980's were the primary focus. These study objectives were accomplished by reviewing the published literature and by interviewing nationally recognized RWC experts.

The key findings of the review included: (1) The NSPS certification procedure only qualitatively predicts the level of emissions from wood heaters under actual use in homes, (2) Wood stove durability varies with model and a method to assess the durability problem is controversial, (3) Nationally the overwhelming majority of RWC air emissions are from non-certified devices (primarily from older non-certified woodstoves), (4) New technology appliances and fuels can reduce emissions significantly, (5) The ISO and EPA NSPS test procedures are quite dissimilar and data generated by the two procedures would not be comparable, and, (6) The effect of wood moisture and wood type on particulate emission appears to be real but to be less than an order of magnitude.

Table of Contents

Appendix A
Residential Wood Combustion Literature

The following is a list of references related to residential wood combustion technology and air quality impacts. This list constitutes partial fulfillment (review of published literature) of the *EPA: Residential Wood Combustion Technology Review* project funded by the United States Environmental Protection Agency (US EPA).

The references listed within this document have been grouped into six (6) categories. These categories are:

The content of some referenced documents may fall into more than one of the six categories. In these cases the category representing the predominant subject matter was selected. All documents are listed only once. Within a category the references are arranged in descending chronological order. References within the same year, under one category, are arranged alphabetically by the first author's last name.

CATEGORY #1 IN-HOME EMISSION STUDIES

#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
1	Correll, Robert; Jaasma, Dennis R.; Mukkamala, Yagna	1997	Field Performance of Woodburning Stoves in Colorado during the 1995-96 Heating Season	Department of Mechanical Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA; Prepared for the U. S. Environmental Protection Agency, Office of Research and Development, Air Pollution Prevention and Control Division, National Risk Management Research Laboratory, Research Triangle Park, NC (EPA-600/R-97-112) (NTIS PB98-106487)
2	Jaasma, Dennis R.; Stern, Curtis H.; Champion, Mark	1994	Field Performance of Woodburning Stoves in Crested Butte during the 1991-92 Heating Season	Department of Mechanical Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA; Prepared for the U. S. Environmental Protection Agency, Office of Research and Development, Air and Energy Engineering Research Laboratory, Research Triangle Park, NC (EPA-600/R-94-061) (NTIS PB94-161270)
A-1 3	Barnett, Stockton G.	1993	Summary Report of the In-Home Emissions and Efficiency Performance of Five Commercially Available Masonry Heaters	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the Masonry Heater Association
4	Barnett, Stockton G.	1992	In-Home Evaluation of Emissions from a Grundofen Masonry Heater	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for Mutual Materials Company, Bellevue WA; the Masonry Heater Association; and Dietmeyer, Ward and Stroud
5	Barnett, Stockton G.	1992	In-Home Evaluation of Emissions from a Biofire 4x3 Masonry Heater	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for Biofire, Inc.
6	Barnett, Stockton G.; McCrillis, Robert C.; Crooks, Richard B.	1992	Evaluation of Emissions from Masonry Heaters and Masonry Fireplaces in Homes	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the U.S. Environmental Protection Agency, Air and Energy Engineering Research Laboratory, Research Triangle Park, NC; and Mutual Materials Company, Bellevue, WA (EPA-600/A-93-059) (NTIS PB93-173078)

CATEGORY #1 IN-HOME EMISSION STUDIES

#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
7	Barnett, Stockton G.	1992	In-Home Evaluation of Emissions from a Tulikivi KTU 2100 Masonry Heater	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the Tulikivi Group
8	Barnett, Stockton G.; Bighouse, Roger D.	1992	In-Home Demonstration of the Reduction of Woodstove Emissions from the Use of Densified Logs	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the Oregon Department of Energy; and the U.S. Environmental Protection Agency, (Administered by the Bonneville Power Administration, Portland, OR) (DOE/BP-35836 -1)
9	Crouch, J.; Crank, W.	1992	Update on the Crested Butte Woodstove Experiment	Transactions of the A&WMA/EPA International Specialty Conference, PM_{10} Standards and Nontraditional Particulate Source Controls, Volume II, TR-22; Published by Air & Waste Management Association, Pittsburgh, PA, pp. 680-685 (ISBN 0-923204-09-1)
10	A-2 Henry, D.	1992	A Comparison and Analysis of the Field and Laboratory Test Data for the Noncatalytic Stoves in the Klamath Falls Field Performance Study	Transactions of the A&WMA/EPA International Specialty Conference, PM_{10} Standards and Nontraditional Particulate Source Controls, Volume II, TR-22; Published by Air & Waste Management Association, Pittsburgh, PA, pp. 593-600 (ISBN 0-923204-09-1)
11	Osterburg, R.	1992	Modeling the Ambient PM_{10} Impact of a Woodstove Replacement Program in Crested Butte, Colorado	Transactions of the A&WMA/EPA International Specialty Conference, PM_{10} Standards And Nontraditional Particulate Source Controls, Volume II, TR-22; Published by Air & Waste Management Association, Pittsburgh, PA, pp. 686-699 (ISBN 0-923204-09-1)
12	Barnett, Stockton G.	1991	In-Home Evaluation of Emissions from Masonry Fireplaces and Heaters	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the Western States Clay Products Association, San Mateo, CA
13	Barnett, Stockton G.	1991	In-Home Fireplace Performance: Comparison of a Conventional Fireplace with a Retrofit Firecrest Masonry Insert in the Zagelow Residence, Vancouver, WA	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the Mutual Materials Company, Bellevue, WA
14	Barnett, Stockton G.;	1991	In-Home Performance of Exempt Pellet	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
	Fields, Paula G.		Stoves in Medford, Oregon	U.S. Department of Energy; Oregon Department of Energy; Tennessee Valley Authority; and Oregon Department of Environmental Quality, (Administered by the Bonneville Power Administration, Portland, OR) (DOE/BP-04143-2)
15	Barnett, Stockton G.; Houck, James E.; Roholt, Robert B.	1991	In-Home Performance of Pellet Stoves in Medford and Klamath Falls, Oregon	Proceedings of the Air & Waste Management Association 84th Annual Meeting & Exhibition, Vancouver, BC (91-129.3)
16	Houck, James E.; Barnett, Stockton G.; Roholt, Robert B.	1991	In-Home Performance of Residential Cordwood Stoves	Proceedings of the National Bioenergy Conference, Coeur d'Alene, ID, (91-129.3)
17	A-3 Jaasma, Dennis R.; Champion, Mark; Gundappa, Mahesh	1991	Field Performance of Woodburning and Coalburning Appliances in Crested Butte During the 1989-90 Heating Season	Department of Mechanical Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA; Prepared for the U.S. Environmental Protection Agency, Office of Research and Development, Air and Energy Engineering Research Laboratory, Research Triangle Park, NC; the Town of Crested Butte, Crested Butte, CO; and Colorado Department of Health, Denver, CO (EPA-600/7-91-005) (NTIS PB91-106921)
18	Barnet, Stockton G.; Roholt, Robert B.; Houck, James E.	1990	1.Field Performance of Best Existing Stove Technology (BEST) Hybrid Woodstoves in Their Second Year of Use 2.Evaluation of a Modified Evacuation Cylinder Particulate Emissions Sampler (MECS)	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the Oregon Department of Environmental Quality, Portland, OR
19	Barnet, Stockton G.; Roholt, Robert B.	1990	In-Home Performance of Certified Pellet Stoves in Medford and Klamath Falls, Oregon	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the U.S. Department of Energy; and Oregon Department of Environmental Quality, Portland, OR; (Administered by the Bonneville Power Administration, Portland, OR) (DOE/BP-04143-1)
	Barnett, Stockton G.;		Field Performance of Advanced Technology	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
20	Fesperman, James	1990	Woodstoves in Their Second Season of Use in Glens Falls, New York, 1990	Canada Center for Mineral and Energy Technology, Energy, Mines, and Resources, Canada, Ottowa, Ontario
21	Barnett, Stockton G.	1990	In-Home Evaluation of Emission Characteristics of EPA-Certified High Technology Non-Catalytic Woodstoves in Klamath Falls, Oregon, 1990 Final Report	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for Canada Center for Mineral and Energy Technology, Energy, Mines, and Resources, Canada, Ottowa, Ontario
22	Dernbach, Sue	1990	Woodstove Field Performance in Klamath Falls, Oregon	Elements Unlimited, Portland, OR; Prepared for the Wood Heating Alliance, Washington, DC
23	A-4 Jaasma, Dennis R.; Champion, Mark; Shelton, Jay W.	1990	Woodstove Smoke and CO Emissions: Comparison of Reference Methods with the VPI Sampler	Journal of the Air & Waste Management Association, Vol. 40, No. 6 pp. 866-871
24	Barnett, Stockton G.	1989/ 1990	Final Report Field Performance of Advanced Technology Woodstoves in Glens Falls, NY, 1988-89, Volume I; and Technical Appendix, Volume II	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the New York State Energy Research and Development Authority; U.S. Environmental Protection Agency; CONEG Policy Research Center, Inc.; Canadian Combustion Research Laboratory; and Wood Heating Alliance (EPA-600/7-90-019a&b) (NTIS PB91-125641 and -125658)
25	Jaasma, Dennis R.; Champion, Mark	1989	Field Performance of Woodburning Stoves in the 1988-89 Heating Season	Department of Mechanical Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA; Prepared for the Town of Crested Butte, Crested Butte, CO; Colorado Department of Health, Denver, CO; and the U.S. Environmental Protection Agency, Region 8, Denver, CO
26	Simons, Carl A.; Jones, Stanton K.	1989	Performance Evaluation of the Best Existing Stove Technology (BEST) Hybrid Woodstove and Catalytic Retrofit Device	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the Oregon Department of Environmental Quality, Portland, OR
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28	Elements Unlimited	1988	In-Situ Emission Factors for Residential Wood Combustion Units	Elements Unlimited; Prepared for the Emissions Standards Division, U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Air Quality Planning and Standards, Research Triangle Park, NC (EPA-450/3-88-013)
29	OMNI Environmental Services, Inc.	1988	Final Report Particulate Emission Test, Emission Control System Inspection and Leak Check of the Blaze King "King" in Home PO2 Dr. John Rau	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the Oregon Department of Environmental Quality, Portland, OR
30	Simons, Carl A.; Christiansen, Paul D.; Houck, James E.; Pritchett, Lyle C.	1988	Woodstove Emission Sampling Methods Comparability Analysis and In-Situ Evaluation of New Technology Woodstoves, Task G Final Report	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the U.S. Department of Energy, Pacific Northwest and Alaska Regional Biomass Energy Program, (Administered by the Bonneville Power Administration, Portland, OR) (DOE/BP-18508-6)
31	A-5 Simons, Carl A.; Christiansen, Paul D.; Pritchett, Lyle C.; Enns, Victor; Hayden, A.C.S.	1988	An In-Situ Residential Performance Evaluation of Conventional and New Woodheat Technologies in Whitehorse, Yukon Territory	Proceedings of the 1988 Air Pollution Control Association Meeting, Dallas, TX (88-89.3)
32	Burnet, Paul G.	1987	Field Investigations of Catalytic and Low Emissions Woodstove Particulate Emissions, Efficiency and Safety	Proceedings of the 1987 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants, Pittsburgh, PA, U.S. Environmental Protection Agency, pp. 697-706 (EPA-600/9-87-010) (NTIS PB88-113402)
33	OMNI Environmental Services, Inc.	1987	Final Woodstove and Catalytic Combustion Inspections: NCWS Study Homes	Prepared for the Coalition of Northeastern Governors; New York State Energy Research and Development Authority; and the U.S. Environmental Protection Agency

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
34	OMNI Environmental Services, Inc.	1987	Performance Monitoring of Advanced Technology Wood Stoves: Field Testing for Fuel Savings, Creosote Buildup and Emissions, Volume I; and Technical Appendix, Volume II; also Published as: The Northeast Cooperative Woodstove Study	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for New York State Energy Research and Development Authority; CONEG Policy Research Center, Inc.; and U.S. Environmental Protection Agency, Research Triangle Park, NC (EPA-600/7-87-026a&b) (NTIS PB88-140769 and -140777)
35	OMNI Environmental Services, Inc.	1987	An In-Situ Performance Evaluation of the Catalytic Retrofit Devices	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the Oregon Department of Environmental Quality, Portland, OR
36	Simons, Carl A.; Christiansen, Paul D.; Pritchett, Lyle C.; Buyerman, Glenn A.	1987	Whitehorse Efficient Woodheat Demonstration	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the City of Whitehorse, Whitehorse, Yukon
37	Houck, James E.	1986	A System to Obtain Time Integrated Woodstove Emission Samples	Proceedings of the 1986 EPA/APCA Symposium on Measurement of Toxic Pollutants, Raleigh, NC; U.S. Environmental Protection Agency (EPA-600/9-86-013) (NTIS PB87-182713)
38	A-6 Morgan, S.	1986	Evaluating the Field Performance of High Efficiency and Catalytic Wood Stoves	Proceedings of the 1986 EPA/APCA Symposium on Measurement of Toxic Pollutants, Raleigh, NC, U.S. Environmental Protection Agency; Published by the Air Pollution Control Association, VIP-7, Pittsburgh, PA, pp. 713-723 (EPA-600/9-86-013) (NTIS PB87-182713)
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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
41	Hornig, James F.; Soderberg, Roger H.; Larson, Deborah	1981	Ambient Air Assessment in a Rural New England Village where Wood is the Dominant Fuel	Proceedings of the Wood Heating Seminars 1980/1981, Wood Heating Alliance, Washington DC, pp. 140-153
42	Sanborn, Cedric R.; Poirot, Richard L.; Heil, Gregory A.; Blanchet, Michael A.	1981	Preliminary Analysis of the Ambient Impacts of Residential Woodburning in Waterbury, Vermont	Proceedings of the Wood Heating Seminars 1980/1981, Wood Heating Alliance, Washington DC, pp. 231-241
43	Modera, M.P.; Sonderegger, R.C.	1980	Determination of In-Situ Performance of Fireplaces	Energy Performance of Buildings Group, Energy & Environment Division, Lawrence Berkeley Laboratory, University of California, Berkeley, CA (LBL-10701; UC-95d; EEB-EPB-80-8)
44	PEDCo Environmental, Inc.	1977	Source Testing for Fireplaces, Stoves, and Restaurant Grills in Vail, Colorado	PEDCo Environmental, Inc., Kansas City, MO

CATEGORY #2 LABORATORY EMISSION AND ENGINEERING STUDIES

#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
1	Valenti, Joseph C.; Clayton, Russell K.	1998	Emissions from Outdoor Wood-Burning Residential Hot Water Furnaces	Acurex Environmental Corporation, Prepared for the U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC (EPA-600/R-98-017) (NTIS PB98-131980)
2	Hubbard, A.J.	1995	Hazardous Air Emissions Potential from a Wood-Fired Furnace	Combustion Science and Technology, Vol. 108, pp. 297-309
3	McCrillis, Robert C.	1995	Review and Analysis of Emissions Data for Residential Wood-Fired Central Furnaces	Proceedings of the 88th Annual Air & Waste Management Association Meeting and Exhibit, San Antonio, TX, U.S. Environmental Protection Agency, Air and Energy Engineering Research Laboratory, Research Triangle Park, NC (95-RP137.04)
A-8 4	Tiegs, Paul E.	1995	Design and Operating Factors which Affect Emissions from Residential Wood-Fired Heaters: Review and Update	Proceedings of the 88th Annual Air & Waste Management Association Meeting & Exhibition, San Antonio, TX (95-RP-137.02)
5	Bighouse, Roger D.; Barnett, Stockton G.; Houck, James E.; Tiegs, Paul E.	1994	Woodstove Durability Testing Protocol	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the U. S. Environmental Protection Agency, Office of Research and Development, Office of Environmental Engineering and Technology Demonstration, Washington, DC (EPA-600/R-94-193) (NTIS PB95-136164)
6	Barnett, Stockton G.; Bighouse, Roger D.; Houck, James E.	1993	Final Report Manufacturers Seminar on Woodstove Stress Testing	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the Coalition of Northeastern Governors, Policy Research Center, Washington, DC; and Pacific Northwest and Alaska Regional Biomass Program, Bonneville Power Administration, U. S. Department of Energy, Portland, OR
7	Bighouse, Roger D.; Houck, James E.; Barnett, Stockton G.; McCrillis, Robert C.	1993	Stress Testing of Woodstoves	Proceedings of the 86th Annual Air & Waste Management Association Meeting & Exhibition, Denver, CO (93-RP-136.05) (EPA-600/A-93-268) (NTIS PB94-120011)
8	Bighouse, Roger D.; Houck,	1993	Evaluation of Emissions and Energy	Science Applications International Corporation, Beaverton, OR;

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
	James E.		Efficiencies of Residential Wood Combustion Devices Using Manufactured Fuels	Prepared for the Oregon Department of Energy, Salem, OR
9	Houck, James E.; Bighouse, Roger D.	1993	Reduction in Particulate and Carbon Monoxide Emissions from Fireplace and Woodstoves with the Use of Sawdust/Wax Firelogs	Science Applications International Corporation, Beaverton, OR; Prepared for the Hearth Products Association, Washington, DC; and Firelog Manufacturers Association, c/o Canadian Firelog Ltd., Richmond, B.C., Canada
A-9 10	Karlsson, M.	1993	Emissions from Wood-Fired Domestic Central Heating Boilers Load Dependence, (English Translation of Emissioner från vedpannor lastföhållandets betydelse)	SP Report Swedish National Testing Institute (SP), Energy Division, p. 48
11	Karlsson, M.; Gustavsson, L.	1993	Characterization of Combustion Emissions from Wood-Fired Domestic Central Heating Boilers, (English Translation of Karaktärisering avrökgaser från vedpannor),	SP Report Swedish National Testing Institute (SP), Energy Division, p. 49
12	McCrillis, Robert C.; Watts, Randall R.; Zweidinger, Roy B.	1993	Comparison of Residential Oil Furnace and Woodstove Emissions	Proceedings of the 1993 U.S. EPA/A&WMA International Symposium on Measurement of Toxic and Related Air Pollutants, Durham, NC; Published by the Air & Waste Management Association, VIP-34, Pittsburgh, PA, pp. 213-220
13	McCrillis, Robert C.; Jaasma, Dennis R.	1993	Woodstove Emission Measurement Methods: Comparison and Emission Factors Update	Environmental Monitoring and Assessment, volume 24, pp. 1-12
14	Barnett, Stockton G.	1992	Particulate and Carbon Monoxide Emissions from the Use of Hazelnut Logs in a Conventional Masonry Fireplace	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the Hazelnut Growers of Oregon, Cornelius, OR
15	Barnett, Stockton G.	1992	Particulate and Carbon Monoxide Emissions	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
			from the Use of Palm Branch Logs in a Conventional Masonry Fireplace	Clean Burning Fuels, Inc., Tucson, AZ
16	Champion Mark; et al.	1992	Fireplace Smoke and CO Emissions: Comparison of a Field Sampler with Reference Methods	Transactions of the A&WMA/EPA International Specialty Conference, PM_{10} Standards and Nontraditional Particulate Source Controls, Volume II, TR-22; Published by Air & Waste Management Association, Pittsburgh, PA, pp. 536-552 (ISBN 0-923204-09-1)
17	Nielson, P.A.; Joergensen, V.	1992	Mutagenic Activity in Samples of Emissions from Straw Combustion and Wood Chip Combustion, (English translation of Mutagen aktititet i prøver af røggas fra halm g flisfry)	The Danish National Food Regulatory Administration (Levnedsmiddelstyrelsen) Report NEI-DE-744
A-10 18	Shelton, Jay W.	1992	Testing of Sawdust-Wax Firelogs in an Open Fireplace	Transactions of the A&WMA/EPA International Specialty Conference, PM_{10} Standards and Nontraditional Particulate Source Controls, Volume II, TR-22; Published by Air & Waste Management Association, Pittsburgh, PA, pp. 553-571 (ISBN 0-923204-09-1)
19	Stroud, T.	1992	Thermal Mass Solid Fuel Technology as a Low-Emission Residential Energy Option	Transactions of the A&WMA/EPA International Specialty Conference, PM_{10} Standards and Nontraditional Particulate Source Controls, Volume II, TR-22; Published by Air & Waste Management Association, Pittsburgh, PA, pp. 572-584 (ISBN 0-923204-09-1)
20	Anonymous	1991	WHA Fireplace Emissions Test Method Procedures	No Publication Information Listed
21	Hayden, A.C.S.; Braaten, R.W.	1991	Reduction of Fireplace and Woodstove Pollutant Emissions through the Use of Manufactured Firelogs	Proceedings of the 84th Annual Air & Waste Management Association Meeting & Exhibition, Vancouver, B.C.
22	Stern, Curtis H.; Jaasma, Dennis R.	1991	Study of Emissions from Masonry Fireplaces Final Report	Department of Mechanical Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA; Prepared for

CATEGORY #2 LABORATORY EMISSION AND ENGINEERING STUDIES

#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
				the Brick Institute of America, Reston, VA
23	anonymous	1990	Continuation of the Design of a 12-Hour Catalytic Furnace	Department of Energy, Mines and Resources, Canada (Contract No. 23216-8-90005/01-SZ)
24	Burnet, Paul G; Houck, James E.; Roholt, Robert B.	1990	Effects of Appliance Type and Operating Variables on Woodstove Emissions, Volume I Report and Appendices A-C, Volume II Appendices D-F	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the U.S. Environmental Protection Agency, Air and Energy Engineering Research Laboratory, Research Triangle Park, NC (EPA-600/2-90-001a&b) (NTIS PB90-151457 and -151465)
25	Karlsson, M.	1990	Emissions from Small Scale Wood Burning Comparison of Test Methods, (English translation of Emissioner vid småklig vedeldning jämförelse av provningsmetoder)	Swedish Energy Agency (Statens energiverk) (FBT 90/3, Project Number 276 359)
26	Shelton, Jay W.; Sorensen, Doug; Stern, Curtis H.; Jaasma, Dennis R.	1990	Fireplace Emissions Test Method Development	Shelton Research Inc., Santa Fe, NM; and the Department of Mechanical Engineering, Virginia Polytechnic Institute & State University, Blacksburg, VA; Prepared for the Wood Heating Alliance, Washington, DC, Fireplace Emissions Research Coalition
A-11 27	Stern, Curtis H.; Jaasma, Dennis R.; Shelton, Jay W.	1990	Final Report on the Masonry Heater Emissions Test Method Development	Department of Mechanical Engineering, Virginia Polytechnic Institute & State University, Blacksburg, VA; and Shelton Research, Inc., Sante Fe, NM; Prepared for the Wood Heating Alliance, Fireplace Emissions Research Coalition
28	Bushnell, Dwight J.; Haluzok, Charles; Dadkhah-Nikoo, Abbas	1989	Biomass Fuel Characterization: Testing and Evaluating the Combustion Characteristics of Selected Biomass Fuel Final Report	Department of Mechanical Engineering, Oregon State University, Corvallis, OR; Prepared for the Bonneville Power Administration, Portland, OR (DOE/BP-1363)
29	Leese, K.E.; Harkins, S.M.	1989	Effects of Burn Rate, Wood Species, Moisture Content and Weight of Wood Loaded on Woodstove Emissions	Research Triangle Institute, Research Triangle Park, NC; Prepared for the U.S. Environmental Protection Agency, Office of Research and Development, Air and Energy Engineering Research Laboratory, Research Triangle Park, NC (EPA-600/2-89/025) (NTIS PB89-196828)

CATEGORY #2 LABORATORY EMISSION AND ENGINEERING STUDIES

#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
30	Burnet, Paul G.; Simons, Carl A.	1988	Identification of Factors which Affect Combustion Efficiency and Environmental Impacts from Woodstoves, Task D Final Report	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the U.S. Department of Energy, Pacific Northwest and Alaska Regional Biomass Energy Program, (Administered by the Bonneville Power Administration, Portland, OR) (DOE/BP-18508-4)
31	Hayden, A.C.S.; Braaten, R.W.	1988	Techniques to Reduce the Emissions from Existing Woodburning Appliances	Proceedings of the 1988 Air Pollution Control Association Meeting, Dallas, TX (88-89.1)
32	McCrillis, Robert C.	1988	Effects of Operating Variables on Emissions from Woodstoves	Proceedings of the 1988 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants, Research Triangle Park, NC; U.S. Environmental Protection Agency; Published by the Air Pollution Control Association, VIP-10, Pittsburgh, PA, pp. 835-840 (EPA-600/9-88-015) (NTIS PB90-225863)
33	OMNI Environmental Services, Inc.	1988	Environmental Impacts of Advanced Biomass Combustion Systems Final Report	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the U.S. Department of Energy, Pacific Northwest and Alaska Regional Biomass Energy Program, (Administered by Bonneville Power Administration, Portland, OR)
34	Aiken, M.	1987	Canadian Firelog Ltd. Emission Testing	Air Program, B.C. Research, Vancouver, B.C.; Prepared for Canadian Firelog Ltd., Richmond, B.C.
35	Merrill, Raymond G.; Harris, D. Bruce	1987	Field and Laboratory Evaluation of a Woodstove Dilution Sampling System	U.S. Environmental Protection Agency, Air and Energy Research Laboratory, Research Triangle Park, NC (EPA-600/D-87-216) (NTIS PB87-210381)
A-12 36	Shelton, Jay W.; Gay, Larry	1987	Colorado Fireplace Report	Shelton Research, Inc., Sante Fe, NM; Prepared for the Colorado Air Pollution Control Division, Denver, CO
37	Swinton, Michael C.; Sinha, Robin P.; Haysom, John C.	1987	Modifications and Refinement of the Computer Model Wood Burning Simulator	Scandia Consultants Limited; Prepared for Canada Mortgage and Housing Corporation
38	Swinton, Michael C.	1987	Residential Combustion Venting Failure a	Scandia Consultants Limited, Scandia Sheltair Consortium; Prepared

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
			Systems Approach Final Report Project 2 Modifications And Refinements To The Flue Simulator Model	for the Research Division, Policy Development and Research Sector, Canada Mortgage and Housing Corporation
39	Burnet, Paul G.; Edmisten, Norman G.; Tiegs, Paul E.; Houck, James E.; Yoder, Rachel A.	1986	Particulate, Carbon Monoxide, and Acid Emission Factors for Residential Wood Burning Stoves	Journal of the Air Pollution Control Association, Vol. 36, No. 9, pp. 1012-1018
40	Cottone, Lawrence E.; Messer, Edward	1986	Test Method Evaluation and Emission Testing for Rating Wood Stoves	U.S. Environmental Protection Agency, Air and Energy Engineering Research Laboratory, Research Triangle Park, NC (EPA-600/2-86-100) (NTIS PB87-119897)
41	McCrillis, Robert C.; Merrill, Raymond G.; Westlin, P.R.; Weant, G.E.; Wagoner, D.E.	1986	Comparisons Between MM5, OM7, and Draft ASTM Measurements of Wood Stove Emissions	Proceedings of the 1986 Air Pollution Control Association Annual Meeting (86-74.8) EPA-600/D-86-150) (NTIS PB86-223096)
42	Shelton, Jay W.; Gay, Larry	1986	Evaluation of Low-Emission Wood Stoves Final Report	Shelton Research, Inc., Sante Fe, NM; Prepared for the California Air Resources Board, Sacramento, CA
A-13 43	Tiegs, Paul E.; Burnet, Paul G.	1986	Improving Flue Loss Methods for Measuring Wood Heater Thermal Performance	OMNI Environmental Services, Inc., Beaverton, OR
44	Barnett, Stockton G.	1985	Handbook for Measuring Woodstove Emissions and Efficiency Using the Condar System (The Manufacturer's Instructions for Source Sampling Method 41 of Oregon's D.E.Q.)	No Publication Information Listed
45	Becker, Mimi; Barnett, Stockton G.; Cowden, James W.; Barnett, Lucy; Graham,	1985	Residential Wood Combustion Emissions and Safety Guidebook	Environmental Resource Center, Hiram College, Hiram, OH; Prepared for the Council of Great Lakes Governors, Great Lakes Regional

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
	Penny; Van Den Bossche, Krista; Hannan, Karen			Biomass Energy Program, Madison, WI
46	Energy Task Force of the Urban Consortium for Technology Initiatives	1985	Residential Space Heating with Wood: Efficiency and Environmental Performance	Energy Task Force of the Urban Consortium for Technology Initiatives, Environmental Health and Energy Department, Energy Management Division, Albuquerque, NM
47	McCrillis, Robert C.; Merrill, Raymond G.	1985	Emission Control Effectiveness of a Woodstove Catalyst and Emission Measurement Methods Comparison	Proceedings of the 78th Annual Meeting of the Air Pollution Control Association, Detroit, MI (EPA-600/D-85-132) (NTIS PB85-218816)
48	OMNI Environmental Services, Inc.	1985	Standard Test Method for Determining the Heat Output Range and Maximum Burn Cycle Duration	OMNI Environmental Services, Inc., Beaverton, OR
49	Shelton, Jay W.; Jaasma, Dennis R.	1985	Critical Assessment of Various Flue Loss Methods for Solid Fuel Heater Efficiency Measurement	Shelton Energy Research, Santa Fe, NM; Presented at the 1985 Annual Meeting of the American Society of Heating, Refrigerating & Air Conditioning Engineers
A-14 50	Shelton, Jay W.	1985	ASTM Emissions and Efficiency Tests on Four Stoves	Shelton Energy Research, Santa Fe, NM; Prepared for the Wood Heating Alliance, Washington, DC
51	Shelton, Jay W.	1985	Overview of Efficiency Measuring Methods	Shelton Energy Research, Santa Fe, NM
52	Shelton, Jay W.	1985	Wood Stove Particulate Matter Test Methods and Emissions Factors	Shelton Energy Research Report No. 1185, Santa Fe, NM; Prepared for the Colorado Department of Health, Air Pollution Control Division, Stationary Sources Program
53	Shelton, Jay W.; Barczys, C.	1985	Creosote The Truth about Green Wood	Shelton Energy Research, Santa Fe, NM
54	Shelton, Jay W.	1985	Is 100% Overall Energy Efficiency Possible in Solid Fuel Residential Heaters?	Shelton Energy Research, Santa Fe, NM

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
55	Allen, John M.; Piispanen, William H.; Cooke, Marcus	1984	Study of the Effectiveness of a Catalytic Combustion Device on a Wood Burning Appliance	Battelle Columbus Laboratories, Columbus, OH; Prepared for the U.S. Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Research Triangle Park, NC (EPA-600/7-84-046) (NTIS PB84-171545)
56	Lipari, Frank; Dasch, Jean M.; Scruggs, William F.	1984	Aldehyde Emissions from Wood-Burning Fireplaces	Environmental Science & Technology, Vol. 18, No. 5, pp. 326-330
57	Shelton, Jay W.; Graeser, L.; Jaasma, Dennis R.	1984	Sensitivity Study of Traditional Flue Loss Methods for Determining Efficiencies of Solid Fuel Heaters	Shelton Energy Research, Santa Fe, NM; Presented at the 1984 Annual Meeting of the American Society of Mechanical Engineers
58	Tiegs, Paul E.; Edmisten, Norman G.; Hatch, Candice L.	1984	Technical Report Comparative Analysis of Current Woodstove Technologies: Emissions and Efficiencies	Proceedings of the 77th Annual Air Pollution Control Association Meeting & Exhibition, San Francisco, CA
59	Truesdale, R.S.; Mack, K.L.; White, J.B.; Leese, K.E.; Cleland, J.G.	1984	Characterization of Emissions from the Combustion of Wood and Alternative Fuels in a Residential Woodstove	Research Triangle Institute, Research Triangle Park, NC; and the U.S. Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Research Triangle Park, NC (EPA-600/7-84-094) (NTIS PB85-105336)
A-15 60	Van der Heeden, D.J.	1984	Vergelijkend Onderzoek naar de Luchtverontreiniging van 17 Kachels voor Vaste Brandstof (Dutch) Comparison of Air Pollution by 17 Solid Fuel Stoves	Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, Consumentenbond
61	Tennessee Valley Authority	1983	Residential Wood Heater Test Report Phase II Testing, Volume I	Tennessee Valley Authority, Division of Energy Conservation and Rates, Energy Use Test Staff, Chattanooga, TN
62	Barnett, Stockton G.	1982	Woodstove Design and Control Mode as Determinants of Efficiency, Creosote Accumulation, and Condensable Particulate Emissions	Proceedings of the Residential Wood & Coal Combustion Specialty Conference, the Air Pollution Control Association, Louisville, KY, pp. 70-88

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64	Hayden, A.C.S.	1982	Effects of Firing Rate and Design on Domestic Wood Stove Performance	Proceedings of the Residential Wood & Coal Combustion Specialty Conference, the Air Pollution Control Association, Louisville, KY, pp. 56-69
65	Jaasma, Dennis R.	1982	Measurement Techniques and Emission Factors for Hand-Fired Coalstoves	Proceedings of the Residential Wood & Coal Combustion Specialty Conference, the Air Pollution Control Association, Louisville, KY, pp. 129-150
66	Knight, C.V.	1982	Emission and Thermal Performance Mapping for an Unbaffled, Air-Tight Wood Appliance and a Box-Type Catalytic Appliance	Proceedings of the Residential Wood & Coal Combustion Specialty Conference, the Air Pollution Control Association, Louisville, KY, pp. 25-55
67	Ramdahl, Thomas; Alfheim, Ingrid; Rustad, Ståle; Olsen, Torbjørn	1982	Chemical and Biological Characterization of Emissions from Small Residential Stoves Burning Wood and Charcoal	Chemosphere, Vol. 11, No. 6, pp. 601-611
68	Sanborn, Cedric R.	1982	Characterization of Emissions from Residential Coal Stoves	Proceedings of the Residential Wood & Coal Combustion Specialty Conference, the Air Pollution Control Association, Louisville, KY, pp. 151-160
A-16 69	Shelton, Jay W.; McGrath, J.; Lewis, C.	1982	Relative Creosote Accumulation in Double-Wall Mass-Insulated Chimneys vs. Triple-Wall Air-Insulated Chimneys	Shelton Energy Research, Santa Fe, NM
70	Shelton, Jay W.; Graeser, L.	1982	An Investigation of the Effects of Ambient Temperature and Forced Convection on Radiant Stove Efficiency	Shelton Energy Research, Santa Fe, NM; Prepared for the Wood Heating Alliance, Washington, DC; and Brookhaven National Laboratory, Upton, NY
71	Shelton, Jay W.; Lewis, C.	1982	Measured Creosote Reducing Effects of the Smoke Dragon, the Smoke Consumer, and a Barometric Draft Control	Shelton Energy Research, Santa Fe, NM

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73	Truesdale, Robert S.	1982	Residential Stove Emissions from Coal and Other Alternative Fuels Combustion	Proceedings of the Residential Wood & Coal Combustion Specialty Conference, Air Pollution Control Association, Louisville, KY, pp. 115-128
74	Allen, John M.; Cooke, W. Marcus	1981	Control of Emissions from Residential Wood Burning by Combustion Modification	Battelle Columbus Laboratories, Columbus, OH; and the U.S. Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Research Triangle Park, NC (EPA-600/7-81-091) (NTIS PB81-217655)
75	Allen, John M.	1981	Control of Emissions from Residential Wood Burning by Combustion Modification	Proceedings of the Wood Heating Seminars 1980/1981, Wood Heating Alliance, Washington DC, pp. 167-190
76	Barnett, Stockton G.	1981	The Effects of Woodstove Design on Condensible Particulate Emissions, In-Home Delivered Efficiency, and Creosote Formation Rate	Proceedings of the Wood Heating Seminars 1980/1981, Wood Heating Alliance, Washington DC, pp. 268-269
77	Barnett, Stockton G.; Shea, Damian	1981	Effects of Woodstove Design and Operation on Condensible Particulate Emissions	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 227-266
78	Brandon, Robert J.	1981	Residential Wood Fired Furnaces: Results from a Demonstration of Advanced Designs	Proceedings of Energy from Biomass and Wastes V, Institute of Gas Technology, Chicago, IL
79	Brandon, Robert J.; Murray, D.	1981	Pellet Wood Stokers Evaluation and Testing of Available Systems	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 941-965

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A-17 80	Brandon, Robert J.	1981	An Assessment of the Efficiency and Emissions of Ten Wood Fired Furnaces	Proceedings of the Wood Heating Seminars 1980/1981, Wood Heating Alliance, Washington DC, p. 267
81	Butcher, Samuel S.; Ellenbecker, Michael J.	1981	Particulate Emission Factors for Small Wood and Coal Stoves	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 289-303
82	Cooke, W. Marcus; Allen, John M.; Hall, Robert E.	1981	Characterization of Emissions from Residential Wood Combustion Sources	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 139-163
83	Dickinson, Roger; Payne, Robert C.	1981	United Kingdom Efficiency Tests and Standards for Residential Solid Fuel Heating Appliances	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 1055-1088
84	Giammer, Robert D.	1981	Evaluation of Emissions from Residential Coal-Fired Boilers under Stokeless Operation	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 304-312
85	Hall, Robert E.	1981	Emissions Assessment of a Standard Wood Stove Comparing Stack versus Dilution Tunnel Sampling	Proceedings of the Wood Heating Seminars 1980/1981, Wood Heating Alliance, Washington DC, p. 270
A-18 86	Harper, Jerome P.; Knight, C.V.	1981	Measurement of Wood Heater Thermal and Emissions Performance	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 210-226
	Hubble, B.R.; Harkness,		Results of Laboratory Tests on Wood Stove	Proceedings of the Wood Heating Seminars 1980/1981, Wood

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
87	J.B.L.	1981	Efficiency and Emissions	Heating Alliance, Washington DC, p. 277
A-18 88	Hubble, B.R.; Stetter, J.R.; Gebert, E.; Harkness, J.B.L.; Flotard, R.D.	1981	Experimental Measurements of Emissions from Residential Wood-Burning Stoves	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 79-138
89	Hughes, Thomas W.; DeAngelis, Darryl G.	1981	Emissions from Coal-Fired Residential Combustion Equipment	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 333-348
90	Jaasma, Dennis R.	1981	Catalysis of Woodstove Effluent	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 832-850
91	Jaasma, Dennis R.	1981	Measurements of Chemical Changes Due to Catalysis of Woodstove Effluent	Proceedings of the Wood Heating Seminars 1980/1981, Wood Heating Alliance, Washington DC, pp. 221-230
92	Kowalczyk, John F.; Bosserman, Peter B.; Tombleson, Barbara J.	1981	Particulate Emissions from New Low Emission Wood Stove Designs Measured by EPA Method V	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 54-78
93	Macumber, Dale W.; Jaasma, Dennis R.	1981	Efficiency and Emissions of a Hand-Fired Residential Coalstove	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 313-332
94	Muhlbaier, Jean L.	1981	A Characterization of Emissions from Wood-Burning Fireplaces	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982),

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
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95	Peters, J.A.; Hughes, T.W.; DeAngelis, D.G.	1981	Wood Combustion Emissions at Elevated Altitudes	Proceedings of the Wood Heating Seminars 1980/1981, Wood Heating Alliance, Washington DC, pp. 252-259
96	Peters, James A.	1981	POM Emissions from Residential Woodburning: An Environmental Assessment	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 267-288
A-20 97	Peters, J.A.;Hughes, T.W.; DeAngelis, D.G.	1981	Wood Combustion Emissions at Elevated Altitudes	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 199-209
98	Pullen, Donald R.; Holden, Roger	1981	Design Features and Test Experiences with Domestic Wood Fired Heaters in New Zealand	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 1166-1179
99	Roberts, John; Austin, Fred; Rossano, A.T.; Willenberg, Jay	1981	Measuring and Improving the Efficiency of Large Wood-Fired Furnaces Impact on Emissions and Fuel Use	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 1089-1116
100	Rudling, Lars; Bengt, Ahlingt; Lofröth, Goran	1981	Chemical and Biological Characterization of Emissions from Combustion of Wood and Wood-Chips in Small Furnaces and Stoves	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 34-53
101	Rustad, Ståle; Olsen, Torbjørn	1981	Charcoal The Feasible Fuel for a Small, Automatically Fed, Clean Burning Residential Stove	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982),

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				pp. 984-995
102	Sanborn, Cedric R.; Blanchet, Michael	1981	Particulate Emissions from Residential Wood Combustion in Vermont	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 188-198
103	Shelton, Jay W.	1981	Thermal Performance Testing Methods for Residential Solid Fuel Heaters	Shelton Energy Research, Santa Fe, NM
104	Shelton, Jay W.; McGrath, Jane	1981	The Effects of Fuel Moisture Content, Species and Power Output on Creosote Formation	Shelton Energy Research, Santa Fe, NM
105	Shelton, Jay W.; Alfano, Joseph; Buchen, Anthony	1981	The Effects of Creosote on Stovepipe Heat Transfer	Shelton Energy Research, Santa Fe, NM
106	Shelton, Jay W.	1981	Results of the Research on Catalytic Combustion on Wood Stoves	Proceedings of the Wood Heating Seminars 1980/1981, Wood Heating Alliance, Washington DC, p. 278
A-21 107	Shelton, Jay W.	1981	Thermal Performance Testing of Residential Solid Fuel Heaters	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 1117-1159
108	Shelton, Jay W.; Barczys, Cathleen	1981	Dilution Air for Reducing Creosote	Shelton Energy Research, Santa Fe, NM
109	Short, C.A.	1981	Home Heating with Wood Chips	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 966-983
110	VanDewoestine, Robert V.; Zimar, Frank	1981	Catalytic Combustion in Residential Wood Stoves	Proceedings of the Wood Heating Seminars 1980/1981, Wood Heating Alliance, Washington DC, pp. 154-166

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
111	Zimar, Frank; VanDewoestine, Robert V.; Allaire, Roger A.	1981	The Effect of Catalytic Combustion on Creosote Reduction, Combustion Efficiency, and Pollution Abatement for Residential Wood Heaters	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 924-940
112	Day, Bill	1980	Wood Stove Durability: A Literature Review with Illustrations	Northwest Information Enterprises, Beaverton, OR; Produced for Western Solar Utilization Network, Portland, OR (WSUN-27)
113	DeAngelis, D.G.; Ruffin, D.S.; Peters, J.A.; Reznik, R.B.	1980	Source Assessment: Residential Combustion of Wood	Monsanto Research Corporation, Dayton, OH; Prepared for the U.S. Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Research Triangle Park, NC (EPA-600/2-80-042b) (NTIS PB81-136160)
114	DeAngelis, D.G.; Ruffin, D.S.; Reznik, R.B.	1980	Preliminary Characterization of Emissions from Wood-Fired Residential Combustion	Monsanto Research Corporation, Dayton, OH; Prepared for the U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC (EPA-600/7-80-040) (NTIS PB80-182066)
115	State of California Air Resources Board	1980	Emissions from Residential Fireplaces Report No. C-80-027	State of California Air Resources Board, Stationary Source Control Division, Engineering Evaluation Branch, Eureka, CA
A-22 116	Butcher, Samuel S.; Sorenson, Edmund M.	1979	A Study of Wood Stove Particulate Emissions	Journal of the Air Pollution Control Association, Vol. 29, No. 7, pp. 724-728
117	Butcher, Samuel S.; Buckley, Douglas I.	1977	A Preliminary Study of Particulate Emissions from Small Wood Stoves	Journal of the Air Pollution Control Association, Vol. 27, No. 4, pp. 346-348
118	Snowden, W.D.; Alguard, D.A.; Swanson, G.A.; Stolberg, W.E.	1975	Source Sampling Residential Fireplaces for Emission Factor Development	Valentine, Fisher & Tomlinson, Seattle, WA; Prepared for the U.S. Environmental Protection Agency, Office of Air Quality Planning & Standards, Monitoring & Data Analysis Division, Research Triangle Park, NC (EPA-450/3-76-010)
119	British Standards Institute	1969	Recommendations for the Design and Testing	British Standards Institute, British Standards House,

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
			of Smoke Reducing Solid Fuel Burning Domestic Appliances	London, England
120	Allen, John M.	Undated	Control of Emissions from Residential Wood Burning by Combustion Modification	Battelle Columbus Laboratories, Columbus, OH
121	Brandon, Robert J.	Undated	An Assessment of the Efficiency and Emissions of Ten Wood Fired Furnaces	Institute of Man and Resources, Charlottetown, Prince Edward Island, Canada
A-23 122	Jaasma, Dennis R.; Shelton, Jay W.	Undated	Proposed Method for Determination of Energy Efficiency of Wood Heaters	Virginia Polytechnic Institute and State University, Blacksburg, VA; and Shelton Energy Research, Santa Fe, NM

CATEGORY #3 WOOD USE AND ENERGY SURVEYS

#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
1	Kochera, Andrew	1997	Residential Use of Fireplaces	Housing Economics, pp. 10-11
2	Energy Information Administration	1995	Housing Energy Consumption and Expenditures 1993	Energy Information Administration, Office of Energy Markets and End Use, Washington, DC (DOE/EIA-0321(93))
3	Energy Information Administration	1995	State Energy Data Report 1993 Consumption Estimates	Energy Information Administration, Office of Energy Markets and End Use, Washington, DC (DOE/EIA-0214(93))
4	Energy Information Administration	1994	Estimates of U.S. Biofuels Consumption 1992	Energy Information Administration, Office of Energy Markets and End Use, Washington, DC (DOE/EIA-0548(92))
5	Oregon Department of Environmental Quality	1994	Portland 1993 Oregon Woodheating Survey, Overview Report	Oregon Department of Environmental Quality, Air Quality Division, Portland, OR
6	Sifford, Alex	1994	Residential Biofuel Marketing & Delivery Method Study	Oregon Department of Energy, Salem, OR
A-24 7	Energy Information Administration	1993	Housing Energy Consumption and Expenditures 1990; Supplement: Regional	Energy Information Administration, Office of Energy Markets and End Use, Washington, DC (DOE/EIA-0321(90)/S)
8	Energy Information Administration	1993	Housing Energy Consumption and Expenditures 1990	Energy Information Administration, Office of Energy Markets and End Use, Washington, DC (DOE/EIA-0321(90))
9	OMNI Environmental Services, Inc.	1992	Study of Firewood Sources and Costs in Klamath Falls, Oregon and Sandpoint, Idaho	OMNI Environmental Services, Inc. Beaverton, OR; Prepared for the Air & Waste Management Association, Pacific Northwest International Section (PNWIS), Bellevue, WA
10	Energy Information Administration	1991	Estimates of U.S. Biofuels Consumption 1990	Energy Information Administration, Office of Energy Markets and End Use, Washington, DC (DOE/EIA-0548(90))
11	ES Field Services, Inc.	1991	Pocatello Air Quality RWC Device Usage, Survey Results	ES Field Services, Inc.; Prepared for Marketing Research, Boise, ID

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
12	Kelly, Lou Ellyn; Park, Y.M.	1991	Klamath Falls Wood Heating Survey, 1991	Klamath County Department of Health Services, Klamath Falls, OR; Oregon Department of Environmental Quality, Air Quality Division, Portland, OR
13	U.S. Department of Agriculture; U.S. Forest Service	1991	Wenatchee National Forest, Naches Ranger District, Environmental Assessment, Personal Use Firewood Program and Appendix	U.S. Department of Agriculture; U.S. Forest Service, Pacific Northwest Region, Wenatchee National Forest, Naches Ranger District, Wenatchee, WA
14	Zamula, William W.	1989	Directorate for Economic Analysis Room Heating Equipment Exposure Survey Final Report	U.S. Consumer Product Safety Commission, Washington, DC
15	Greene, William T.; Simons, Carl A.	1988	Estimating the Volume of Residential Wood Burning in the Pacific Northwest and Alaska, Task C Final Report	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the U.S. Department of Energy, Pacific Northwest and Alaska Regional Biomass Energy Program, (Administered by the Bonneville Power Administration, Portland, OR) (DOE/BP-18508-3)
16	Armitage, Sarah V.	1987	Report on the 1987 Klamath Falls Area Wood Heating Survey	Oregon Department of Environmental Quality, Air Quality Division, Program Planning and Development, OR, Section Report No. 87-11
17	Steffel, Richard	1986	1986 Missoula Wood-Use Survey Residential Wood Burning and Pollutant Emissions	Eco-Resource Systems, Missoula, MT; Prepared for the Missoula City-County Health Department, Missoula, MT
A-25 18	Cote, William A.; Kaleel, Robert J.	1985	A Survey of Residential Combustion of Wood and Coal in Colorado	TRC Environmental Consultants, Inc. Englewood, CO; Prepared for the U.S. Environmental Protection Agency, Region VIII, Air Programs Branch, Air and Hazardous Materials Division, Denver, CO; and Colorado Department of Health, Air Pollution Control Division, Denver, CO
19	Force, Jo Ellen	1985	Evaluation of Residential Wood Energy Use in Idaho Final Report	Department of Forest Resources, University of Idaho, Moscow, ID; Prepared for the Idaho Department of Water Resources, Boise, ID
20	Hayden, A.C.S.; Braaten, R.W.	1985	Wood Stove Operation and Advanced Design to Reduce Emissions of Incomplete	Canadian Combustion Research Laboratory, ERL/CANMET, Energy, Mines & Resources Canada, Ottawa, Canada; Prepared for the

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
			Combustion Products	Northeast Regional Air Pollution Conference, Amherst, MA
21	Oregon Department of Environmental Quality	1985	Medford Area Wood Heating Survey	Oregon Department of Environmental Quality, Air Quality Division, Portland, OR
22	Church, Scott; Steffel, Richard; Vallie, Robin; Grenfell, Judy	1984	1983 Wood-Cutting Permit Survey, A Study of Firewood Collection and Storage Patterns among Wood Burners in Missoula, Montana	Environmental Health Division, Missoula City-County Health Department, Missoula, MT
23	Church, Scott; Steffel, Richard; Vallie, Robin	1984	1983 Wood-Cutting Permit Survey	Missoula City-County Health Department, Missoula, MT
24	Energy Information Administration	1984	Estimates of U.S. Wood Energy Consumption 1980-1983	Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, U.S. Department of Energy, Washington, DC (DOE/EIA-0341(83))
25	Lippert, Frederick W.; Dungan, Jennifer L.	1983	Residential Firewood Use in the U.S.	Science, Vol. 219, pp. 1425-1427
26	Skog, Kenneth E.; Watterson, Irene A.	1983	Survey Completion Report Residential Fuelwood Use in the U.S.: 1980-81	U.S. Department of Agriculture; U.S. Forest Service, Forest Products Laboratory, Madison, WI
27	Martin, Werner; Koenigshofer, Daniel R.	1982	Survey and Analysis of Current European Technologies for Wood Combustion	Integrated Energy Systems, Inc., Chapel Hill, NC; Prepared for the U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Research Triangle Park, NC (EPA-600/7-83-006) (NTIS PB83-156729)
A-26 28	Simmons Market Research Bureau, Inc.	1982 - present	Simmons Study of Media & Markets	Simmons Market Research Bureau, Inc.
29	Butcher, Thomas A.; Isler, Robert J.	1981	Coal-Oil Mixtures An Alternative Fuel for the Commercial Markets and Large Residential Markets	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982),

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
				pp. 706-728
30	High, Colin	1981	The Wood Resource and Its Use for Energy in the U.S.	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 670-679
31	Petty, P.; Hopp, W.; Chockie, A.	1981	Biomass Energy Utilization in the Pacific Northwest: Impacts Associated with Residential Use of Solid Fuels	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 680-705
32	Strehler, Arno	1981	Energy from Straw and Woodwaste	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 729-745
33	Wainwright, Phyllis Brooks	1981	Wood Energy The North Carolina Effort	Proceedings of the Wood Heating Seminars 1980/1981, Wood Heating Alliance, Washington DC, pp. 260-265
34	Mediamark Research Inc.	1979 - present	Mediamark Research Household & Personal Appliances, Etc. Report	Mediamark Research Inc.
A-27 35	Bernergård, Leif	Undated	Small-Scale Solid Fuel Combustion in Sweden	National Environmental Protection Board, Solna, Sweden

CATEGORY #4 AMBIENT AIR QUALITY AND HEALTH STUDIES

#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
1	Houck, James E.	1993	Atmospheric Emissions of Carbon Dioxide, Carbon Monoxide, Methane, Non-Methane Hydrocarbons, and Sub-Micron Elemental Carbon Particles from Residential Wood Combustion	Proceedings of the 86th Annual Air & Waste Management Association Meeting & Exhibition, Denver, CO (93-RP136.01)
2	Klinedinst, Donna B.; Klouda, George A.; Currie, Lloyd A.; et al.	1993	Radiocarbon Measurements of Extractable Organic Matter from the Integrated Air Cancer Project Study in Roanoke, VA	Proceedings of the 1993 U.S. EPA/A&WMA International Symposium on Measurement of Toxic and Related Air Pollutants, Durham, NC; Published by Air & Waste Management Association, VIP-34, Pittsburgh, PA, pp. 197-206
3	Lewis, Charles W.; Zweidinger, Roy B.; Claxton, Larry D.; et al.	1993	Source Apportionment of Fine Particle Organics and Mutagenicity in Wintertime, Roanoke	Proceedings of the 1993 U.S. EPA/A&WMA International Symposium on Measurement of Toxic and Related Air Pollutants, Durham, NC; Published by Air & Waste Management Association, VIP-34, Pittsburgh, PA, pp. 207-212
A-28 4	Lewtas, Joellen	1993	Complex Mixtures of Air Pollutants: Characterizing the Cancer Risk of Polycyclic Organic Matter	Environmental Health Perspectives, Vol. 100, pp. 211-218
5	Lewtas, Joellen; Walsh, D.B.; Lewis, C.W.; et al.	1993	The Integrated Air Cancer Project: Overview of Roanoke Study and Comparison to Boise Study	Proceedings of the 1993 U.S. EPA/A&WMA International Symposium on Measurement of Toxic and Related Air Pollutants, Durham, NC; Published by Air & Waste Management Association, VIP-34, Pittsburgh, PA, pp. 175-184
6	Stevens, R.K.; Hoffman, A.J.; Baugh, J.D.; et al.	1993	A Comparison of Air Quality Measurements in Roanoke, VA, and Other Integrated Air Cancer Project Monitoring Locations	Proceedings of the 1993 U.S. EPA/A&WMA International Symposium on Measurement of Toxic and Related Air Pollutants, Durham, NC; Published by Air & Waste Management Association, VIP-34, Pittsburgh, PA, pp. 185-189
7	McCrillis, Robert C.; Watts, Randall R.; Warren, Sarah H.	1992	Effects of Operating Variables on PAH Emissions and Mutagenicity of Emissions from Woodstoves	Journal of Air & Waste Management Association, Vol. 42, No. 5, pp. 691-694 (EPA-600/J-92-226) (NTIS PB92-195809)

CATEGORY #4 AMBIENT AIR QUALITY AND HEALTH STUDIES

#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
8	Steiber, Raymond S.; McCrillis, Robert C.; Dorsey, James A.; Merrill, Raymond G.	1992	Characterization of Condensible and Semivolatile Organic Materials from Boise Woodstove Samples	Proceedings of the 85th Annual Air & Waste Management Association Meeting & Exhibition, Kansas City, MO (92-118.03) (EPA-600/A-92-160) (NTIS PB92-206606)
9	Lewis, Charles W.; Stevens, Robert K.; Claxton, Larry D.; Barraclough, Donna; Klouda, George A.	1991	Source Apportionment of Mutagenic Activity of Fine Particle Organics in Boise, Idaho	Proceedings of the 84th Annual Air & Waste Management Association Meeting & Exhibit (91-131.3)
10	Steiber, Raymond S.; McCrillis, Robert C.	1991	Comparison of Emissions and Organic Fingerprints from Combustion of Oil and Wood	Proceedings of the 84th Annual Air & Waste Management Association Meeting & Exhibition, Vancouver, BC, pp. 2-10 (91-136.2) (EPA-600/D-91-152) (NTIS PB91-223222)
A-29 11	Anderson, Norman	1989	Final Report Risk Assessment Document for Residential Wood Combustion Emissions	Environmental Toxicology Program, Environmental Health Unit, Division of Disease Control, Bureau of Health, ME (Appropriation #1310-1012)
12	Rau, John A.	1989	Tracers of Pollution from Wood Burning and Receptor Modeling	Transactions of the International Specialty Conference, Receptor Models in Air Resources Management, San Francisco, CA; Published by Air & Waste Management Association, Pittsburgh, PA, pp. 353-366 (ISBN 0-923204-01-6)
13	Rau, John A.	1989	Do Residential Wood Smoke Particles Lose Organic Carbon during Their Atmospheric Residence Time? A Receptor Modeling Study	Proceedings of the 82nd Annual Air & Waste Management Association Meeting & Exhibition, Denver, CO (89-145.5)
14	U.S. Government Interagency Program's Pacific Northwest and Alaska Regional Bioenergy Program	1989	Environmental Impact of Wood Combustion in Residential Woodstoves	Woodstove Research Summaries, U.S. Government Interagency Program's Pacific Northwest and Alaska Regional Bioenergy Program Yearbook, pp. 25-30 (DOE/BP-1179)

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
15	U.S. Government Interagency Program's Pacific Northwest and Alaska Regional Bioenergy Program	1989	Environmental Impact of Advanced Biomass Combustion Systems	Woodstove Research Summaries, U.S. Government Interagency Program's Pacific Northwest and Alaska Regional Bioenergy Program Yearbook, pp. 30-32 (DOE/BP-1179)
16	Wolgamott, D. Mitch; Erickson, Spencer L.	1989	Carbon Monoxide in a Wood Burning Community	Proceedings of the 26th Annual Air & Waste Management Association, Pacific Northwest International Section Meeting & Exhibition, Spokane, WA
17	Burton, Robert M.	1988	Final Design and Field Evaluation of the High Volume $PM_{2.5}$ Virtual Impactor	Proceedings of the 1988 EPA/APCA Symposium on: Measurement of Toxic and Related Air Pollutants, Research Triangle Park, NC; U.S. Environmental Protection Agency; Published by the Air Pollution Control Association, VIP-10, Pittsburgh, PA, pp. 890-895 (EPA-600/9-88-015) (NTIS PB90-225863)
A-30 18	Cupitt, Larry T.	1988	Transformation of Boise Sources: The Production and Distribution of Mutagenic Compounds in Wood Smoke and Auto Exhaust	Proceedings of the 1988 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants, Research Triangle Park, NC; U.S. Environmental Protection Agency; Published by the Air Pollution Control Association, VIP-10, Pittsburgh, PA, pp. 885-889 (EPA-600/9-88-015) (NTIS PB90-225863)
19	Cupitt, Larry T.	1988	The Integrated Air Cancer Project: Overview and Boise Survey Results	Proceedings of the 1988 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants, Research Triangle Park, NC; U.S. Environmental Protection Agency; Published by the Air Pollution Control Association, VIP-10, Pittsburgh, PA, pp. 799-803 (EPA-600/9-88-015) (NTIS PB90-225863)
20	Currie, L.A.	1988	What Should We Measure? Aerosol Data: Past and Future	Proceedings of the 1988 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants, Research Triangle Park, NC; U.S. Environmental Protection Agency; Published by the Air Pollution Control Association, VIP-10, Pittsburgh, PA, pp. 853-863 (EPA-600/9-88-015) (NTIS PB90-225863)

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
21	Hawthorne, Steven B.	1988	Methoxylated Phenols as Candidate Tracers for Atmospheric Wood Smoke Pollution	Proceedings of the 1988 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants, Research Triangle Park, NC; U.S. Environmental Protection Agency; Published by the Air Pollution Control Association, VIP-10, Pittsburgh, PA, pp. 57-62 (EPA-600/9-88-015) (NTIS PB90-225863)
22	Highsmith, V. Ross	1988	Impact of Residential Wood Combustion and Automotive Emissions on the Boise, Idaho Airshed	Proceedings of the 1988 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants, Research Triangle Park, NC; U.S. Environmental Protection Agency; Published by the Air Pollution Control Association, VIP-10, Pittsburgh, PA, pp. 841-852 (EPA-600/9-88-015) (NTIS PB90-225863)
23	Houck, James E.; Simons, Carl A.; Pritchett, Lyle C.	1988	Estimating Carbon Monoxide Air Quality Impacts from Woodstoves, Task A Final Report	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the U.S. Department of Energy, Pacific Northwest and Alaska Regional Biomass Energy Program, (Administered by the Bonneville Power Administration, Portland, OR) (DOE/BP-18508-2)
24	Lewis, Charles W.; Baumgardner, Ralph E.; Stevens, Robert K.; Claxton, Larry D.; Lewtas, Joellen	1988	The Contribution of Woodsmoke and Motor Vehicle Emissions to Ambient Aerosol Mutagenicity	Environmental Science and Technology, Vol. 22, No. 8, p. 968
A-31 25	Lewis, Charles W.	1988	Sources of Fine Particle Organic Matter in Boise	Proceedings of the 1988 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants, Research Triangle Park, NC; U.S. Environmental Protection Agency; Published by the Air Pollution Control Association, VIP-10, Pittsburgh, PA, pp. 864-869 (EPA-600/9-88-015) (NTIS PB90-225863)
26	McMullen, Roy G.; Evans, Dallas E.	1988	Fireplaces and Carbon Monoxide Levels in Houston, Texas during Exceedances of the 8-Hour Average Carbon Monoxide Standard 1983 through 1986	Proceedings of the 81st Annual Air and Pollution Control Association Meeting, Dallas, TX

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
27	Merrill, Raymond G., Jr.	1988	Semivolatile and Condensible Extractable Organic Materials Distribution in Ambient Air and Woodstove Emissions	Proceedings of the 1988 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants, Research Triangle Park, NC; U.S. Environmental Protection Agency; Published by the Air Pollution Control Association, VIP-10, Pittsburgh, PA, pp. 821-827 (EPA-600/9-88-015) (NTIS PB90-225863)
28	Steiber, R.S.	1988	GC/MS Analysis of Woodstove Emissions and Ambient Samples from a Wood Smoke Impacted Area	Proceedings of the 1988 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants, Research Triangle Park, NC; U.S. Environmental Protection Agency; Published by the Air Pollution Control Association, VIP-10, Pittsburgh, PA, pp. 828-834 (EPA-600/9-88-015) (NTIS PB90-225863)
29	Stevens, R.K.	1988	Annular Denuder Results from Boise, ID	Proceedings of the 1988 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants, Research Triangle Park, NC; U.S. Environmental Protection Agency; Published by the Air Pollution Control Association, VIP-10, Pittsburgh, PA, pp. 870-878 (EPA-600/9-88-015) (NTIS PB90-225863)
30	Watts, R.	1988	Mutagenicity of Organics Associated with $PM_{2.5}$ and PM_{10} HiVol Particles from a Wood Smoke Impacted Residential Area	Proceedings of the 1988 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants, Research Triangle Park, NC; U.S. Environmental Protection Agency; Published by the Air Pollution Control Association, VIP-10, Pittsburgh, PA, pp. 879-884 (EPA-600/9-88-015) (NTIS PB90-225863)
31	Zweidinger, Roy	1988	Distribution of Volatile Organic Hydrocarbons and Aldehydes during the IACP Boise, Idaho Residential Study	Proceedings of the 1988 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants, Research Triangle Park, NC; U.S. Environmental Protection Agency; Published by the Air Pollution Control Association, VIP-10, Pittsburgh, PA, pp. 814-820 (EPA-600/9-88-015) (NTIS PB90-225863)
A-32 32	Bell, Douglas A.	1987	Non-Aqueous Ion Exchange Chromatography as a Preparative Fractionation Method for Short Term Bioassay Analysis of Wood	Proceedings of the 1987 EPA/APCA Symposium: Measurement of Toxic and Related Air Pollutants; U.S. Environmental Protection Agency, Pittsburgh, PA, pp. 677-684 (EPA-600/9-87-010) (NTIS PB88-

CATEGORY #4 AMBIENT AIR QUALITY AND HEALTH STUDIES

#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
			Smoke Extracts	113402)
A-33 33	Braaten, R.W.	1987	Effects of Retrofit to Reduce Emissions from Existing Wood Stoves	Proceedings of the 1987 EPA/APCA Symposium: Measurement of Toxic and Related Air Pollutants; U.S. Environmental Protection Agency, Pittsburgh, PA, pp. 685-690 (EPA-600/9-87-010) (NTIS PB88-113402)
34	Claxton, Larry D.	1987	The Mutagenicity of Ambient and Source Samples from Woodsmoke Impacted Air Sheds	Proceedings of the 1987 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants; U.S. Environmental Protection Agency, Pittsburgh, PA, pp. 591-596 (EPA-600/9-87-010) (NTIS PB88-113402)
35	Cupitt, Larry T.	1987	IACP Emission: Transformations and Fate	Proceedings of the 1987 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants; U.S. Environmental Protection Agency, Pittsburgh, PA, pp. 597-604 (EPA-600/9-87-010) (NTIS PB88-113402)
36	Greene, William T.; Freeburn, Scott A.	1987	Preliminary Health Effects Evaluation for Pollutants Generated by Field Burning, Slash Burning, and Residential Wood Combustion	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the Oregon Department of Environmental Quality, Eugene, OR
37	Highsmith, V. Ross	1987	The Collection of Neighborhood Air Samples Impacted by Residential Wood Combustion in Raleigh, NC and Albuquerque, NM	Proceedings of the 1987 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants; U.S. Environmental Protection Agency, Pittsburgh, PA, pp. 562-572 (EPA-600/9-87-010) (NTIS PB88-113402)
38	Houck, James E.	1987	The Contribution of Residential Wood Combustion of Respirable and Inhalable Particulate Concentrations in Missoula, Montana	Proceedings of the 1987 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants; U.S. Environmental Protection Agency, Pittsburgh, PA, pp. 691-696 (EPA-600/9-87-010) (NTIS PB88-113402)
39	Khalil, M.A.K.; Rasmussen, R.A.; Rau, John A.	1987	Air Pollution from Residential Wood Burning: A Case Study in Olympia, WA	Proceedings of the 80th Annual Air Pollution Control Association Meeting, New York, NY (87-101.1)

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
A-34 40	Klouda, George A.	1987	The Source Apportionment of Carbonaceous Products by Micro-Radiocarbon Measurements for the Integrated Air Cancer Project (IACP)	Proceedings of the 1987 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants; U.S. Environmental Protection Agency, Pittsburgh, PA, pp. 573-578 (EPA-600/9-87-010) (NTIS PB88-113402)
41	Lewtas, Joellen	1987	Overview of the Integrated Air Cancer Project	Proceedings of the 1987 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants; U.S. Environmental Protection Agency, Pittsburgh, PA, pp. 555-561 (EPA-600/9-87-010) (NTIS PB88-113402)
42	Merrill, Raymond G.	1987	Progress toward Identifying Source Specific Tracers	Proceedings of the 1987 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants; U.S. Environmental Protection Agency, Pittsburgh, PA, pp. 585-590 (EPA-600/9-87-010) (NTIS PB88-113402)
43	Merrill, Raymond G.; Brusick, David	1987	Mutagenicity and Toxicity of Residential Wood Combustion Residue Samples	U.S. Environmental Protection Agency, Air and Energy Engineering Laboratory, Research Triangle Park, NC; and Hazelton Laboratories of America, Kensington, MD
44	Schonburn, Michael; et al.	1987	Options for Reducing Emissions from Wood Burning Units in the Denver Metropolitan Area	Denver Metropolitan Air Quality Council, Denver, CO; and Colorado University, Denver Graduate School of Public Affairs, Denver, CO
45	Zweidinger, Roy	1987	Volatile Organic Hydrocarbon and Aldehyde Composition in Raleigh, NC during the 1985 Woodsmoke Study	Proceedings of the 1987 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants; U.S. Environmental Protection Agency, Pittsburgh, PA, pp. 579-584 (EPA-600/9-87-010) (NTIS PB88-113402)
46	Bell, D.A.; Kamens, R.M.; Claxton, Larry D.; Lewtas, Joellen	1986	Photoreaction of Wood Smoke Particles: Destruction and Creation of Mutagens in Sunlight	Proceedings of the 79th Annual Air Pollution Control Association Meeting, Minneapolis, MN
47	Buchanan, James W.; Shutian, Li; Calloway,	1986	A Refinement of the Potassium Tracer Method	Proceedings of the 79th Annual Air Pollution Control Association

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
	Clifton		for Residential Wood Smoke	Meeting, Minneapolis, MN (86-77.6)
48	Buchanan, James W.	1986	A Refinement of the Potassium Tracer Method for Residential Wood Smoke	Proceedings of the 1986 EPA/APCA Symposium on Measurement of Toxic Pollutants, Raleigh, NC; U.S. Environmental Protection Agency; Published by the Air Pollution Control Association, VIP-7, Pittsburgh, PA, pp. 748-754 (EPA-600/9-86-013) (NTIS PB87-182713)
A-35 49	Edgerton, S.A.; Khalil, M.A.K.; Rasmussen, R.A.	1986	Source Emission Characterization of Residential Wood-Burning Stoves and Fireplaces: Fine Particle/Methyl Chloride Ratios for Use in Chemical Mass Balance Modeling	Environmental Science and Technology, Vol. 20, No. 8, pp. 803-807
50	Gebhart, D. Howard; Anderson, Stephen R.	1986	A Study Design for Characterization of Residential Wood Combustion Impacts in Suburban Settings Case Study: Fort Collins, Colorado	Proceedings of the 79th Annual Air Pollution Control Associations Meeting, Minneapolis, MN (86-74.3)
51	Kleindienst, Tadeusz E.; Shepson, Paul B.; Edney, Edward O.; Claxton, Larry D.; Cupitt, Larry T.	1986	Wood Smoke: Measurement of the Mutagenic Activities of Its Gas- and Particulate-Phase Photooxidation Products	Environmental Science and Technology, Vol. 20, No. 5, pp. 493-501
52	Kleindienst, T.E.; Shepson, P.B.; Edney, E.O.	1986	Mutagenic Activities of Wood Smoke Photooxidation Products	U.S. Environmental Protection Agency, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC (EPA-600/3-86-049) (NTIS PB86-239837)
53	Klouda, George A.; Currie, L.A.; Donahue, D.J.; Jull, A.J.T.; Naylor, M.H.	1986	Urban Atmospheric ^{14}CO and $^{14}CH_4$ Measurements by Accelerator Mass Spectrometry	Radiocarbon, Vol. 28, No. 2A, pp. 625-633
54	Leese, K.E.; McCrillis, Robert C.	1986	Integrated Air Cancer Project, Source Measurement	Proceedings of the 79th Annual Air Pollution Control Association Meeting, Minneapolis, MN (EPA-600/D-86-152) (NTIS PB86-222924)

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
55	OMNI Environmental Services, Inc.	1986	Effects of Thermal Stress on Catalytic Combustion Performance Volume I	OMNI Environmental Services, Inc.; Prepared for the Matsushita Battery Industrial Co., Ltd., Osoka, Japan
56	Rau, John A.	1986	Residential Wood Combustion Aerosol Characterization as a Function of Size and Source Apportionment Using Chemical Mass Balance Modeling	Ph. D. Dissertation, Oregon Graduate Center, Chemical, Biological, and Environmental Sciences Department, Beaverton, OR
A-36 57	Edgerton, Sylvia A.	1985	Gaseous Tracers in Receptor Modeling: Methyl Chloride Emission from Wood Combustion	Ph. D. Dissertation, Oregon Graduate Center, Environmental Science Department, Beaverton, OR
58	Environmental Research & Technology, Inc.	1985	Air Quality Monitoring and Control for the City of Fort Collins Volume IV: Results of the 1984-1985 Winter Residential Wood Combustion Study	Prepared for the City of Fort Collins Community Development Department Planning Division, Fort Collins, CO
59	Inoye, Daniel	1985	Estimation of Carbon Monoxide and Particulate Emissions from Woodburning Devices in the Fresno/Clovis Metropolitan Area	No Publication Information Listed
60	Kamens, Richard M.; Bell, Douglas A.; Dietrich, Andrea; Perry, Jean; Goodman, Randall; Claxton, Larry D.; Tejada, Sylvestre	1985	Mutagenic Transformations of Dilute Wood Smoke Systems in the Presence of Ozone and Nitrogen Dioxide. Analysis of Selected High-Pressure Liquid Chromatography Fractions from Wood Smoke Particle Extracts	Environmental Science and Technology, Vol. 19, No. 1, pp. 63-69
61	Rau, John A.; Huntzicker, James J.	1985	Size Distribution and Chemical Composition of Residential Wood Smoke	Proceedings of the 78th Annual Air Pollution Control Association Meeting, Detroit, MI (85-43.3)
62	Stapleton, Jim	1985	Air Pollution Due to Residential Space Heating in the Mid-Hudson Valley	Hudsonia Limited, Bard College, Annandale, NY; Prepared for the Central Hudson Gas and Electric Corp., Poughkeepsie, NY

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
63	Core, John E.; Cooper, John A.; Neulicht, Roy M.	1984	Current and Projected Impacts of Residential Wood Combustion on Pacific Northwest Air Quality	Journal of the Air Pollution Control Association, Vol.31, No. 2, pp. 138-143
A-37 64	Currie, Lloyd A.; Klouda, George A.; Voorhees, Kent J.	1984	Atmospheric Carbon: The Importance of Accelerator Mass Spectrometry	Nuclear Instruments and Methods in Physics Research, Vol. 233 [B5], No. 2, pp. 371-379
65	Department of Ecology, State of Washington	1984	Residential Wood Stove Emissions in Yakima and Olympia	State of Washington Department of Ecology, Olympia, WA
66	Duker, D.C.; Levaggi, D.A.; Umeda, T.; DeMandel, R.E.; Perardi, T.E.	1984	Measurements of a Carbon Monoxide Cloud in San Jose, California	Proceedings of the 77th Annual Air Pollution Control Association Meeting, San Francisco, CA (84-87.4)
67	Kamens, Richard M.; Rives, Glenn D.; Perry, Jean M.; Bell, Douglas A.; Paylor, R. Flynn; Goodman, Randall G.; Claxton, Larry D.	1984	Mutagenic Changes in Dilute Wood Smoke as It Ages and Reacts with Ozone and Nitrogen Dioxide: An Outdoor Chamber Study	Environmental Science and Technology, Vol. 18, No. 7, pp. 523-530
68	Zak, B.D.; Einfeld, W.; Church, H.W.; Gay, G.T.; Jensen, A.L.; Trijonis, J.; Ivey, M.D.; Homann, P.S.; Tipton, C.	1984	The Albuquerque Winter Visibility Study Vol. 1 Overview and Data Analysis	U.S. Department of Energy, Sandia Report (SAND84-0173/1 DE84 014356)
69	Hytönen, S.; Alfheim, I.; Sorsa, M.	1983	Effect of Emissions from Residential Wood Stoves on SCE Induction in CHO Cells	Mutation Research, Vol. 118, pp. 69-75
70	Kelly, Mary E.	1983	Sources and Emissions of Polycyclic Organic Matter (POM)	U.S. Environmental Protection Agency, Research Triangle Park, NC (EPA-450/5-83-010b) (NTIS PB84-144153)
71	Ramdahl, Thomas	1983	Retene-A Molecular Marker of Wood	Nature, Vol. 306, No. 8, pp. 580-582

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
			Combustion in Ambient Air	
72	Beck, Barbara D.	1982	Prediction of the Pulmonary Toxicity of Respirable Combustion Products from Residential Wood & Coal Stoves	Proceedings of the Residential Wood & Coal Combustion Specialty Conference, the Air Pollution Control Association, Louisville, KY, pp. 264-280
73	Imhoff, Robert E.	1982	Final Report on a Study of the Ambient Impact of Residential Wood Combustion in Petersville, AL	Proceedings of the Residential Wood & Coal Combustion Specialty Conference, the Air Pollution Control Association, Louisville, KY, pp. 161-188
A-38 74	Johnston, Ralph E.; Arkell, Donald R.	1982	A Preliminary Analysis of the Impact of Residential Wood Combustion Emissions on Ambient Carbon Monoxide Levels	Lane Regional Air Pollution Authority, Eugene, OR
75	Kamens, Richard M.	1982	An Outdoor Exposure Chamber to Study Wood Combustion Emissions under Natural Conditions	Proceedings of the Residential Wood & Coal Combustion Specialty Conference, the Air Pollution Control Association, Louisville, KY, pp. 207-225
76	Klouda, George A.	1982	Estimating the Impact of Atmospheric Carbonaceous Particulates on Urban and Rural Environments by Radiocarbon Measurements	Proceedings of the Residential Wood & Coal Combustion Specialty Conference, the Air Pollution Control Association, Louisville, KY, pp. 189-206
77	Lipfert, Frederick W.	1982	A National Assessment of the Air Quality Impacts of Residential Firewood Use	Proceedings of the Residential Wood & Coal Combustion Specialty Conference, the Air Pollution Control Association, Louisville, KY, pp. 226-239
78	Allwine, K.J., Jr.	1981	Assessment of the Long-Range Transport of Residential Woodstove Fine Particulate Emissions for Two Future U.S. Energy Scenarios	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 398-414
79	Barnard, Barry L.	1981	Regulating Residential Biomass Combustion in the Tennessee Valley Region	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR;

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80	Benton, Gary; Miller, Don Paul; Reimold, Mary; Sisson, Richard	1981	A Study of Occupant Exposure to Particulates and Gases from Woodstoves in Homes	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 456-468
A-39 81	Bohac, Charles; Duncan, Joseph R.; Beeman, Larry E.	1981	Residential Wood Combustion Issues for the Tennessee Valley	Proceedings of the Wood Heating Seminars 1980/1981, Wood Heating Alliance, Washington DC, p. 274
82	Brimblecombe, Peter	1981	Environmental Impact of Fuel Changes in Early London	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 1-11
83	Carlson, James H.	1981	Residential Wood Combustion in Missoula, Montana: An Overview of Its Air Pollution Contributions, Health Effects, and Proposed Regulatory Solutions	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 539-550
84	Colome, Steven D.; Spengler, John D.	1981	Residential Indoor and Matched Outdoor Pollutant Measurements with Special Consideration of Wood-Burning Homes	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 435-455
85	Cooper, John A.	1981	Chemical and Physical Methods of Apportioning the Contributions of Emissions from Residential Solid Fuels to Reductions in Air Quality	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 349-364
86	Currie, L.A.; Klouda, George	1981	Radiocarbon: Nature's Tracer for	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR;

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87	DeCesar, Richard T.	1981	The Quantitative Impact of a Residential Wood Combustion and Other Vegetative Burning Sources on the Air Quality in Medford, Oregon	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 551-565
88	Greene, W.T.; Tombleson, B.J.	1981	Institutional and Regulatory Approaches to Control Residential Wood Burning Emissions	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 1229-1252
89	Hornig, James F.; Soderberg. Roger H.; Larsen, Deborah; Parravano, Carlo	1981	Ambient Air Assessment in Rural Village and Small Town Locations in New Hampshire where Wood Is an Important Fuel	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 506-519
A-40 90	Imhoff, Robert E.; Manning, Justice A.; Cook, William M.; Hayes, Timothy L.	1981	Preliminary Report on a Study of the Ambient Impact of Residential Wood Combustion in Petersville, Alabama	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 520-538
91	Jacobs, Philip; Snowden, Bunch	1981	Health Costs of Residential Wood Combustion	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 657-669
92	Kelsey, Morris I.; Kraybill, H.F.; Helmes, C. Tucker, Sigman, Caroline C.	1981	A Data Base of Organic Pollutants that Have Been Evaluated for Carcinogenicity and Mutagenicity	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 577-605
				Proceedings of the Wood Heating Seminars 1980/1981, Wood

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
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94	Kosel, Peter H.	1981	Pollution and Fireplaces in California	Proceedings of the 1981 Wood Combustion Environmental Assessment Conference
95	Kowalczyk, J.F.; Greene, W.T.	1981	New Techniques for Identifying Ambient Air Impacts from Residential Wood Heating	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 469-494
96	Lawther, P.J.	1981	Historic Changes in Air Pollution in Great Britain	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 566-576
A-41 97	Lewtas, Joellen	1981	Comparison of the Mutagenic and Potentially Carcinogenic Activity of Particle Bound Organics from Wood Stoves, Residential Oil Furnaces, and Other Combustion Sources	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 606-619
98	Lim, K.J.; Lips, H.I.	1981	Overview of Emissions from Wood Combustion	Proceedings of the Wood Heating Seminars 1980/1981, Wood Heating Alliance, Washington DC, p. 273
99	Lipfert, Frederick W.	1981	An Assessment Methodology for the Air Quality Impact of Residential Wood Burning	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 415-434
100	Machlin, Paula R.	1981	Residential Solid Fuels in the Environmental Protection Agency Region VIII States	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 1197-1215
101	Martin, Werner	1981	European Experiences and Activities in	Proceedings of the 1981 International Conference on Residential

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102	Meyer, H. Robert	1981	The Contribution of Residential Wood Combustion Local Airshed Pollutant Concentrations	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 386-397
103	Morris, Gregory	1981	Health Effects of Residential Wood Combustion The Implications of Environmental Stochasticity	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 648-656
104	Mors, Terry A.; Blair, Terence T.; Cole, Robert H.	1981	Regulatory Options for Controlling Emissions from Combustion of Wood in Residential Applications	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 1253-1271
105	Murphy, Dennis J.; Buchan, Roy M.; Fox, Douglas G.	1981	Ambient Particulate and Benzo (α) Pyrene Concentrations from Residential Wood Combustion, in a Mountain Resort Community	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 495-505
A-42 106	Santodonato, Joseph; Basu, Dipak; Bruce, Robert	1981	Multimedia Human Exposure to Polycyclic Aromatic Hydrocarbons and Their Association with Cancer Risk	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 620-647
107	Schwengels, Paul; Bohac, Charles; Krickenberger, Kit	1981	An Integrated Environmental Assessment of Biomass Energy Development in the Tennessee Valley	Proceedings of the Wood Heating Seminars 1980/1981, Wood Heating Alliance, Washington DC, p. 272
			Environmental Impact of Residential Wood	Journal of the Air Pollution Control Association, Vol. 30, No. 8,

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109	Davis, Briant L.	1980	Composition and Sources of Airborne Particulate Matter Observed in Wintertime at Missoula, Montana	Prepared for the Montana State Department of Health and Environmental Science, Missoula, MT
110	Harris, Howard W.	Undated	An Investigation of Elevated Carbon Monoxide and Nephelometer Data in a Portland Residential Neighborhood Affected by Wood Smoke	Oregon Department of Environmental Quality, Portland, OR
111	Hornig, James F.; Soderberg, Roger H.; Barefoot, Aldos C., III	Undated	Woodsmoke Analysis: Vaporization Losses of PAH from Filters and Levoglucosan as a Distinctive Marker for Woodsmoke	Proceedings for the Eighth International Symposium on Polynuclear Aromatic Hydrocarbons: Mechanisms, Methods and Metabolism, Wilmington, DE, pp. 561-568
112	Lao, R.C.; Thomas, R.S.; Lanoy, M.; Lee, S. Win	Undated	Investigation of PAH and Polychlorinated Organic Pollutant Emissions from Wood Combustion Sources	Laboratory Services Division, Air Pollution Control Directorate, Environment Canada, Ottawa, Canada, pp. 745-755
A-43 113	Weston, Roy F.	Undated	Particulate Emissions from Residential Wood Combustion Final Report	Roy F. Weston Co., West Chester, PA; Prepared for Northeast Regional Biomass Program, CONEG Policy Research Center, Inc.

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1	U.S. Environmental Protection Agency	1996 1993 1992 1983	Emission Factor Documentation for AP-42 Section 1.9, Residential Fireplaces, and Section 1.10, Residential Wood Stoves	U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Office of Air and Radiation, Research Triangle Park, NC, (Section 1.9 EPA-450/4-82-004, and Section 1.10 EPA-450/4-82-003)
2	Collier, David L.	1995	Medford And Klamath Falls, Oregon Success in Controlling Residential Wood Combustion Possible Implications of New Particulate Matter Standard	Proceedings of an International Specialty Conference, Particulate Matter: Health and Regulatory Issues; Published by Air & Waste Management Association, Pittsburgh, PA, VIP-49, Pittsburgh, PA, pp. 776-788
A-443	Appel, J.	1992	Current Limitations and Future Prospects of Residential Wood Combustion Controls in the Pacific Northwest	Transactions of the A&WMA/EPA International Specialty Conference, PM_{10} Standards and Nontraditional Particulate Source Controls, Volume II, TR-22; Published by Air & Waste Management Association, Pittsburgh, PA, pp. 614-624 (ISBN 0-923204-09-1)
4	Hough, M.; et al.	1992	Progress to Achieve Residential Wood Combustion PM_{10} Emission Reductions in Medford, Oregon as Determined by Compliance Surveys and Ambient Monitoring	Transactions of the A&WMA/EPA International Specialty Conference, PM_{10} Standards and Nontraditional Particulate Source Controls, Volume II, TR-22; Published by Air & Waste Management Association, Pittsburgh, PA, pp. 637-645 (ISBN 0-923204-09-1)
5	Manderino, L.	1992	An Integrated Community Approach to Reducing Residential Woodsmoke: Innovative Funding of Control Strategies	Transactions of the A&WMA/EPA International Specialty Conference, PM_{10} Standards and Nontraditional Particulate Source Controls, Volume II, TR-22; Published by Air & Waste Management Association, Pittsburgh, PA, pp. 716-729 (ISBN 0-923204-09-1)
6	Maykut, N.; Fry, S.	1992	Woodsmoke Control in the Puget Sound Region	Transactions of the A&WMA/EPA International Specialty Conference, PM_{10} Standards and Nontraditional Particulate Source Controls, Volume II, TR-22; Published by Air & Waste

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8	OMNI Environmental Services, Inc.	1992	Residential Wood Combustion Control Measures for the Pocatello PM_{10} Nonattainment Area	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the U.S. Environmental Protection Agency, Region X, Seattle WA
9	Ono, D.; Taylor, W.	1992	Town of Mammoth Lakes Air Quality Regulations	Transactions of the A&WMA/EPA International Specialty Conference, PM_{10} Standards and Nontraditional Particulate Source Controls, Volume II, TR-22; Published by Air & Waste Management Association, Pittsburgh, PA, pp. 657-668 (ISBN 0-923204-09-1)
A- 45 10	Pettingill, D.; et al.	1992	Evaluation of Washoe County, NV Control Strategies for Reducing Emissions from Residential Woodburning	Transactions of the A&WMA/EPA International Specialty Conference, PM_{10} Standards and Nontraditional Particulate Source Controls, Volume II, TR-22; Published by Air & Waste Management Association, Pittsburgh, PA, pp. 646-656 (ISBN 0-923204-09-1)
11	Shwayder, P.	1992	Burning Wood A Political Perspective: Case Studies from the Denver Region	Transactions of the A&WMA/EPA International Specialty Conference, PM_{10} Standards and Nontraditional Particulate Source Controls, Volume II, TR-22; Published by Air & Waste Management Association, Pittsburgh, PA, pp. 669-679 (ISBN 0-923204-09-1)
12	Stapp, S.; Harley, R.	1992	An Effective Woodburning Control Program: Albuquerque/Bernalillo County, New Mexico, USA	Transactions of the A&WMA/EPA International Specialty Conference, PM_{10} Standards and Nontraditional Particulate Source Controls, Volume II, TR-22; Published by Air & Waste Management Association,

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13	Stoneman, C.; Pace, T.	1992	Technical Guidance for Residential Wood Combustion: Reasonably and Best Available Control Measures	Transactions of the A&WMA/EPA International Specialty Conference, PM_{10} Standards and Nontraditional Particulate Source Controls, Volume II, TR-22; Published by Air & Waste Management Association, Pittsburgh, PA, pp. 601-613 (ISBN 0-923204-09-1)
14	Davis, Bob	1989	Guidance Document for Residential Wood Combustion Emission Control Measures	U.S. Environmental Protection Agency Office of Air and Radiation, Office of Air Quality Planning and Standards, Research Triangle Park, NC, (EPA-450/2-89-015) (NTIS PB90-130444)
15	Butler, Alan T.	1988	Control Of Woodstoves by State Regulation as a Fine Particulate Emission Control Strategy	Transactions of the APCA/EPA International Specialty Conference, PM_{10} Implementation Standards, TR-13, San Francisco, CA; Published by the Air Pollution Control Association, Pittsburgh, PA, pp. 654-663
16	Hough, Merlyn	1988	Oregon's Approach to Reducing Residential Woodsmoke as Part of the PM_{10} Strategy	Transactions of the APCA/EPA International Specialty Conference, PM_{10} Implementation Standards, TR-13, San Francisco, CA; Published by the Air Pollution Control Association, Pittsburgh, PA, pp. 646-653
17	Westlin, Peter R.	1987	The Environmental Protection Agency's Accreditation Program for Wood Heater Testing Laboratories	Proceedings of the 1987 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants, U.S. Environmental Protection Agency, Pittsburgh, PA, pp. 707-711 (EPA-600/9-87-010) (NTIS PB88-113402)
A-46 18	Gay, Robert; Shah, Jitendra	1986	Technical Support Document for Residential Wood Combustion	NERO and Associates, Inc., Portland, OR; Prepared for the U.S. Environmental Protection Agency, Office Of Air and Radiation, Office of Air Quality Planning and Standards, Research Triangle Park, NC, (EPA-450/4-85-012) (NTIS PB97-149538)
19	Jenkins, Pamela G.	1986	Wood Smoke: Emissions, Impacts, and Reduction Strategies.	Washington Department of Ecology, Air Program, Olympia, WA

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21	Radian Corporation	1986	Wood Load Effect on Particulate Emissions from Residential Woodburning Appliances	Radian Corporation, Research Triangle Park, NC; Prepared for the U.S. Environmental Protection Agency, Emission Standard and Engineering Division, Research Triangle Park, NC (DCN no. 86-231-020-25-02)
22	OMNI Environmental Services, Inc.	1985	Standard Test Method for Determining the Heat Output Range and Maximum Burn Cycle Duration, Residential Wood-Fired Closed Combustion-Chamber Heating Appliances	OMNI Environmental Services, Inc., Beaverton, OR
23	Braaten, R.W.; Hayden, A.C.S.	1984	Status of Canadian Standard for Efficiency and Emissions of Domestic Wood-Fired Appliances	Canadian Combustion Research Laboratory, ERL/CANMET, Energy, Mines & Resources Canada, Ottawa, Canada
24	Grotheer, Wayne E.	1984	Overview of Control Strategies for Residential Wood Combustion	Proceedings of the 77th Annual Air Pollution Control Association Conference, San Francisco, CA (84-70.1)
A-47 25	Carlsson, Sten-Åke	1981	Residential Wood Combustion in Sweden Environmental Aspects and Regulations	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 1160-1165
26	Greene, William T.; Tomleson, Barbera J.	1981	Institutional and Regulatory Approaches to Control Residential Wood Burning Emissions	Proceedings of the Wood Heating Seminars 1980/1981, Wood Heating Alliance, Washington DC, p. 271
27	Hall, R.E.	1981	EPA's Research Program for Controlling Residential Wood Combustion Emissions	Proceedings of the Wood Heating Seminars 1980/1981, Wood Heating Alliance, Washington DC, pp. 44-63

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29	Hall, Robert E.; DeAngelis, Daryl G.	1980	EPA's Research Program for Controlling Residential Wood Combustion Emissions	Journal of the Air Pollution Control Association, Vol. 30, No. 8, pp. 862-867

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2	Tiegs, Paul E.; Vaughan, Patrick; Bighouse, Roger D.	1993	Spillage of Combustion Byproducts from Woodstoves Operated in Negative Pressure Environments	OMNI Environmental Services, Beaverton, OR; Prepared for Bonneville Power Administration, Resource Management Residential Department (DE-AP79-92BP60576-M001)
3	Walsh, Debra; Warren, Sarah; Zweidinger, Roy; et al.	1993	Mutagenicity of Indoor Air in Boise, Idaho and Roanoke, Virginia	Proceedings of the 1993 U.S. EPA/A&WMA International Symposium on Measurement of Toxic and Related Air Pollutants, Durham, NC; Published by Air & Waste Management Association, VIP-34, Pittsburgh, PA, pp. 190-196
A-47 4	Broome, F.	1992	The Development of Clean-Burning Noncatalytic Manufactured Fireplaces	Transactions of the A&WMA/EPA International Specialty Conference, PM_{10} Standards and Nontraditional Particulate Source Controls, Volume II, TR-22; Published by Air & Waste Management Association, Pittsburgh, PA, pp. 585-588 (ISBN 0-923204-09-1)
5	Bushway, Stephen	1992	The New Woodburner's Handbook A Guide to Safe, Healthy & Efficient Woodburning	Capitol City Press Fast Printing, Storey Communications, Inc., Pownal, VT
6	CONEG Policy Research Center	1992	Pamphlet How to Burn Wood Right Choosing and Using Your Wood Stove in Today's Environment	CONEG Policy Research Center, New York State Energy Research and Development Authority
7	Myren, A., Jr.	1992	The Development of the Clean Burning Inside-Out Flame in Noncatalytic Woodstoves	Transactions of the A&WMA/EPA International Specialty Conference, PM_{10} Standards and Nontraditional Particulate Source Controls, Volume II, TR-22; Published by Air & Waste Management Association, Pittsburgh, PA, pp. 589-592 (ISBN 0-923204-09-1)
8	Barnett, Stockton G.	1991	Report to the City of Fresno, California on the Implications of a Project that Measured Masonry Fireplace and Heater Emissions in Homes	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the City of Fresno, CA; Prepared for the Masonry Institute and Western States Clay Products Association, San Mateo, CA

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10	Melcon, Daniel	1989	Pellet Primer An Introduction to Heating with Wood Pellets	Biomass Publications of America, Portland, OR
11	Barden, Albert; Hyytiäinen, Heikki	1988	Finnish Fireplaces Heart of the Home	Building Book Ltd., Finland
12	Evans, Robert J.; Milne, Thomas A.	1988	Relevancy of Wood Pyrolysis Chemistry to Wood Stove Emissions	Chemical Conversion Research Branch, Solar Energy Research Institute, Golden, CO; Presented at the 1988 American Chemical Society National Summer Meeting, Denver, CO
A-47 13	Greene, William T.	1988	Cost/Benefit Analysis of Mitigation Measures for Minimizing Environmental Impacts of Residential Wood Combustion, Task F Final Report	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the U.S. Department of Energy, Pacific Northwest and Alaska Regional Biomass Energy Program, (Administered by the Bonneville Power Administration, Portland, OR) (DOE/BP-18508-7)
14	Greene, William T.; Simons, Carl A.; Houck, James E.	1988	Mitigation Measures for Minimizing Environmental Impacts from Residential Wood Combustion, Task E Final Report	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the U.S. Department of Energy, Pacific Northwest and Alaska Regional Biomass Energy Program, (Administered by the Bonneville Power Administration, Portland, OR) (DOE/BP-18508-5)
15	Highsmith, V. Ross	1988	Influence of Residential Wood Combustion Emissions on Indoor Air Quality of Boise, Idaho Residences	Proceedings of the 1988 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants, Research Triangle Park, NC; U.S. Environmental Protection Agency; Published by the Air Pollution Control Association, VIP-10, Pittsburgh, PA, pp. 804-813 (EPA-600/9-88-015) (NTIS PB90-225863)
16	Peacock, Richard D.	1987	Wood Heating Safety Research: An Update	Fire Technology, Vol. 223, No. 4, pp. 229-312
17	Wilson, Pamela L.; Funck, James W.; Avery, Robert B.	1987	Fuelwood Characteristics of Northwestern Conifers and Hardwoods Research Bulletin 60	Forest Research Laboratory, College of Forestry, Oregon State University, Corvallis, OR

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19	Harris, Robert A.; McMinn, James W.; Payne, Fred A.	1986	Calculating and Reporting Changes in Net Heat of Combustion of Wood Fuel	Forestry Products Journal, Vol. 36, No. 6, pp. 57-60
20	Humphreys, Mallory P.	1986	Residential Wood Combustion Impacts on Indoor Carbon Monoxide and Suspended Particulates	Proceedings of the 1986 EPA/APCA Symposium on Measurement of Toxic Pollutants, Raleigh, NC; U.S. Environmental Protection Agency; Published by the Air Pollution Control Association, VIP-7, Pittsburgh, PA, pp. 736-747 (EPA-600/9-86-013) (NTIS PB87-182713)
21	OMNI Environmental Services, Inc.	1986	Compendium of Environmental and Safety Regulations and Programs Affecting Residential Wood Heating Appliances	OMNI Environmental Services, Inc., Beaverton, OR; Prepared for the Bonneville Power Administration, Portland, OR
22	Canadian Wood Energy Institute	1985	Conference Proceedings of the Firewood 85	Canadian Wood Energy Institute
A-47 23	Hartman, M.W.; Rives, G.D.	1985	Literature Review and Survey of Emissions from Residential Wood Combustion and Their Impact	Radian Corporation, Research Triangle Park, NC; Prepared for the U.S. Environmental Protection Agency, Office of Research and Development, Air and Energy Engineering Research Laboratory, Research Triangle Park, NC (EPA-600/2-85-047) (NTIS PB85-197820)
24	Ontario Task Force	1985	Report of the Ontario Task Force on Residential Wood Heat Safety	Prepared for the Minister of Energy, Toronto, Ontario, Canada
25	Turbak, Gary	1984	New Technologies Fight Wood-Stove Pollution	Popular Science, December 1984, pp. 90-92
26	Portland, The City of	1983	Woodstoves Installation and Use Portland, OR	The City of Portland, Portland, OR
27	U.S. Environmental Protection Agency	1983	Pamphlet Wood Stove Features and Operation Guideline for Clean Air	U.S. Environmental Protection Agency, Research and Development (EPA-600/D-83-112)

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29	Barnett, Stockton G.	1982	The Effects of Stove Design and Control Mode on Condensible Particulate Emissions, Flue Pipe Creosote Accumulation and the Efficiency of Woodstoves in Homes	Proceedings of the Institute of Gas Technology Symposium for Energy from Biomass and Waste VI Meeting, Lake Buena Vista, FL, pp. 283-322
30	Bortz, Paul	1982	Getting More Heat from Your Fireplace	Garden Way Publishing, Charlotte, VT
31	Busha, William; Morris, Stephen	1982	The Book of Heat A Four Season Guide to Wood and Coal Heating	The Stephen Greene Press, Brattleboro, VT, Lexington, MA (Rev. ed. of: The Book Of Heat (1948))
32	Flagler, Gordon	1982	The North American Wood Heat Handbook	Charles Scribner's Sons, New York, NY (Rev. ed. of: The Canadian Wood Heat Book (1979))
33	Martin, Werner	1982	European Activities in Solid Fuel Fired Heating	Proceedings of the Residential Wood & Coal Combustion Specialty Conference, the Air Pollution Control Association, Louisville, KY, pp. 89-114
34	Miller, D.P.	1982	Indoor Exposure to Carbon Containing Particulates and Vapors in Homes which Use Wood for Heating	Proceedings of the Residential Wood & Coal Combustion Specialty Conference, the Air Pollution Control Association, Louisville, KY, pp. 281-295
A-47 35	Neulicht, Roy M.	1982	Impact of Residential Wood Combustion Appliances on Indoor Air Quality	Proceedings of the Residential Wood & Coal Combustion Specialty Conference, the Air Pollution Control Association, Louisville, KY, pp. 240-252
36	Osborne, Michael C.	1982	Residential Wood & Coal Combustion	Proceedings of the Residential Wood & Coal Combustion Specialty Conference, the Air Pollution Control Association, Louisville, KY, p. 1
37	Traynor, Gregory W.	1982	Indoor Air Pollution from Portable Kerosene-Fired Space Heaters, Wood-Burning Stoves,	Proceedings of the Residential Wood & Coal Combustion Specialty Conference, the Air Pollution Control Association,

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
			and Wood-Burning Furnaces	Louisville, KY, pp. 253-263
38	Anonymous	1981	Fireplaces and Woodstoves	Time-Life Books Inc., Chicago, IL
39	Bendersky, Charles	1981	Results of the DOE Think Shop on Residential Wood Combustion	Proceedings of the Wood Heating Seminars 1980/1981, Wood Heating Alliance, Washington DC, p. 275
40	Cohen, Maurice	1981	The Woodcutters Companion A Guide to Locating, Cutting, Transporting, and Storing Your Own Firewood	Rodale Press, Emmaus, PA
41	Earl, William L.	1981	An Investigation of Wood Pyrolysis Using Solid State ^{13}C Nuclear Magnetic Resonance	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 772-788
42	Faista, Michael B.; Davidovits, Paul	1981	Formation of Submicron Ash Particles in Coal Combustion	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 808-831
43	Harper, Jerome P.	1981	Residential Wood Heating Efficiency and Emissions An Overview	Proceedings of the Wood Heating Seminars 1980/1981, Wood Heating Alliance, Washington DC, p. 276
44	Hayden, A.C.S.; Braaten, R.W.	1981	Efficient Wood Stove Design and Performance	Proceedings of the Wood Heating Seminars 1980/1981, Wood Heating Alliance, Washington DC, pp. 16-43
A-47 45	Knight, D. Karen	1981	Wood Heat Emission	Proceedings of the Wood Heating Seminars 1980/1981, Wood Heating Alliance, Washington DC, pp. 73-86
46	Linström, Olle	1981	Gasification/Combustion of Wood	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 789-807

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
47	Morstead, H.	1981	Fireplace Technology in an Energy Conscious World	Center for Research & Development in Masonry, Calgary, Alberta, Canada
48	Osborne, Michael C.	1981	The Inter-Government Research and Development Program for Residential Wood Combustion	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 17-33
49	Shafizadeh, Fred	1981	Chemistry of Pyrolysis and Combustion of Wood	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 746-771
50	Shelton, Jay W.	1981	Wood Heating System Design Conflicts and Possible Resolutions	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 873-891
51	Stegmeir, Paul B.	1981	Wood Energy From the Forest to the Furnace	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 12-16
52	Thornton, Mark M.; Malte, Philip C.	1981	Combustion Rate of Model Wood Volatiles	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 851-872
53	Toynbee, Peter A.	1981	Domestic Coal Firing in Smokeless Zones	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR; Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 892-911
A-47	Trivett, Gordon S.; Al-Taweel, Adel M.; Bond, W.	1981	Fluidized Bed Combustion on the Domestic Scale	Proceedings of the 1981 International Conference on Residential Solid Fuels, Environmental Impacts and Solutions, Portland, OR;

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
54	Terence; MacKay, David M.			Published by Oregon Graduate Center, Beaverton, OR (1982), pp. 912-923
55	Harrington, Geri	1980	Fireplace Stoves, Hearths, & Inserts A Coal- & Wood-Burner's Guide & Catalog	Harper & Row, Publishers, New York, NY
56	Newcomb, Wilburn, W.	1980	Wood Stove Handbook	Theodore Audel & Co., A Division of Howard W. Sams & Co., Inc., Indianapolis, IN
57	Oregon State University Extension Service	1980	Fuelwood Facts Extension Circular 1023	Oregon State University Extension Service, Corvallis, OR
58	U.S. Department of Energy	1980	Heating with Wood	U.S. Department of Energy, Washington, DC (DOE/CS-0158)
59	Shelton, Jay. W.	1979	Wood Heat Safety	Garden Way Publishing, Charlotte, VT
60	Adkins, Jan	1978	The Art and Ingenuity of the Woodstove	Everest House Publishers, New York, NY
61	Soderstrom, Neil	1978	Heating Your Home with Wood	Popular Science, Harper & Row; Published by Book Division, Times Mirror Magazines, Inc., New York, NY
62	Twitchell, Mary	1978	Wood Energy A Practical Guide to Heating with Wood	Garden Way Publishing, Charlotte, VT
63	Vivian, John	1978	The New, Improved Wood Heat (Reprint)	Rodale Press, Emmaus, PA (Rev. ed. Of: Wood Heat (1976))
64	Harrington, Geri	1977	The Wood Burning Stove Book	Macmillan Publishing Co., Inc., New York, NY
65	Ross, Bob; Ross, Carol	1976	Modern and Classic Woodburning Stoves and the Grass Roots Energy Revival	Overlook Press, Woodstock, NY
A-47 66	Shelton, Jay W.	1976	The Woodburner's Encyclopedia Wood as Energy	Vermont Crossroads Press, Waitsfield, VT
67	Vivian, John	1976	Wood Heat	Rodale Press, Emmaus, PA

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#	AUTHOR	DATE	TITLE	PUBLICATION INFORMATION
68	Gay, Larry	1974	The Oregon Woodcutting and Heating Book	Garden Way Publishing, Charlotte, VT (Rev. ed. of: Heating With Wood)
69	Gay, Larry	1974	The Complete Book of Heating with Wood	Garden Way Publishing, Charlotte, VT
70	Havens, David	1973	The Woodburners Handbook Rekindling an Old Romance	Harpswell Press, Brunswick, ME
71	Young, Harold E.	1971	Preliminary Estimates of Bark Percentages and Chemical Elements in Complete Trees of Eight Species in Maine	Forestry Products Journal, Vol. 21, No. 5, pp. 56-59
72	Mingle, J.G.; Boubel, R.W.	1968	Proximate Fuel Analysis of Some Western Wood and Bark	Wood Science, Vol. 1, No. 1, pp. 29-36
73	Anonymous	Undated	Wood Heating Handbook	Prepared for the Great Lakes Regional Biomass Energy Program, Council of Great Lakes Governors, Madison, WI
A-47 74	Trefil, James S.	Undated	Wood Stoves Glow Warmly Again in Millions of Homes	No Publication Information Listed, pp. 55-62

Appendix B

Summary of Expert Interviews

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List of Tables

List of Experts Interviewed

Mr. John Crouch
Director of Local Government Relations
Hearth Products Association
7840 Madison Avenue, Suite 185
Fair Oaks, CA 95628
interviewed January 20, 1998

Mr. Rick Curkeet, P.E.
Manager
Intertek Testing Services
8431 Murphy Drive
Middleton, WI 53562
interviewed January 14, 1998

Mr. Bob Ferguson
President
Ferguson, Andors and Company
P.O. Box 678
South Royalto, VT 05068
interviewed January 16, 1998

Dr. Skip Hayden
Director
Combustion and Carbonization Research Laboratory
555 Booth Street
Ottawa Ontario K1A0G
CANADA
interviewed February 26, 1998

Mr. Daniel Henry
Vice President
Aladdin Steel Products, Inc.
401 N. Wynne Street
Colville, WA 99114
interviewed January 16, 1998

Dr. Dennis Jaasma
Associate Professor
Department of Mechanical Engineering
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061
interviewed February 20, 1998

Mr. Robert C. McCrillis, P.E.
Mechanical Engineer
Mail Drop 61
U.S. Environmental Protection Agency
National Risk Management Research Laboratory
Air Pollution Prevention and Control Division
86 T.W. Alexander Drive
Research Triangle Park, NC 27711
interviewed January 14, 1998

Mr. Ben Myren
President
Myren Consulting
512 Williams Lake Road
Colville, WA 99114
interviewed February 5, 1998

Mr. Michael Van Buren
Technical Director
Hearth Products Association
1601 North Kent Street, Suite 1001
Arlington, VA 22209
interviewed January 14, 1998

Interview Briefing Package - RWC Technology Review
Environmental Protection Agency Order no. 7C-R285-NASX

prepared by

OMNI Environmental Services, Inc.
5465 SW Western Avenue
Beaverton Oregon 97005
phone (503) 643-3788
fax (503) 643-3799
email: jhouck@omni-test.com
ptiegs@omni-test.com

1. State-of-the-art of wood stove combustion and emission control technologies.

   1.1 *Are in-home emission reductions as compared to conventional stoves shown in Table 1 for catalytic and non-catalytic certified stoves reasonable?*

   1.2 *Are efficiencies shown in Table 2 for catalytic and non-catalytic certified stoves reasonable?*

   1.3 *Can catalytic technology for use in wood stoves be fundamentally improved?*

   1.4 *Is the use of manufactured fuel (densified and wax logs) a credible emission reduction strategy? See Tables 1 & 2 .*

   1.5 *For non-catalytic stoves the heat retention adjustment with refractory material of various densities can reduce particulate emissions. How big an effect can this have?*

   1.6 *Approximately one half of the particulate emissions occur during the kindling phase for non-catalytic wood stoves and more than half for catalytic wood stoves. Are there improvements in technology that can mitigate this problem? Can specially designed high BTU wax logs be used to achieve a fast start and reduce kindling phase emissions?*

   1.7 *Should masonry heaters with tight fitting doors and draft control be classified as a wood stove and be subject to some type of certification even though most weigh more than 800 kg?*

   1.8 *Are the emissions and efficiencies for masonry heaters, based on in-home tests, shown in Tables 1 and 2 reasonable?*

1.9 *The OMNI staff feels the emissions per unit of heat delivered (e.g., lb/MBTU or g/MJ) is a more appropriate way to rank the performance of wood burning appliances than emission factors (lb/ton or g/kg) or emission rates (g/hr). — Comments?*

1.10 *Default efficiency values are used for wood stoves. This coupled with the fact that emission factors or rates (not g/MJ) are used to rank wood stoves does not provide an incentive for manufacturers to increase the efficiency of their stoves. — Comments? Should an efficiency test method as described (FR v. 55, n 161, p. 33925, Aug. 20,1990) be required to be used and the results listed?*

1.11 *Have certified stove design and performance improved since the first certified stoves? If so, how?*

2. State-of-the-art of fireplace emission control technology.

2.1 *Are the emission factors and efficiencies for the in-home use of fireplaces and inserts shown in Tables 3 and 4 reasonable?*

2.2 *There appear to be only a few practical design or technology options for fireplaces that will potentially mitigate particulate emissions. — What designs and technologies are available? What retrofit options are there?*

2.3 *The use of wax fire logs reduces emissions over the use of cordwood. Can the formulation of wax logs be changed to produce even less emissions?*

2.4 *What are the distinctions between a masonry fireplace and a masonry heater?*

2.5 *As with wood stoves, the OMNI staff believe that the mass of emissions per unit of heat delivered is a better way to rank the performance of fireplaces than emission factors or emission rates.*

3. State-of-the-art of wood-fired central heating furnace emission control technology.

3.1 *According to a Department of Energy survey out of the 20.4 million households that used a wood burning appliance in 1993, less than 0.3 million used a wood burning furnace as their primary source of heat. Are there enough wood-fired central heating furnaces in use to merit their closer evaluation? How many commercially available models are there? Are there emissions data for them? Should they be certified?*

4. State-of-the-art of pellet-fired wood stove technology.

4.1 *Are the emissions and efficiencies for the in-home use of pellet stoves shown in Tables 1 and 2 reasonable?*

4.2 *The 35:1 air-to-fuel ratio cut-off for certification has produced two classes of pellet stoves — those that are certified and those that are not. The latter class may have models that are less efficient and have higher emissions than the former. Should the regulations be amended to close the loop-hole and discourage the practice of intentionally designing models with a higher air-to-fuel ratio to avoid certification?*

4.3 *Have pellet stove design and performance improved since the first models were introduced? If so, how?*

5. Ramifications of ISO.

5.1 *The International Organization for Standardization (ISO) has a technical committee for developing emissions, efficiency and safety test standards for wood-fired residential heaters and fireplaces. (See Table 5 for comparison of the draft ISO method 13336 with EPA methods 28, 5G and 5H.) Do you feel that the EPA methods should be replaced with or be made comparable to an international standard?*

6. Correspondence between in-home and laboratory emission test results.

6.1 *How accurately do certification tests predict in-home performance?*

6.2 *How would you design research testing in the laboratory to simulate in-home use?*

7. EPA Method 28 strengths and weaknesses.

7.1 *Method 28 is in part an* "*art*". *Fuel loading density, fuel moisture, fuel characteristics (old vs new growth, grain spacing, wood density) and coal bed conditioning can be adjusted within the specification range of the method to influence results. In your experience what things have the most effect on particulate emissions? How much influence can they have?*

7.2 *Burn rate weighting is based on very limited data and the cities from where the data were obtained are not very representative of wood use nationwide (see Table 6). How can the weighting scheme be improved to be more representative of the nation as a whole?*

7.3 *The equation for the calculation of the air-to-fuel ratio as in Method 28A is in error. The error produces a small but significant difference in the calculated* *air-to-fuel ratio. Should the method be corrected or should it be left as a "predictor" of the air-to-fuel ratio?*

7.4 *The assumed mole fraction of hydrocarbons (Y_{HC}) is defined as a constant in the air-to-fuel ratio calculations in Method 28A. The mole fraction of hydrocarbons in the vapor phase will vary significantly with fuel and combustion conditions. Should hydrocarbon vapors (more appropriately, organic compound vapors) be measured as part of the method?*

8. EPA Methods 5G and 5H correlations.

8.1 *The comparison data to demonstrate the correlation between 5G and 5H are limited. Should the correlation between the two methods be reevaluated?*

9. Performance deterioration of EPA-certified wood stoves in the field.

9.1 *It is the opinion of many in the wood stove industry that catalysts last only five years and that a stove designed for a catalyst operated without a functioning catalyst can produce as much emissions as a conventional stove. — Comments?*

9.2 *Field studies in Glens Falls, NY, Medford, OR, Klamath Falls, OR and Crested Butte, CO showed that emissions from some catalytic stoves became appreciably worse even after two to three years of use. Inspection of stoves in Glens Falls showed that catalyst deterioration and leaky bypass systems were responsible. Have improvements been made in the design of catalytic stoves to minimize these problems? Is it reasonable to require homeowner training on the proper use of catalytic stoves and/or to incorporate into their costs an inspection and catalyst replacement program?*

10. Stress test pros and cons.

10.1 *A short-term laboratory woodstove durability testing protocol was developed to predict the long-term durability of stoves under conditions characteristic of in-home use (see EPA-600/R-94-193). It was concluded in that study that damage occurs during those occasional times when a woodstove is operated in the home at exceptionally high temperatures. The laboratory stress test was designed to operate a woodstove at very high temperatures over a one to two week period to predict long-term durability under in-home use. Is this a reasonable approach?*

10.2 *Should a stress test be made part of the certification process?*

11. Feasibility of developing separate emission factors for dry and wet wood and for softwood and hardwood species classes.

11.1 *Optimum wood moisture for low particulate emissions seems to be in the 18% to 20% range. Are you aware of any data that will allow the impact of wood moisture to be isolated from other variables? Could it be different for wood from different tree species?*

11.2 *Wood from different tree species clearly burns differently. The chemical make-up and density of wood from different tree species is different. For example wood from coniferous trees has more resin than wood from deciduous trees. It is believed that particulate emission factors will be different for wood from different tree species. If this is true different parts of the country may have different emissions factors for residential wood combustion. Are you aware of any data that document different emission factors for wood from different tree species?*

12. Routine maintenance.

12.1 *Would routine maintenance of stoves once they were in a home reduce particulate emissions? Would this be more relevant for catalytic stoves than non-catalytic stoves? Would this be relevant for pellet stoves with electronic and moving parts?*

12.2 *Should the home owner be provided with a maintenance manual or a training course at the time of purchase? Should a maintenance program be part of the purchase price particularly for catalytic stoves?*

12.3 *What would the key elements of routine maintenance be?*

Table 1
Emission Factor Reduction Potential, in Mass/Unit Mass Dry Wood Burned, for Various Alternatives to Conventional Stoves and Cordwood

Appliance	Particulate Emission Factor		
	lb/ton	g/kg	reduction %
Conventional	37	18.5	-
Non-Catalytic	12	6	68
Catalytic	13	6.2	65
Pellet	4	2	89
Masonry Heater	6	3	84
Conventional with densified fuel	25	14	24

Table 2
Effective Pollutant Reduction Potential, in Mass/Thermal Unit Heat Delivered, of Various Alternatives to Conventional Stoves and Cordwood

Appliance	Efficiency %	Heat Content (BTU/lb)	Mass particulate emission/delivered heat		
			lb/MBTU	g/MJ	reduction %
Conventional	54	8,800	3.89	1.68	-
Non-Catalytic	68	8,800	1.14	0.49	71
Catalytic	72	8,800	1.02	0.44	74
Pellet	78	8,500	0.31	0.13	92
Masonry Heater	58	8,800	0.59	0.25	85
Conventional with densified fuel	57	8,800	2.79	1.20	27

Table 3
Emission Factor Reduction Potential, in Mass/Unit Mass Dry Wood Burned, for Various Alternatives to Conventional Fireplaces and Cordwood

Appliance	Particulate Emission Factor		
	lb/ton	g/kg	reduction %
Fireplace	25	12.5	-
Fireplace with wax logs	21	10.5	16(70%)[a]
Non-Catalytic Insert	12	6	65
Catalytic Insert	13	6.5	89
Pellet Insert	4	2	84

[a] Wax logs on a mass particles per time basis show a 70% reduction which may be relevant due to the aesthetic use of fireplaces.

Table 4
Emission Factor Reduction Potential, in Mass/Thermal Unit Heat Delivered,
of Various Alternatives to Conventional Fireplaces and Cordwood

Appliance	Efficiency %	Heat Content (BTU/lb)	Mass particulate emission/delivered heat		
			lb/MBTU	g/MJ	reduction %
Fireplace	7	8,800	19.86	8.55	-
Fireplace with wax logs	8	15,000	8.75	3.76	56
Non-Catalytic Insert	68	8,800	1.14	0.49	94
Catalytic Insert	72	8,500	1.02	0..44	95
Pellet Insert	78	8,500	0..31	0..13	98

Table 5
Comparison of ISO 13336 (Draft) with EPA Methods 28, 5G, and 5H

Test Method	Emission Sampling Technique	Fuel Spacing	Fuel Species	Efficiency	Reporting Units
ISO 13336	dilution tunnel	0.75 inches	many including coal	calorimeter room	gram/kilogram
EPA 28	N/A[a]	1.5 inches	Douglas fir	N/A	grams/hour weighted average
EPA 5G	dilution tunnel	N/A	N/A	N/A	N/A
EPA 5H	direct flue	N/A	N/A	N/A	N/A

[a] N/A = Not Applicable

Table 6

Method 28 - Burn Rate Weighted Probabilities for Calculating Weighted Average Emission Rate Based on 43 Homes in Waterbury, VT, Glens Falls, NY, and Portland, OR.

Waterbury, VT	HDD[a] = 7953
Glens Falls, NY	HDD = 7547
Portland, OR	HDD = 4691

DOE/EIA - 0321 (93)
Wood cords burned from December 1992 through November 1993 by HDD

HDD	Millions of Cords
>7000	7.0
5500-7000	5.6
4000-5499	6.7
<4000	8.0
	27.4 total

[a] HDD = Heating degree days

John Crouch - Director of Local Government Relations,
<u>Hearth Products Association</u>

1. State-of-the-art of wood stove combustion and emission control technologies.

1.1 *Are in-home emission reductions as compared to conventional stoves shown in Table 1 for catalytic and non-catalytic certified stoves reasonable?*

Response: In terms of conventional stoves, the emissions reductions are very different, and the conventional stove numbers and the emission reduction numbers are very different, depending on whether the household studied was an Eastern household or a Western household. I think the conventional stove emissions are higher in the West, because of lower degree days and the tendency of consumers in the West to acquire large firebox stoves and burn them on Western softwood. Now the emission <u>reduction</u> may be greater in the West, ironically, because of course we are tuning our stoves for douglas fir, which is still a softwood even though it is one of the denser softwoods.

1.2 *Are efficiencies shown in Table 2 for catalytic and non-catalytic certified stoves reasonable?*

Response: Probably, although we have to be careful here in that so much of the work in the AP-42 database still relates to our industry's earliest shots at certified stoves. And although certified stoves haven't changed a lot in the last four years, some of the stoves which figured prominently in the in-situ work for those databases are much older than that, and are now history.

1.3 *Can catalytic technology for use in wood stoves be fundamentally improved?*

Response: I think the answer is probably yes, and then the question is, does it need to be? Are catalytics going to be used in the market place? Which, is a polite way to say, does anybody care? The market share for catalytic appliances has decreased markedly in recent years.

1.4 *Is the use of manufactured fuel (densified and wax logs) a credible emission reduction strategy? See Tables 1 & 2 .*

Response: I think it is, but I haven't been able to convince regulators that it is. There is tons and tons of densified fuel sold in some cities. People in this industry or regulators who are not familiar with it probably think that densified Pres-to-Log® type fuel costs too much. Manufactured fuel is a credible emission reduction strategy. It's credible technically, but as a salable strategy, I don't know.

1.5 *For non-catalytic stoves the heat retention adjustment with refractory material of various densities can reduce particulate emissions. How big an effect can this have?*

Response: No comment.

1.6 *Approximately one half of the particulate emissions occur during the kindling phase for non-catalytic wood stoves and more than half for catalytic wood stoves. Are there improvements in technology that can mitigate this problem? Can specially designed high BTU wax logs be used to achieve a fast start and reduce kindling phase emissions?*

Response: No comment.

1.7 *Should masonry heaters with tight fitting doors and draft control be classified as a wood stove and be subject to some type of certification even though most weigh more than 800 kg?*

Response: Yes and no; they shouldn't be classified as a woodstove, but they should be subject to some type of certification. There needs to be a "Certified Masonry Heater" option for these appliances.

1.8 *Are the emissions and efficiencies for masonry heaters, based on in-home tests, shown in Tables 1 and 2 reasonable?*

No comment.

1.9 *The OMNI staff feels the emissions per unit of heat delivered (e.g., lb/MBTU or g/MJ) is a more appropriate way to rank the performance of wood burning appliances than emission factors (lb/ton or g/kg) or emission rates (g/hr). — Comments?*

Response: I agree with that in theory, but I have been in front of a lot of city councils and county supervisors, and anything that would take away from the g/hr concept tends to make people suspicious. So it maybe too late to change the way we do this.

1.10 *Default efficiency values are used for wood stoves. This coupled with the fact that emission factors or rates (not g/MJ) are used to rank wood stoves does not provide an incentive for manufacturers to increase the efficiency of their stoves. — Comments? Should an efficiency test method as described (FR v. 55, n 161, p. 33925, Aug. 20,1990) be required to be used and the results listed?*

Response: Yes, the industry has had enough time now to get used to this idea, and if there were a period of two or three years where manufacturers could test their stove and be ready before their results were listed, it is appropriate.

1.11 *Have certified stove design and performance improved since the first certified stoves? If so, how?*

Response: Absolutely. Certainly the difference between phase I and phase II was for some stoves very significant. There were some stoves that were certified in phase I and the manufacturers gave up when it came time to certify to phase II, because the changes where so dramatic. They just packed it in. There were important changes in phase II that, probably, make the stoves more consistent performers in the field, and that's what everyone is interested in. Could stoves be changed even more? Yes, I think that was the sum total of that Friday's discussion, and I hope that would be the consensus here. They could be changed more, if we had an emissions test that was <u>more accurate</u> in terms of mimicking the real world. Until and unless the emissions test is reconceptualized, certified stoves will remain stuck where they are. This is probably appropriate, given the extremely low volume of sales.

2. State-of-the-art of fireplace emission control technology.

2.1 *Are the emission factors and efficiencies for the in-home use of fireplaces and inserts shown in Tables 3 and 4 reasonable?*

Response: Well they are consistent with what I've seen in other published OMNI reports.

2.2 *There appear to be only a few practical design or technology options for fireplaces that will potentially mitigate particulate emissions. — What designs and technologies are available? What retrofit options are there?*

Response: No comment.

2.3 *The use of wax fire logs reduces emissions over the use of cordwood. Can the formulation of wax logs be changed to produce even less emissions?*

Response: No comment.

2.4 *What are the distinctions between a masonry fireplace and a masonry heater?*

Response: I believe that heat exchange channels, however you define channels, are fundamental to that distinction.

2.5 *As with wood stoves, the OMNI staff believe that the mass of emissions per unit of heat delivered is a better way to rank the performance of fireplaces than emission factors or emission rates.*

Response: I strongly disagree. Fireplaces are not heat producing. Generally, fireplaces are an aesthetic device from which consumers do not expect heat, just the feeling and the perception of warmth, but they don't really expect real heat out of a fireplace. This concept is appropriate in wood heaters, pellet stoves, or masonry heaters, but by definition it is not appropriate in aesthetic fireplaces.

3. State-of-the-art of wood-fired central heating furnace emission control technology.

3.1 *According to a Department of Energy survey out of the 20.4 million households that used a wood burning appliance in 1993, less than 0.3 million used a wood burning furnace as their primary source of heat. Are there enough wood-fired central heating furnaces in use to merit their closer evaluation? How many commercially available models are there? Are there emissions data for them? Should they be certified?*

Response: The EPA New Source Performance Standards killed the indoor furnace industry and created this little loop-hole which the outdoor furnace industry is beginning to exploit and kind of underscores the need for a more comprehensive wood burning regulation which sets out over a several year period to codify all forms of wood burning technology.

4. State-of-the-art of pellet-fired wood stove technology.

4.1 *Are the emissions and efficiencies for the in-home use of pellet stoves shown in Tables 1 and 2 reasonable?*

Response: These are all that we've got, but we must remember that the 'n' value, the number of data points used here, is very small and highly dependent on a handful of households and the stove and the size of the house and whether consumers had made the right choice or not. To my knowledge, most of the pellet stove models that were used in those studies are no longer available for sale. Here is one area where there needs to be some revisiting.

4.2 *The 35:1 air-to-fuel ratio cut-off for certification has produced two classes of pellet stoves — those that are certified and those that are not. The latter class may have models that are less efficient and have higher emissions than the former. Should the regulations be amended to close the loop-hole and discourage the practice of intentionally designing models with a higher air-to-fuel ratio to avoid certification?*

Response: I wouldn't use the term "close the loop-hole". I would say, "is the proper place to cut off the definition of a wood heater?" We all know the whole discussion during the Reg-Neg ignored this emerging category of pellet stoves. So this gets back into my other broader comment, which is, instead of going back in and changing the NSPS in a piecemeal fashion, there needs to be a true revision of the whole thing that deals with the category of pellets and masonry heaters and outdoor furnaces. To go back and mess with it piecemeal, just will create more potential loop-holes and mistakes.

4.3 *Have pellet stove design and performance improved since the first models were introduced? If so, how?*

Response: Sure, more fully automated operations and much better handling of ash.

5. Ramifications of ISO.

5.1 *The International Organization for Standardization (ISO) has a technical committee for developing emissions, efficiency and safety test standards for wood-fired residential heaters and fireplaces. (See Table 5 for comparison of the draft ISO method 13336 with EPA methods 28, 5G and 5H.) Do you feel that the EPA methods should be replaced with or be made comparable to an international standard?*

Response: I don't think we know enough. We really need to see the ISO methodology run on some current EPA certified stoves and see what we get. We just don't know enough yet really to advocate that. But I do feel strongly that if the EPA were to reopen the wood heater process and review that and then choose not to adopt the ISO, that would be the end of the ISO method. So we need to do that before the EPA, if they ever do, reopen the NSPS. So it needs to be done earlier, rather than later.

13. Correspondence between in-home and laboratory emission test results.

6.1 *How accurately do certification tests predict in-home performance?*

Response: I believe certification tests are fairly accurate for that handful of families who burn douglas fir 2 by 4's with an inch and a half of air space around each piece of fuel. For the rest of the country, I suspect it can be improved on.

6.2 *How would you design research testing in the laboratory to simulate in-home use?*

Response: We have got to use different piece sizes and different surface to volume ratios and we have got to reduce the amount of air space between the pieces. And we probably should test the stoves with wider moisture types; the stoves have to be certified not just with a focus on burn rates but with a focus on different moisture levels. Because of course, everyone's woodpile has a little different moisture level in it. And that varies more than density. As a trade-off to all these changes, I think we could simplify the tests as well, just analyze for gas ratios, for instance, <u>or</u> just run a high and low run. The tests as they are currently constituted are far too expensive to run.

14. EPA Method 28 strengths and weaknesses.

7.1 *Method 28 is in part an "art". Fuel loading density, fuel moisture, fuel characteristics (old vs new growth, grain spacing, wood density) and coal bed conditioning can be adjusted within the specification range of the method to influence results. In your experience what things have the most effect on particulate emissions? How much influence can they have?*

Response: See HPA's input (Appendix C, page C-9).

7.2 *Burn rate weighting is based on very limited data and the cities from where the data were obtained are not very representative of wood use nationwide (see Table 6). How can the weighting scheme be improved to be more representative of the nation as a whole?*

Response: See HPA's input (Appendix C, page C-9).

7.3 *The equation for the calculation of the air-to-fuel ratio as in Method 28A is in error.*

The error produces a small but significant difference in the calculated air-to-fuel ratio. Should the method be corrected or should it be left as a "predictor" of the air-to-fuel ratio?

Response: See HPA's input (Appendix C, page C-9).

7.4 *The assumed mole fraction of hydrocarbons (Y_{HC}) is defined as a constant in the air-to-fuel ratio calculations in Method 28A. The mole fraction of hydrocarbons in the vapor phase will vary significantly with fuel and combustion conditions. Should hydrocarbon vapors (more appropriately, organic compound vapors) be measured as part of the method?*

Response: See HPA's input (Appendix C, page C-10).

15. EPA Methods 5G and 5H correlations.

8.1 *The comparison data to demonstrate the correlation between 5G and 5H are limited. Should the correlation between the two methods be reevaluated?*

Response: The overall suggestion of question 8 reflects the possibility of trying to 'tweak' the existing NSPS, dealing with the correlation, and flow rates. I would advocate that what the EPA needs to do is fundamentally start over, which means allow itself several years. Start with test methodology and then move into wood heaters and then masonry heaters and pellet stoves and, if necessary, have different test methodologies for different appliances and not try to fix the weaknesses of the current methodology. Obviously, after such a revision was completed, the industry would need a reasonable period to phase in new models, and all existing models would need to be grandfathered to the end of their certificate date.

16. Performance deterioration of EPA-certified wood stoves in the field.

9.1 *It is the opinion of many in the wood stove industry that catalysts last only five years and that a stove designed for a catalyst operated without a functioning catalyst can produce as much emissions as a conventional stove. — Comments?*

Response: Well I think that it's clear that people are not replacing their catalyst as soon as they should, from what I've been told by the company who sells replacement catalysts--so that's a concern. The work that the late Skip Burnett did on durability also underscored the weakness of some stove designs in terms of their bypass designs. I've not seen data that would confirm that a stove designed for a catalyst can produce as much emissions as a conventional stove. My suspicion is that the opposite is true, that even a poorly functioning catalyst is still an improvement over a conventional stove.

9.2 *Field studies in Glens Falls, NY, Medford, OR, Klamath Falls, OR and Crested Butte, CO showed that emissions from some catalytic stoves became appreciably worse even after two to three years of use. Inspection of stoves in Glens Falls showed that catalyst deterioration and leaky bypass systems were responsible. Have improvements been made in the design of catalytic stoves to minimize these problems? Is it reasonable to require homeowner training on the proper use of catalytic stoves and/or to incorporate into their costs an inspection and catalyst replacement program?*

Response: It would be more important to have a certified installer who was certified to install that stove, adjust the draft, because the stove is naked or unprotected against overdraft. That's as true for non-catalysts as it is for catalysts, but it is much more destructive. What Glens Falls taught us was that it's almost instantly destructive of catalytic stoves as compared to non-catalytic.

17. Stress test pros and cons.

10.1 *A short-term laboratory woodstove durability testing protocol was developed to predict the long-term durability of stoves under conditions characteristic of in-home use (see EPA-600/R-94-193). It was concluded in that study that damage occurs during those occasional times when a woodstove is operated in the home at exceptionally high temperatures. The laboratory stress test was designed to operate a woodstove at very high temperatures over a one to two week period to predict long-term durability under in-home use. Is this a reasonable approach?*

Response: I have fundamental questions whether that was the best approach. A better approach, it seems to me, is to redo the entire NSPS and require woodstoves, if they are going to be tested for a particular draft, to allow themselves to be run only at that draft or within a draft range. Yes, if they are going to be sold without any overdraft protection, then they would need a stress test to prove that they could do that. But the stress test should be removed if they are allowed, encouraged, or required to have overdraft protection. And I think with catalytic stoves that is fundamental, but it's probably also useful in terms of all the others, all the non-catalysts.

10.2 *Should a stress test be made part of the certification process?*

Response: It's asking the wrong question. "Should overdraft protection be made part of the stove design?" is the better question. And the answer is yes.

18. Feasibility of developing separate emission factors for dry and wet wood and for softwood and hardwood species classes.

11.1 *Optimum wood moisture for low particulate emissions seems to be in the 18% to 20% range. Are you aware of any data that will allow the impact of wood moisture to be isolated from other variables? Could it be different for wood from different tree species?*

Response: I think this is a critical area and one that is not adequately addressed at all in the certification test. And as I have said earlier in the woodstove portion, I just think we made a big mistake by field testing the stoves in cold parts of the country where people used hardwood and having them certified in a part of the country where people were using softwood--all of this to apply to air sheds that were in the softwood territory. We either just have to have different tests or the test has to be broadened to have us burn both types of wood, with very different types of moisture categories. Once again, this could only be addressed in the context of redoing the whole NSPS. You couldn't just kind of do some touch up, by changing the fuel species. You need to rethink this from the start. Before you do that, you have to ask if the effort involved will really have any impact on the environment. With so few woodstoves being sold, would a complete rethinking of the NSPS really be warranted?

11.2 *Wood from different tree species clearly burns differently. The chemical make-up and density of wood from different tree species is different. For example wood from coniferous trees has more resin than wood from deciduous trees. It is believed that particulate emission factors will be different for wood from different tree species. If this is true different parts of the country may have different emissions factors for residential wood combustion. Are you aware of any data that document different emission factors for wood from different tree species?*

Response: I think that 11.2 is more critical then 11.1, that density is most critical. Other than OMNI's own fuel study, no I am not aware of any other data. Could emissions be different for different tree species? It could and probably is different.

19. Routine maintenance.

12.1 *Would routine maintenance of stoves once they were in a home reduce particulate emissions? Would this be more relevant for catalytic stoves than non-catalytic stoves?*

Would this be relevant for pellet stoves with electronic and moving parts?

Response: Probably yes. If a pellet stove gets so gummed up it's going to shut down, maintenance is really important for pellet stoves, it affects emissions because it shuts them off.

12.2 *Should the home owner be provided with a maintenance manual or a training course at the time of purchase? Should a maintenance program be part of the purchase price particularly for catalytic stoves?*

Response: Yes it'd be good theoretically. Automobile owners aren't trained in the emissions of their car when they purchase it, but it does have a "check engine light". I suppose that's a good idea, but not many people are buying catalytic stoves anymore, anyway.

12.3 *What would the key elements of routine maintenance be?*

Response: Depends on the stove.

Rick Curkeet, P.E. - Manager, Intertek Testing Services

1. State-of-the-art of wood stove combustion and emission control technologies.

1.1 *Are in-home emission reductions as compared to conventional stoves shown in Table 1 for catalytic and non-catalytic certified stoves reasonable?*

Response: Yes, they are reasonable. However, the baseline for "conventional stoves" does not reflect the broad range of emissions rates for this type of stove. It is much greater than the range indicated in the table.

1.2 *Are efficiencies shown in Table 2 for catalytic and non-catalytic certified stoves reasonable?*

Response: The efficiencies for non-catalytic and pellet stoves are reasonable as averages for the group. There are, of course, specific models which are significantly better and perhaps some that are significantly worse than the table indicates. Catalytic stoves, I would say do somewhat better than the table values on average, but again there is a substantial range between models. I think the conventional stove efficiency estimates are optimistic. Many of the ones we tested in the early days were below 50%.

1.3 *Can catalytic technology for use in wood stoves be fundamentally improved?*

Response: I would say yes, and that also goes for non-catalytic technology. The greatest gains might come from electronic control of combustion air to adjust for fuel and temperature variations and optimize the combustion conditions.

1.4 *Is the use of manufactured fuel (densified and wax logs) a credible emission reduction strategy? See Tables 1 & 2 .*

Response: My first reaction is they could provide consistency in what goes into the unit to get better consistency of performance. My second reaction is that, as a large scale emissions reduction strategy, it is not in the big picture. I don't think we can tell consumers who bought wood stoves because of their ready access to free or low cost cordwood, that they now must purchase manufactured fuel. Burning cordwood is an environmentally friendly use of a readily available renewable energy source and should not be discouraged. Clean burning in well designed appliances is the best answer.

1.5 *For non-catalytic stoves the heat retention adjustment with refractory material of various* *densities can reduce particulate emissions. How big an effect can this have?*

Response: In my experience this is more a "trick of the trade" in obtaining good EPA emissions test results than it is a reliable method of ensuring good field performance. In our experience, this method becomes important when you must get a good test result at a low burn rate. Our clients are often very particular about pre-burn conditions for the low burn tests that will assure the maximum allowable heating of the refractory materials. This improves the chances for a quick secondary combustion light-off and low emissions measurements. I doubt that the average consumer routinely reproduces this in the field.

1.6 *Approximately one half of the particulate emissions occur during the kindling phase for non-catalytic wood stoves and more than half for catalytic wood stoves. Are there improvements in technology that can mitigate this problem? Can specially designed high BTU wax logs be used to achieve a fast start and reduce kindling phase emissions?*

Response: Yes. We have seen designs that have had a special "start-up" setting that helps get a fire started quickly. We've had trouble with these though because EPA has considered such settings as operating controls and required full load tests with the controls fully open. This can result in such high burn rates that it overpowers catalysts or creates artificially high gram per hour emissions rates. As for wax logs, used as kindling I'm not sure it would have a similar impact on all types of stoves. Some might benefit but others might not.

1.7 *Should masonry heaters with tight fitting doors and draft control be classified as a wood stove and be subject to some type of certification even though most weigh more than 800 kg?*

Response: Not if it means they would have to be tested by the current EPA method. The concern I have here is that masonry heaters are generally designed to burn wood loads at one high rate and store the bulk of the heat produced. The EPA method as currently written would force these units to produce a burn rate of less than 1 kilogram per hour. Thus the method is not compatible with the product and cannot produce a meaningful result.

1.8 *Are the emissions and efficiencies for masonry heaters, based on in-home tests, shown in Tables 1 and 2 reasonable?*

Response: No comment.

1.9 *The OMNI staff feels the emissions per unit of heat delivered (e.g., lb/MBTU or g/MJ) is a more appropriate way to rank the performance of wood burning appliances than emission factors (lb/ton or g/kg) or emission rates (g/hr). — Comments?*

Response: I agree 100%. While emissions per heat output ratings may be difficult to fit into the air quality model used by regulators, this format speaks to the purpose and environmental impact of the appliance. The current system does not reward the manufacturer for improving heating efficiency. But better efficiency means the user will need to burn less fuel and will therefore produce less pollution. It is possible to get lower gram per hour test results by simply extending the burn time for a particular setting. This does not result in a real emissions reduction since, if the user is not getting enough heat, he'll simply reload the stove more often, burn smaller pieces or make some other adjustment which bears little relation to the scenario used in the EPA test.

1.10 *Default efficiency values are used for wood stoves. This coupled with the fact that emission factors or rates (not g/MJ) are used to rank wood stoves does not provide an incentive for manufacturers to increase the efficiency of their stoves. — Comments? Should an efficiency test method as described (FR v. 55, n 161, p. 33925, Aug. 20,1990) be required to be used and the results listed?*

Response: I agree (see 10.9). As for an efficiency method, we should use one which is already published and in use – CSA Standard B415.

1.11 *Have certified stove design and performance improved since the first certified stoves? If so, how?*

Response: There have been some marginal improvements and a few significant emissions reductions. Most improvements have been in making units more user friendly and tolerant of fuel and operating variations. I don't think there has been any substantial move toward better efficiency. Between design restrictions inherent in the EPA test method and weak consumer demand there has been very little R&D in this field for several years.

2. State-of-the-art of fireplace emission control technology.

2.1 *Are the emission factors and efficiencies for the in-home use of fireplaces and inserts shown in Tables 3 and 4 reasonable?*

Response: I guess I'd have to say they are fairly reasonable. Of course we're always concerned about how to determine efficiencies of open fireplaces. It's highly dependent on outdoor air temperature and how much excess air is used. At some outdoor air temperature the effective fireplace efficiency will typically be zero – the heat produced all goes to heat the outdoor air drawn in to replace combustion air. This temperature is usually estimated at about 20 to 30 degrees F.

2.2 *There appear to be only a few practical design or technology options for fireplaces that will potentially mitigate particulate emissions. — What designs and technologies are available? What retrofit options are there?*

Response: There are some available. It is really a question of price. If an emission control strategy increases the fireplace cost enough, few people will buy fireplaces. I don't think this is the best answer. Fireplace emissions can be readily reduced by good operating practices by the user and perhaps by some modest and inexpensive design improvements.

2.3 *The use of wax fire logs reduces emissions over the use of cordwood. Can the formulation of wax logs be changed to produce even less emissions?*

Response: No comment.

2.4 *What are the distinctions between a masonry fireplace and a masonry heater?*

Response: A masonry heater is designed to capture and store a substantial portion of the energy produced in combustion. The heat is then transmitted slowly back to the living space. With a fireplace there is no attempt to store the heat produced and most usually is lost up the chimney.

2.5 *As with wood stoves, the OMNI staff believe that the mass of emissions per unit of heat delivered is a better way to rank the performance of fireplaces than emission factors or emission rates.*

Response: I agree to the extent that this approach penalizes manufacturers for design poor heating units. However, fireplaces are usually considered decorative products intended for occasional use. If the user only burns a few pounds of wood once or twice a week the environmental impact of poor combustion and low efficiency may not be significant.

3. State-of-the-art of wood-fired central heating furnace emission control technology.

3.1 *According to a Department of Energy survey out of the 20.4 million households that used a wood burning appliance in 1993, less than 0.3 million used a wood burning furnace as their primary source of heat. Are there enough wood-fired central heating furnaces in use to merit their closer evaluation? How many commercially available models are there? Are there emissions data for them? Should they be certified?*

Response: I don't know how many new units are being produced but I'm sure it's a very small number. Still, one really poor unit can be a significant problem if it's in your neighborhood. There have never been any standards for testing this type of product for emissions and efficiency. However, we have adapted existing methods and can say that the performance range is very wide. Poor designs may be 30% or less efficient and produce nearly 100 grams/hr emissions rates. Good designs are able to approach certified wood stove performance levels.

4. State-of-the-art of pellet-fired wood stove technology.

4.1 *Are the emissions and efficiencies for the in-home use of pellet stoves shown in Tables 1 and 2 reasonable?*

Response: Yes.

4.2 *The 35:1 air-to-fuel ratio cut-off for certification has produced two classes of pellet stoves — those that are certified and those that are not. The latter class may have models that are less efficient and have higher emissions than the former. Should the regulations be amended to close the loop-hole and discourage the practice of intentionally designing models with a higher air-to-fuel ratio to avoid certification?*

Response: Yes. The way to amend the regulation is to simply remove the 35:1 air/fuel ratio exemption. This has never been required by fireplaces (they meet the 5 kg/hr minimum burn rate exemption criterion anyway). Pellet units are readily able to meet emissions requirements and the exemption only encourages making these units less efficient to avoid the regulation.

4.3 *Have pellet stove design and performance improved since the first models were introduced? If so, how?*

Response: Yes, but not a whole lot in terms of emissions. There have been many improvements in operating reliability, fuel handling, safety and other features. Emissions have not had much attention perhaps because they are low enough to begin with that there does not appear to be a lot to be gained.

5. Ramifications of ISO.

5.1 *The International Organization for Standardization (ISO) has a technical committee for developing emissions, efficiency and safety test standards for wood-fired residential heaters and fireplaces. (See Table 5 for comparison of the draft ISO method 13336 with EPA methods 28, 5G and 5H.) Do you feel that the EPA methods should be replaced with or be made comparable to an international standard?*

Response: I believe it has moved well through the ISO process, but there has been no input or endorsement from the US that I know of. In the long run it would be good to harmonize test methods globally.

6. Correspondence between in-home and laboratory emission test results.

6.1 *How accurately do certification tests predict in-home performance?*

Response: They are not at all accurate. The lab test results do show the trend that units which are better in the lab are also better in the home. However, the actual emissions numbers can be very far from what happens in the field. We know, for example, that a unit which may do very well with an 18% moisture Douglas Fir lumber test load, can do very badly with the same fuel configuration at 22% moisture. I doubt that many consumers would pay the attention needed to get a "fussy" stove to do what it does in the lab.

6.2 *How would you design research testing in the laboratory to simulate in-home use?*

Response: Some of the things which need to be looked at are: real cord wood (e.g., broad range of size, shape density, moisture). Things such as starting a fire, when it is reloaded (coal bed size), changing settings during a burn, all can make significant differences in emissions rates. I think it could be more beneficial to look at a broader range of fuels than it is to focus solely on burn rate setting as the current standard now does. I think we need to rely more on the homeowner's ability to adjust the unit for local conditions. At this point it's not considered.

7. EPA Method 28 strengths and weaknesses.

7.1 *Method 28 is in part an "art". Fuel loading density, fuel moisture, fuel characteristics* *(old vs new growth, grain spacing, wood density) and coal bed conditioning can be adjusted within the specification range of the method to influence results. In your experience what things have the most effect on particulate emissions? How much influence can they have?*

Response: Yes, there is no question that all these factors can be adjusted and are adjusted. The manufacturers are extremely concerned about things like coal bed conditioning and moisture content. Currently we see a lot of designs where very minor changes make the difference between a good light-off on a low burn rate and a smoldering dirty low burn test. These things often make the difference between certification and no certification.

7.2 *Burn rate weighting is based on very limited data and the cities from where the data were obtained are not very representative of wood use nationwide (see Table 6). How can the weighting scheme be improved to be more representative of the nation as a whole?*

Response: The first thing I'd recommend is throw out the weighting method and just do a straight average. These units are used throughout the heating season, not just on average days. They will be run more on high fire in a large room in a big house than they will in a small room. They will be turned up when it gets really cold out and turned down when it warms up. They will be used throughout their available range depending on many factors including weather, building size, and insulation level. The EPA averaging method, by trying to represent all operating conditions, actually represents none (or few).

7.3 *The equation for the calculation of the air-to-fuel ratio as in Method 28A is in error. The error produces a small but significant difference in the calculated air-to-fuel ratio. Should the method be corrected or should it be left as a "predictor" of the air-to-fuel ratio?*

Response: First, this becomes a non-issue if the air/fuel ratio exemption is removed. Secondly, the math and chemistry are wrong and should be fixed. I have written EPA on this subject (F_0) and am awaiting a reply.

7.4 *The assumed mole fraction of hydrocarbons (Y_{HC}) is defined as a constant in the air-to-fuel ratio calculations in Method 28A. The mole fraction of hydrocarbons in the vapor phase will vary significantly with fuel and combustion conditions. Should hydrocarbon vapors (more appropriately, organic compound vapors) be measured as part of the method?*

Response: This is the same basic issue as in 7.3. It is not correct to set a fixed hydrocarbon level and then attempt a chemical mass balance. This results in a mathematical paradox of an “over-determined system”. It is not necessary to measure hydrocarbons to resolve this issue. All that is needed is to carry out the mass balance calculation with an assumed hydrocarbon composition to account for the unburned hydrogen and carbon.

8. EPA Methods 5G and 5H correlations.

8.1 *The comparison data to demonstrate the correlation between 5G and 5H are limited. Should the correlation between the two methods be reevaluated?*

Response: It should not be reevaluated. 5H is a poor method and should not be applied to combustion processes which do not operate in steady state.

8.2 *It is the general perception that method 5H produces lower numbers than 5G. Method 5G is less costly and more precise than 5H. — Comments? — Should there be just one sampling method?*

Response: 5H should just be eliminated. The 5G results should be used as measured and not “adjusted” by an unsupported factor.

8.3 *The same points regarding flow rate calculations (air-to-fuel ratio) and hydrocarbons as made for Method 28A are applicable to Method 5H. — Comments?*

Response: I recommend throwing out 5H, so this question is not relevant.

8.4 *The precision of EPA's Method 5 is estimated as being about 20%. Almost one quarter of the 214 stoves listed as certified by the EPA as of 8/12/97 are within 20% of their respective (catalytic or noncatalytic) emission limits. — Comments?*

Response: I agree with the error band, but suspect it is even larger as it is applied to wood stoves in 5H. Maybe plus or minus 50%. I do not think that the error of the method should be added to or subtracted from a test result to determine if something passes. Rather the error should be considered in setting the pass/fail limit so that the desired goal is achieved. It is, of course, difficult to do this and be fair, with a method that has such a large error band.

8.5 *Based on practical experience with the 5G and 5H, how can they be improved?*

Response: I think 5G works quite well as is. We might tweak it here and there, but I see no major improvements that would make a big difference. It is already a pretty accurate method. 5H is simply not appropriate for wood stove testing in my opinion.

9. Performance deterioration of EPA-certified wood stoves in the field.

9.1 *It is the opinion of many in the wood stove industry that catalysts last only five years and that a stove designed for a catalyst operated without a functioning catalyst can produce as much emissions as a conventional stove. — Comments?*

Response: I think catalysts can and do last longer than 5 years when well treated. However, they should probably be replaced anyway. The problem is getting owners to do that, which I don't think can be forced. Yes, catalysts do stop functioning but so do seals on doors and bypasses of non-catalytic stoves. I've seen units that operate just as well with an inactive catalyst substrate as they do with a new active catalyst. Clearly an active catalyst makes the unit easier to operate cleanly and less sensitive to fuel and operating conditions. The real issue is maintenance and the real answer is all stoves will operate better and cleaner if properly maintained.

9.2 *Field studies in Glens Falls, NY, Medford, OR, Klamath Falls, OR and Crested Butte, CO showed that emissions from some catalytic stoves became appreciably worse even after two to three years of use. Inspection of stoves in Glens Falls showed that catalyst deterioration and leaky bypass systems were responsible. Have improvements been made in the design of catalytic stoves to minimize these problems? Is it reasonable to require homeowner training on the proper use of catalytic stoves and/or to incorporate into their costs an inspection and catalyst replacement program?*

Response: First, I'd say improvements have definitely been made. I would say that in general the units still in production (and it's a pretty small list these days) are probably the best performers. That's why they're still here. I think it would be very difficult to set up any mechanism which would require people to perform a particular type of maintenance on their stove. It would be like trying to make a law that said you have to change your car's oil every 3000 miles. It would be more effective to try to educate people about the need for routine maintenance and perhaps emphasize the efficiency benefits. I can't see requiring people to pass a test or buy a license to own a wood stove.

10. Stress test pros and cons.

10.1 *A short-term laboratory woodstove durability testing protocol was developed to predict the long-term durability of stoves under conditions characteristic of in-home use (see EPA-600/R-94-193). It was concluded in that study that damage occurs during those* *occasional times when a woodstove is operated in the home at exceptionally high temperatures. The laboratory stress test was designed to operate a woodstove at very high temperatures over a one to two week period to predict long-term durability under in-home use. Is this a reasonable approach?*

Response: I don't believe this kind of stress test is needed. Manufacturers might want to use it just as a means of making sure they won't get a lot of complaints. However, as part of a certification process it poses a lot of questions. I would compare the proposed stress test concept to trying to determine the life expectancy of an automobile design by taking it to a test track and driving it at 150 miles per hour until something breaks. If the car lasts for only 10,000 miles under these conditions would you expect that that's how long it would last under normal driving conditions? There are a lot of things that can go wrong with a wood stove (other than overheating) which will affect its performance. Catalysts can be plugged, poisoned or coated with creosote. Gaskets can become worn or permanently compressed and leak. Welds can break and open even with normal temperatures. Durability testing is a complicated issue and should not be imposed without some real certainty that what is being done is really meaningful. It is very easy to create problems that don't come up in real life and miss the ones that do.

10.2 *Should a stress test be made part of the certification process?*

Response: No, a stress test should not be part of the certification process.

11. Feasibility of developing separate emission factors for dry and wet wood and for softwood and hardwood species classes.

11.1 *Optimum wood moisture for low particulate emissions seems to be in the 18% to 20% range. Are you aware of any data that will allow the impact of wood moisture to be isolated from other variables? Could it be different for wood from different tree species?*

11.2 *Wood from different tree species clearly burns differently. The chemical make-up and density of wood from different tree species is different. For example wood from coniferous trees has more resin than wood from deciduous trees. It is believed that particulate emission factors will be different for wood from different tree species. If this is true different parts of the country may have different emissions factors for residential wood combustion. Are you aware of any data that document different emission factors for wood from different tree species?*

Response
11.1-11.2: I would not recommend separate factors. It would be better to include the broad range

of fuel characteristics in the test process and make sure the average emissions came out in the acceptable range. I think it would be more valuable to test with high density dry wood, low density wet wood, etc. and run four tests that way and average the results than it is to run four different burn rates with one fuel.

12. Routine maintenance.

12.1 *Would routine maintenance of stoves once they were in a home reduce particulate emissions? Would this be more relevant for catalytic stoves than non-catalytic stoves? Would this be relevant for pellet stoves with electronic and moving parts?*

Response: Yes, it would apply to all three types of stoves to some degree. I think we assume that catalytic stoves need more maintenance than non-catalytic. I don't think that is necessarily true. I think we can see a lot of emissions and deterioration due to plugging up air inlets with ash, or maybe due to the deterioration of gasketing. As for pellet stoves, they seem to require a basic level of maintenance to keep them running which is probably sufficient.

12.2 *Should the home owner be provided with a maintenance manual or a training course at the time of purchase? Should a maintenance program be part of the purchase price particularly for catalytic stoves?*

Response: They should be offered. Training would be a very good idea, particularly if the dealer could provide it when the product is purchased. I'm not sure how you would make this happen – who would pay for it, etc. – but it would be nice.

12.3 *What would the key elements of routine maintenance be?*

Response: Keep it clean, replace worn or broken parts, make sure functioning parts function.

Bob Ferguson - President, Ferguson, Andors & Company

1. State-of-the-art wood stove combustion and emission control technologies.

1.1 *Are in-home emission reductions as compared to conventional stoves shown in Table 1 for catalytic and non-catalytic certified stoves reasonable?*

Response: I don't think the numbers looked too unreasonable and are fairly consistent with the reductions we have always talked about in general. The reductions do appear to consider a partially degraded catalyst or leaking bypass for the catalytic stove and no degradation for the non-catalytic.

1.2 *Are efficiencies shown in Table 2 for catalytic and non-catalytic certified stoves reasonable?*

Response: This table shows the non-catalytic efficiency as being higher than the EPA default number, which I always felt was too low. I think that it is hard to get a woodstove efficiency much above the low 70% range and still have it work well in the field.

1.3 *Can catalytic technology for use in wood stoves be fundamentally improved?*

Response: I have always felt that the substrate and catalyst suppliers could improve the technology. If the safe operating temperature range could be increased by a few hundred degrees, catalyst degradation would be dramatically reduced in the field. This would also allow designers to push the catalyst further in the application in the stove which is probably the only way you can ever get to a "zero emissions" stove. Manufacturers would be better off with a catalyst that cost 50% more, if performance and durability could be improved.

1.4 *Is the use of manufactured fuel (densified and wax logs) a credible emission reduction strategy? See Tables 1 & 2 .*

Response: We have had limited experience with wood-wax logs, but have not seen them as offering a big emission reduction potential. It depends on how the emissions are reported (g/hr, g/kg or g/MJ) and what the firing procedure is. We also have noticed an odor, which could be a nuisance if wood-wax logs were being burned regularly in many homes. I don't know if this is the case with all wood-wax logs.

1.5 *For non-catalytic stoves the heat retention adjustment with refractory material of various densities can reduce particulate emissions. How big an effect can this have?*

Response: This has a big effect. How big? Like many important design parameters, the difference between passing and failing--it could be a factor of two or more. None of these stoves would work at low burn rates without the right combination of insulation and/or refractory materials.

1.6 *Approximately one half of the particulate emissions occur during the kindling phase for non-catalytic wood stoves and more than half for catalytic wood stoves. Are there improvements in technology that can mitigate this problem? Can specially designed high BTU wax logs be used to achieve a fast start and reduce kindling phase emissions?*

Response: From my perspective it's a mass problem. You've got to get the stove hot and it takes a certain amount of heat input to warm up a 400 pound stove. I don't think you can get a big improvement by just looking at the initial kindling phase. I think that improvement can be made during refueling by the techniques employed.

1.7 *Should masonry heaters with tight fitting doors and draft control be classified as a wood stove and be subject to some type of certification even though most weigh more than 800 kg?*

Response: The 800 kg limit was arbitrary based on scale capacity and accuracy. It is my understanding that emissions from masonry heaters are quite low if operated in the manner intended by the designers. How many heaters are being installed nationwide? It doesn't seem worth the effort to develop methods and standards to regulate a small number of generally clean-burning heaters.

1.8 *Are the emissions and efficiencies for masonry heaters, based on in-home tests, shown in Tables 1 and 2 reasonable?*

Response: I have no direct knowledge.

1.9 *The OMNI staff feels the emissions per unit of heat delivered (e.g., lb/MBTU or g/MJ) is a more appropriate way to rank the performance of wood burning appliances than emission factors (lb/ton or g/kg) or emission rates (g/hr). Comments?*

Response: From a logical perspective, it is a better measurement for heating equipment but I don't think the issue of ranking between different types of wood burning appliances is a particularly relevant issue. Within a single product category, such as woodstoves, I don't know how significant the changes in ranking will be in going from g/hr to g/MJ. I do know that adding an efficiency test method will add even more uncertainty to the results. Adding efficiency (delivered heat) to comparisons between product categories, woodstoves vs. fireplaces for example, could dramatically impact emission rankings regardless of whether it was compared to emission rate or factor.

1.10 *Default efficiency values are used for wood stoves. This coupled with the fact that emission factors or rates (not g/MJ) are used to rank wood stoves does not provide an incentive for manufacturers to increase the efficiency of their stoves. Comments? Should an efficiency test method as described (FR v. 55, n 161, p. 33925, Aug. 20,1990) be required to be used and the results listed?*

Response: There is no commonly used or well proven efficiency method. There doesn't seem to be any market-driven incentive. Emissions and efficiencies don't sell woodstoves. Aesthetics, features and costs are the motivators. Until there is market pressure, you won't see efficiency measured or reported. From a regulatory perspective, there is no justification to require efficiency testing and I don't think it should be done. The increased costs offer no payback to the manufacturer, who already feels over regulated. The woodstove industry at present sales levels does not warrant any additional regulatory costs.

1.11 *Have certified stove design and performance improved since the first certified stoves? If so, how?*

Response: I think it has improved. Non-catalytic emission technology has improved (at least in terms of emission performance) more than the catalytic technology. I think the warranty costs have caused all surviving manufacturers to produce more durable products, rather than concerns over long term emission performance. The market forces are at work on this issue.

2. State-of-the-art of fireplace emission control technology.

2.1 *Are the emission factors and efficiencies for the in-home use of fireplaces and inserts shown in Tables 3 and 4 reasonable?*

Response: I don't have any first hand knowledge, only what I have read.

2.2 *There appear to be only a few practical design or technology options for fireplaces that will potentially mitigate particulate emissions. — What designs and technologies are available? What retrofit options are there?*

Response: Although there have been some attempts at developing products that retrofit into fireplaces while maintaining true fireplace features, I'm not sure that there is anything that is commercially viable (or even available) at the moment, other than fireplace inserts. There is some question as to whether fireplace inserts have made things better or worse, as they tend to change the use of the fireplace from occasional to more frequent or continuous use. This has both emission and safety implications. Any new technology for use in a fireplace has to have a low retail price point or it will not sell. Most fireplaces are used only occasionally and people will not be able to justify the cost of adding expensive technology for such limited use.

2.3 *The use of wax fire logs reduces emissions over the use of cordwood. Can the formulation of wax logs be changed to produce even less emissions?*

Response: I have to bet that it could be. Also, I think that the way the log is burned could have an impact on emissions. Right now, you just throw them on a conventional log grate. Some other type of holder could help.

2.4 *What are the distinctions between a masonry fireplace and a masonry heater?*

Response: Obviously, there are not that many open doors, screens or loose fitting glass doors on masonry heaters. They have a much more controlled air flow path and, obviously, intentional heat storage, compared to the straight-up flow path of a traditional masonry fireplace.

2.5 *As with wood stoves, the OMNI staff believe that the mass of emissions per unit of heat delivered is a better way to rank the performance of fireplaces than emission factors or emission rates.*

Response: Most fireplaces are not used as heaters, so there is no need to rank them on a heat delivered basis. They are primarily used for aesthetic purposes and are used, at best, only occasionally. They can be used as an emergency heat source, but this is very rare. Fireplaces as heating sources started to phase out soon after Ben Franklin invented the first stove.

3. State-of-the-art of wood-fired central heating furnace emission control technology.

3.1 *According to a Department of Energy survey out of the 20.4 million households that used a wood burning appliance in 1993, less than 0.3 million used a wood burning furnace as their primary source of heat. Are there enough wood-fired central heating furnaces in use to merit their closer evaluation? How many commercially available models are there? Are there emissions data for them? Should they be certified?*

Response: I don't feel there are enough units being sold to merit any activity what-so-ever. There are only a handful of manufacturers. I don't think there has been anything published--so if testing has been conducted, it is probably a good assumption that the numbers aren't that good. They shouldn't be certified, as you would have to develop test methods and standards. The country would be better off using the money to pay manufacturers to phase out of production, sort of like the agricultural method of paying farmers not to grow certain crops.

4. State-of-the-art of pellet-fired wood stove technology.

4.1 *Are the emissions and efficiencies for the in-home use of pellet stoves shown in Tables 1 and 2 reasonable?*

Response: Exempt units are likely to be less efficient and represent the majority of existing pellet stoves.

4.2 *The 35:1 air-to-fuel ratio cut-off for certification has produced two classes of pellet stoves ― those that are certified and those that are not. The latter class may have models that are less efficient and have higher emissions than the former. Should the regulations be amended to close the loop-hole and discourage the practice of intentionally designing models with a higher air-to-fuel ratio to avoid certification?*

Response: The 35:1 cutoff was intended for fireplaces. However, pellet stoves are the only product that even take advantage of the air-fuel exemptions. Fireplaces generally use the burn rate exemption. Pellet stoves probably don't need to be regulated at all. They are all quite clean burning. Let the marketplace decide if exempt stoves are acceptable. If pellet stove users demand products that use fewer pellets (more efficient), the manufacturers will respond.

4.3 *Have pellet stove design and performance improved since the first models were introduced? If so, how?*

Response: They have definitely improved. The driving force has been the cost of warranty. There are some pellet stoves that are considered to be very reliable. In fact, I'd say that all the pellet stove manufacturers that are still alive out there produce a reliable product, or they would have been driven from the market.

5. Ramifications of ISO.

5.1 *The International Organization for Standardization (ISO) has a technical committee for developing emissions, efficiency and safety test standards for wood-fired residential heaters and fireplaces. (See Table 5 for comparison of the draft ISO method 13336 with EPA methods 28, 5G and 5H.) Do you feel that the EPA methods should be replaced with or be made comparable to an international standard?*

Response: It is a good idea, but the question is how to get people to solve their specific differences?

6. Correspondence between in-home and laboratory emission test results.

6.1 *How accurately do certification tests predict in-home performance?*

Response: Not very accurately on average. There are a lot of stoves out there that have been designed to perform well during certification testing, without consideration for actual in-home performance. I think the performance in the home can vary widely, from good to bad for any given stove.

6.2 *How would you design research testing in the laboratory to simulate in-home use?*

Response: You would have to look at fuel variables (e.g., species, moisture, piece size, air spacing, logs versus cribs), fuel cycle variations (e.g., charcoal bed size and preparation, reload time, startup time, end-of-test). And then other factors, such as installation variables which could affect things like draft. It is a big job!!!

7. EPA Method 28 strengths and weaknesses.

7.1 *Method 28 is in part an "art". Fuel loading density, fuel moisture, fuel characteristics (old vs new growth, grain spacing, wood density) and coal bed conditioning can be adjusted within the specification range of the method to influence results. In your experience what things have the most effect on particulate emissions? How much influence can they have?*

Response: I think that they all have an effect and that the effect of each can be large. Within the necessary allowable ranges for these parameters, people have turned their manipulation into an art. The influence can be the difference between passing and failing.

7.2 *Burn rate weighting is based on very limited data and the cities from where the data were obtained are not very representative of wood use nationwide (see Table 6). How can the weighting scheme be improved to be more representative of the nation as a whole?*

Response: Things have changed since the data were accumulated. Most people were using woodstoves as primary heating sources, and that is no longer the case. They are used less frequently and for backup heat. Coming up with a weighting scheme which is good nationwide is tough. Manufacturers all consider themselves as national companies and will always want one test series that will allow them to sell their products anywhere.

7.3 *The equation for the calculation of the air-to-fuel ratio as in Method 28A is in error. The error produces a small but significant difference in the calculated air-to-fuel ratio. Should the method be corrected or should it be left as a "predictor" of the air-to-fuel ratio?*

Response: I'm not sure how important it really is. Most air-fuel ratio exempted products are pellet stoves, which are low emitters. I don't know how hard it would be to fix it, or if the accuracy and precision is any worse than the emission test method.

7.4 *The assumed mole fraction of hydrocarbons (Y_{HC}) is defined as a constant in the air-to-fuel ratio calculations in Method 28A. The mole fraction of hydrocarbons in the vapor phase will vary significantly with fuel and combustion conditions. Should hydrocarbon vapors (more appropriately, organic compound vapors) be measured as part of the method?*

Response: To what advantage? I don't see the point in terms of exemption issues.

8. EPA Methods 5G and 5H correlations.

8.1 *The comparison data to demonstrate the correlation between 5G and 5H are limited. Should the correlation between the two methods be reevaluated?*

Response: This is a big issue for me. The correlation has always been questionable, in my opinion. There were very little data comparing methods in the area where it counts the most, at low emission rates. There were three correlation curves presented and EPA chose the one which most severely penalized method 5G. You can't have a zero emission stove, if you use 5G. Use getting rid of 5H as justification for developing a good correlation of the methods at low emission rates.

8.2 *It is the general perception that method 5H produces lower numbers than 5G. Method 5G is less costly and more precise than 5H. — Comments? — Should there be just one sampling method?*

Response: It proves that it is a correlation issue, if true. 5G is penalized at low emission rates.

8.3 *The same points regarding flow rate calculations (air-to-fuel ratio) and hydrocarbons as made for Method 28A are applicable to Method 5H. — Comments?*

Response: This is not new. There have always been problems with the algorithm. This is another reason to get rid of 5H.

8.4 *The precision of EPA's Method 5 is estimated as being about 20%. Almost one quarter of the 214 stoves listed as certified by the EPA as of 8/12/97 are within 20% of their respective (catalytic or noncatalytic) emission limits. — Comments?*

Response: If 20% are within the limit, how many stoves have failed, or how many extra runs have been conducted that were 20% or less over? You will always have this issue, regardless of the precision. The passing grades were pushed lower in the beginning to account for precision, even though no one knew what the precision was. Obviously, the catching method is not the biggest problem here. The biggest variations occur in the Method 28 parameters. If Method 5 is 20%, what is the overall precision of woodstove emission testing?

8.5 *Based on practical experience with the 5G and 5H, how can they be improved?*

Response: 5H is inherently more complicated than 5G. EPA made 5G more complicated than it needs to be under the guise of QA, but for the most part it's quite workable as is. It is hard to make generalizations about improving the method. A line-by-line analysis is needed.

9. Performance deterioration of EPA-certified wood stoves in the field.

9.1 *It is the opinion of many in the wood stove industry that catalysts last only five years and that a stove designed for a catalyst operated without a functioning catalyst can produce as much emissions as a conventional stove. — Comments?*

Response: I think there is a range of performance for catalytic stoves with removed or non-functioning catalyst. Some stoves have done other things besides just sticking a catalyst element in the ceiling and probably don't perform as badly as a conventional stove unless really turned down low. Non-catalytic stoves can also perform as badly as a conventional stove if operated improperly.

9.2 *Field studies in Glens Falls, NY, Medford, OR, Klamath Falls, OR and Crested Butte, CO showed that emissions from some catalytic stoves became appreciably worse even after two to three years of use. Inspection of stoves in Glens Falls showed that catalyst deterioration and leaky bypass systems were responsible. Have improvements been made in the design of catalytic stoves to minimize these problems? Is it reasonable to require homeowner training on the proper use of catalytic stoves and/or to incorporate into their costs an inspection and catalyst replacement program?*

Response: Yes, I think they probably have. Certainly things like bypass dampers have improved. Stoves are generally being used less, which prolongs catalyst life. Training has always been a good idea, but is hard to accomplish, generically. It has to be stove specific to be effective. Building additional cost into the stove will further diminish sales (which are pitiful anyway). Fewer old stoves will be replaced, if costs for new ones go up more.

10. Stress test pros and cons.

10.1 *A short-term laboratory woodstove durability testing protocol was developed to predict the long-term durability of stoves under conditions characteristic of in-home use (see EPA-600/R-94-193). It was concluded in that study that damage occurs during those occasional times when a woodstove is operated in the home at exceptionally high temperatures. The laboratory stress test was designed to operate a woodstove at very high temperatures over a one to two week period to predict long-term durability under in-home use. Is this a reasonable approach?*

Response: I know you can break anything if you try hard enough, so at what point do you say it's okay? Is high temperature the only factor you should look at?

10.2 *Should a stress test be made part of the certification process?*

Response: Unless you can make an airtight case that a stress test is good predictor of long-term in-home durability, you can't justify its use. It would take years to properly determine this, rather than speculating at the expense of the manufacturers. The products already have to pass what amounts to a rare event stress test in order to get through safety testing. Market forces regarding warranty already push manufacturers toward producing durable products.

11. Feasibility of developing separate emission factors for dry and wet wood and for softwood and hardwood species classes.

11.1 *Optimum wood moisture for low particulate emissions seems to be in the 18% to 20% range. Are you aware of any data that will allow the impact of wood moisture to be isolated from other variables? Could it be different for wood from different tree species?*

Response: I don't know of any recent data. Obviously no one is out there generating comparative data because they can't afford to. I feel that it could be different for different species.

11.2 *Wood from different tree species clearly burns differently. The chemical make-up and density of wood from different tree species is different. For example wood from coniferous trees has more resin than wood from deciduous trees. It is believed that particulate emission factors will be different for wood from different tree species. If this is true different parts of the country may have different emissions factors for residential wood combustion. Are you aware of any data that document different emission factors for wood from different tree species?*

Response: There are some data, using a dilution tunnel, that looked at oak and fir and some with maple cordwood vs. fir cribs. These data were presented during Reg Neg but were sort of dismissed because they were generated by manufacturer(s).

12. Routine maintenance.

12.1 *Would routine maintenance of stoves once they were in a home reduce particulate emissions? Would this be more relevant for catalytic stoves than non-catalytic stoves? Would this be relevant for pellet stoves with electronic and moving parts?*

Response: I think that routine maintenance would help, as there is deterioration of important components such as door and bypass gaskets which can affect emissions. I feel that all stoves need maintenance on a regular basis.

12.2 *Should the home owner be provided with a maintenance manual or a training course at the time of purchase? Should a maintenance program be part of the purchase price particularly for catalytic stoves?*

Response: Probably not. People don't want to pay for it. Even if they do, some will not want to be bothered as time goes on. I'm not sure how you get people to do the right thing.

12.3 *What would the key elements of routine maintenance be?*

Response: Check and replace worn gaskets. Look for warpage or cracking and repair or replace parts. Inspect the venting system. Make sure all moving parts are functional. Clean or vacuum out air passageways. Inspect, clean or replace catalyst element(s).

Skip Hayden, Ph.D.-Senior Research Scientist
Advanced Combustion Technologies Laboratory

1. State-of-the-art of wood stove combustion and emission control technologies.

1.1 *Are in-home emission reductions as compared to conventional stoves shown in Table 1 for catalytic and non-catalytic certified stoves reasonable?*

Response: We don't see catalysts up here very much, let's put it that way.

1.2 *Are efficiencies shown in Table 2 for catalytic and non-catalytic certified stoves reasonable?*

Response: Yes, I think that was reasonable. There certainly is a wide variation on what we see, but 68 would be a better average. We haven't seen many, the catalyst might be slightly higher strictly because of this pressure drop, but the higher incomplete combustion products sometimes might cancel it out. So I wouldn't feel that the catalyst had significant advantages in terms of efficiency over the life of the appliance.

Statement: *OK, we had 72%.*

Response: Yes, I think that's an overestimate.

1.3 *Can catalytic technology for use in wood stoves be fundamentally improved?*

Response: Yes. If I took the better advanced combustion (non-catalyst) designs and worked in a catalyst after the combustion chamber of those designs as a tertiary clean-up, we could end up with some stoves with extremely clean operation. So basically instead of loading the catalyst and requiring it to go through a very wide range, you'd be requiring it to operate the way it does best in a car, even, where it's working with a relatively consistent fuel gas.

1.4 *Is the use of manufactured fuel (densified and wax logs) a credible emission reduction strategy? See Tables 1 & 2 .*

Response: Potentially yes.

1.5 *For non-catalytic stoves the heat retention adjustment with refractory material of various densities can reduce particulate emissions. How big an effect can this have?*

Response: It's an intertwining effect with the air release. I don't think it's in itself the solution, so I have a hard time to define an answer to that question.

1.6 *Approximately one half of the particulate emissions occur during the kindling phase for non-catalytic wood stoves and more than half for catalytic wood stoves. Are there improvements in technology that can mitigate this problem? Can specially designed high BTU wax logs be used to achieve a fast start and reduce kindling phase emissions?*

Response: Yes they would work. Basically what you're trying to do is to get a heated up chamber and some hot ash at the same time, without undergoing too much by-pass of the whole system.

Question: *I just threw that out there as an example. Are there any other technologies?*

Response: Certainly a small auxiliary ignition system would also do the trick.

1.7 *Should masonry heaters with tight fitting doors and draft control be classified as a wood stove and be subject to some type of certification even though most weigh more than 800 kg?*

Response: Yes. We have specific requirements for masonry heaters in our R2000 requirements.

1.8 *Are the emissions and efficiencies for masonry heaters, based on in-home tests, shown in Tables 1 and 2 reasonable?*

Response: The efficiency range is extremely dependent on a specific heater. We've seen a factor of over two for different heaters, and even for the same heater under different stages of development.

1.9 *The OMNI staff feels the emissions per unit of heat delivered (e.g., lb/MBTU or g/MJ) is a more appropriate way to rank the performance of wood burning appliances than emission factors (lb/ton or g/kg) or emission rates (g/hr). — Comments?*

Response: Yes and no. One of the problems we've got with some appliance designs--and, if you want, higher mass appliances fall into this category--is having sort of an uncontrolled heat release. If the appliance is used where it would normally be expected to be used, lets say between 7:00 PM and 9:00 PM, or something like that, and then it's releasing heat into the house over a time when we've been counseling people to significantly reduce their thermostats and, hence, the heat input into the house, it's not necessarily an optimal usage of that heat. So, while the efficiency generation of the appliance is good, it is not as effective a use of that energy as it would be if you were to put that heat into an insulated masonry and you had a means to extract the heat from that insulated masonry at some much later time when it was required. It's sort of the opposite to if you're using the space-heating ability of a woodstove, as opposed to a central furnace; you're able to in effect lower sometimes the overall heat demand of the house--because you're heating the primary space to be heated and letting the other parts go a little bit. Sometimes when we see seasonal efficiencies of woodstoves, and this is were I go back into those numbers that your were quoting, we can see significantly higher efficiencies than that, effective efficiencies, if the location of that appliance is in good concert with the design of the house and the usage patterns within the house.

1.10 *Default efficiency values are used for wood stoves. This coupled with the fact that emission factors or rates (not g/MJ) are used to rank wood stoves does not provide an incentive for manufacturers to increase the efficiency of their stoves. — Comments? Should an efficiency test method as described (FR v. 55, n 161, p. 33925, Aug. 20,1990) be required to be used and the results listed?*

Response: I think that using default values is wrong; you should have an efficiency test or at least a valid means of calculating efficiency from the emissions test.

1.11 *Have certified stove design and performance improved since the first certified stoves? If so, how?*

Response: Marginally with some, more with others, since EPA 1990 certification, primarily in terms of the resilience of the product (especially baffles) and in the more intelligent multi-location usage of preheated air release. But due to the changing industry, the continued move to improve that product has in general not been what it could be. In recent years, most of the emphasis, intelligence and efforts have gone into gas fireplaces, rather than further advancing, what were potentially really excellent woodstove designs.

2. State-of-the-art of fireplace emission control technology.

2.1 *Are the emission factors and efficiencies for the in-home use of fireplaces and inserts* *shown in Tables 3 and 4 reasonable?*

Question: *Fireplaces with wax logs 10.5 grams per kg?*

Response: We've seen lower than that, but also the firing rate with wax logs, just by the way they are run, is significantly lower, as well, giving further absolute emission reductions. Grams per hour reductions of a factor of four or five are possible. And that is with a non-efficient fireplace. That really is the important number for emissions, although it does nothing for efficiency.

Question: *OK, some other numbers from that table, I have a non-catalytic insert at six grams per kg, catalytic insert at 6.5, and a pellet insert at two?*

Response: Well, pellet inserts can be all over the map. We've got one now that's around 0.3, while some exempt units can be over 12.

Question: *OK, we had efficiencies on one of those tables. We had a typical open radiant fireplace as being 7% efficient.*

Response: We'd say plus or minus. It depends on the climate and the amount of what you're taking as the sort of the mean outside air temperature being heated up before it goes out. We think +/-5% to 7%, it's a little colder in Canada, so that you can actually have a fireplace, with its very large air demands, operating at a negative overall efficiency on the colder winter days.

Question: *Let's talk a little about the efficiencies of fireplace inserts, they are basically woodstoves, just a little less efficient.*

Response: The efficiency can be lower by as much as half, because a lot of the inserts go into fireplaces on outside walls, particularly ones that go in masonry fireplaces, and have no insulation on their outer casing (i.e. of the insert). On field trials, where we'd test an insert in the lab and its performance was effectively the same as a woodstove, above 50%, give or take a couple of percent, in some field installations we saw the real efficiency drop to the 30% range in the house, because you weren't able to extract that heat from the unit into the heated house space. Instead it was being conducted to the outdoors through the masonry. Hence, one of the prime recommendations that we have in Canada for inserts is that they should have an insulated outer casing.

2.2 *There appear to be only a few practical design or technology options for fireplaces that will potentially mitigate particulate emissions. — What designs and technology are available? What retrofit options are there?*

Response: Basically, I would say that the same options you have for wood stoves, in effect, are available to you for fireplaces. We have a real hard time in Canada having such an appliance (i.e., a conventional wood burning fireplace) in a new house, which is significantly inefficient, being an appliance that runs at a high burn rate at high excess air, while polluting at the same time. Taking the same advanced combustion technology developed for woodstoves and using it in a fireplace design can be most effective. So reducing excess air and improving the completeness of combustion can be combined to give you significant reduction in particulate emissions. At the same time, efficiency is high and burn rate is low. This presupposes a tight unit that operates with the door always shut, except on loading, a ceramic glass front to allow most of the radiation from the flame into the room, good heat exchange, insulated outer casing and even sealed combustion. There is a major potential future for efficient clean burning wood fireplaces operating at low excess air with an attractive flame, allowing a renewable energy resource with CO_2-neutral emissions to be used in the majority of North American homes, allowing this technology to be a contributing factor in mitigating global warming.

2.3 *The use of wax fire logs reduce emissions over the use of cordwood. Can the formulation of wax logs be changed to produce even less emissions?*

Response: Yes, it would be significant. However, we still consider it to be only a decorative use of the fireplace with no significant energy input into the house, and consider that to be a wasteful use of a renewable energy resource.

2.4 *What are the distinctions between a masonry fireplace and a masonry heater?*

Response: I would put a lower or upper limit on excess air and I would also define it as a unit that has no combustion air contact with the dwelling in which it's installed. The masonry heater also has a significant amount of heat exchange surface.

2.5 *As with wood stoves, the OMNI staff believe that the mass of emissions per unit of heat delivered is a better way to rank the performance of fireplaces than emission factors or emission rates.*

Response: The problem is on defining exactly what efficiency is and how it is truly measured. Probably around 90% of the fireplaces in North America are being installed on outside walls. Right away, require that you have some kind of estimate, not only of combustion heat loss, but of casing loss and, potentially, of radiative, versus convective, versus off-cycle loss, as well as a charge for heated house air drawn through the appliance, especially when it is running.

3. State-of-the-art of wood-fired central heating furnace emission control technology.

3.1 *According to a Department of Energy survey out of the 20.4 million households that used a wood burning appliance in 1993, less than 0.3 million used a wood burning furnace as their primary source of heat. Are there enough wood-fired central heating furnaces in use to merit their closer evaluation? How many commercially available models are there? Are there emissions data for them? Should they be certified?*

Response: The number of central wood furnaces in Canada, certainly in comparison to the United States, would be higher. In our Eastern provinces, it's a relatively common add-on to existing oil furnaces. Generally, they are as dirty as can be.

Question: *Do you have any emission data on them?*

Response: There were a couple of papers produced at the wood conference that we had down in New Orleans in the early 80's. In addition to the emissions seen from normal wood burning, as per stoves, there are dramatic peaks in emissions every time the furnace cycles "on" or "off", as well as very high emissions during the "off" or "stewing" condition. Finally, the advances in wood combustion technology seen in the better stoves, have not found their way into the furnace designs, which generally use 1970's combustion technology.

Question: *Do you think they should be certified?*

Response: Certainly, if the use of these central furnaces/boilers grows at all, they should not be exempt, because they are potentially very dirty, as explained above. In Canada, there is a draft CSA B415.2 emissions standard for boilers and furnaces.

4. State-of-the-art of pellet-fired wood stove technology.

4.1 *Are the emissions and efficiencies for the in-home use of pellet stoves shown in Tables 1 and 2 reasonable?*

Response: We saw a variation from one to two to up to ten g/h (and even higher), and the efficiencies from the high 70's to the low 50's and below for units running on very high excess air. I think those numbers in the table are optimistic, particularly for the exempt units.

4.2 *The 35:1 air-to-fuel ratio cut-off for certification has produced two classes of pellet stoves — those that are certified and those that are not. The latter class may have models that are less efficient and have higher emissions than the former. Should the regulations be amended to close the loop-hole and discourage the practice of intentionally designing models with a higher air-to-fuel ratio to avoid certification?*

Response: Yes. In Canada, we recommend that people buy only EPA-approved pellet stoves. We have developed a high ash pellet stove that's operating around 85% and its emissions are about 0.3 g/hr or less.

4.3 *Have pellet stove design and performance improved since the first models were introduced? If so, how?*

Response: In particular, some units have learned how to handle high ash fusion and some units have learned how to run at more concentrated (i.e. lower) excess air levels. Some units have been improved to handle accumulations of ash without disrupting the combustion process. Feeding techniques have advanced, as well as knowledge of satisfactory venting procedures.

5. Ramifications of ISO.

5.1 *The International Organization for Standardization (ISO) has a technical committee for developing emissions, efficiency and safety test standards for wood-fired residential heaters and fireplaces. (See Table 5 for comparison of the draft ISO method 13336 with EPA methods 28, 5G and 5H.) Do you feel that the EPA methods should be replaced with or be made comparable to an international standard?*

Response: I am unfamiliar with the ISO procedure. I feel that, as far as emissions are concerned, the EPA standard in general is pretty good.

6. Correspondence between in-home and laboratory emission test results.

6.1 *How accurately do certification tests predict in-home performance?*

Response: It depends on the design of the unit. A design with simple, obvious air control often has performance which reflects the lab very well. Complex operating procedures often do not translate into realized performance.

6.2 *How would you design research testing in the laboratory to simulate in-home use?*

Response: Ron Braaten (on my staff) would be a better one to talk to than me, although I do believe that it can be done simply and intelligently.

7. EPA Method 28 strengths and weaknesses.

7.1 *Method 28 is in part an "art". Fuel loading density, fuel moisture, fuel characteristics (old vs new growth, grain spacing, wood density) and coal bed conditioning can be adjusted within the specification range of the method to influence results. In your experience what things have the most effect on particulate emissions? How much influence can they have?*

Response: Ron is better equipped to answer that one.

7.2 *Burn rate weighting is based on very limited data and the cities from where the data were obtained are not very representative of wood use nationwide (see Table 6). How can the weighting scheme be improved to be more representative of the nation as a whole?*

Response: In Canada, house insulation/heating load levels are usually set to reflect differences in degree days, so that results from one zone are fairly easily transported to another.

7.3 *The equation for the calculation of the air-to-fuel ratio is in Method 28A is in error. The error produces a small but significant difference in the calculated air-to-fuel ratio. Should the method be corrected or should it be left as a "predictor" of the air-to-fuel ratio?*

Response: Believe it should be corrected.

7.4 *The assumed mole fraction of hydrocarbons (Y_{HC}) is defined as a constant in the air-to-fuel ratio calculations in Method 28A. The mole fraction of hydrocarbons in the vapor phase will vary significantly with fuel and combustion conditions. Should hydrocarbon vapors (more appropriately, organic compound vapors) be measured as part of the method?*

Response: We have done so using some complex hydrocarbon analyzers (not just standard FID's or heated FID's). In the initial development of clean burning equipment, it is important. It may not be so on an on-going basis where inference techniques can be utilized.

8. EPA Methods 5G and 5H correlations.

8.1 *The comparison data to demonstrate the correlation between 5G and 5H are limited. Should the correlation between the two methods be reevaluated?*

Response: Ask Ron. (See response to 7.1)

8.2 *It is the general perception that method 5H produces lower numbers than 5G. Method 5G is less costly and more precise than 5H. — Comments? — Should there be just one sampling method?*

Response: Yes, I think there should be just one.

8.3 *The same points regarding flow rate calculations (air-to-fuel ratio) and hydrocarbons as made for Method 28A are applicable to Method 5H. — Comments?*

Statement: See my response to 7.3.

8.4 *The precision of EPA's Method 5 is estimated as being about 20%. Almost one quarter of the 214 stoves listed as certified by the EPA as of 8/12/97 are within 20% of their respective (catalytic or noncatalytic) emission limits. — Comments?*

Response: Ask Ron. However, if wood burning is going to increase as a technique to help mitigate the global warming problem and meet climate change targets, technology should be improved, and the standards moved downwards, perhaps to 2.5 and 4 g/hr for catalytic and non-catalytic technologies, respectively.

8.5 *Based on practical experience with the 5G and 5H, how can they be improved?*

Response: Ask Ron. (See response to 7.1)

9. Performance deterioration of EPA-certified wood stoves in the field.

9.1 *It is the opinion of many in the wood stove industry that catalysts only last five years and that a stove designed for a catalyst operated without a functioning catalyst can produce as much emissions as a conventional stove. — Comments?*

Response: That's certainly possible, plus it can spill more combustion gases into the house. My experience has been that the deterioration will occur in sooner than 5 years.

9.2 *Field studies in Glens Falls, NY, Medford, OR, Klamath Falls, OR and Crested Butte, CO showed that emissions from some catalytic stoves became appreciably worse even after two to three years of use. Inspection of stoves in Glens Falls showed that catalyst deterioration and leaky bypass systems were responsible. Have improvements been made in the design of catalytic stoves to minimize these problems? Is it reasonable to require homeowner training on the proper use of catalytic stoves and/or to incorporate into their costs an inspection and catalyst replacement program?*

Response: We counsel Canadians to buy advanced combustion stoves, rather than catalyst stoves. You can't get that kind of performance over the long term, or even necessarily over the short term.

10. Stress test pros and cons.

10.1 *A short-term laboratory woodstove durability testing protocol was developed to predict the long-term durability of stoves under conditions characteristic of in-home use (see EPA-600/R-94-193). It was concluded in that study that damage occurs during those occasional times when a woodstove is operated in the home at exceptionally high temperatures. The laboratory stress test was designed to operate a woodstove at very high temperatures over a one to two week period to predict long -term durability under in-home use. Is this a reasonable approach?*

Response: Well I think it's reasonable; in fact we're one of the initiators of that concept and were participants in it. However, I conceived it more as a tool for manufacturers to develop a more durable product than as a requirement for certification. I think that in general there are better ways to require a certain amount of dollars being spent rather than having a fairly costly test done. I would be concerned that this would significantly increase the cost of the appliance.

10.2 *Should a stress test be made part of the certification process?*

Response: For advanced combustion stoves, no. For catalyst stoves, perhaps.

11. Feasibility of developing separate emission factors for dry and wet wood and for softwood and hardwood species classes.

11.1 *Optimum wood moisture for low particulate emissions seems to be in the 18% to 20%*

range. Are you aware of any data that will allow the impact of wood moisture to be isolated from other variables? Could it be different for wood from different tree species?

Response: We did some work on wood moisture a few years ago, but I can't remember what the results were. Our general recommendation is that people use cordwood that's been air dried for at least one year. We also don't see significant difference between soft and hard wood in a good design.

11.2 *Wood from different tree species clearly burns differently. The chemical make-up and density of wood from different tree species is different. For example wood from coniferous trees has more resin than wood from deciduous trees. It is believed that particulate emission factors will be different for wood from different tree species. If this is true different parts of the country may have different emissions factors for residential wood combustion. Are you aware of any data that document different emission factors for wood from different tree species?*

Response: We did some work, but found that with a good combustion design there was not a significant difference.

12. Routine maintenance.

12.1 *Would routine maintenance of stoves once they were in a home reduce particulate emissions? Would this be more relevant for catalytic stoves than non-catalyticalytic stoves? Would this be relevant for pellet stoves with electronic and moving parts?*

Response: One of the features of the routine maintenance would be the tightness of the gasket around the door and that might or might not, depending on the design, give you more or less particulate emissions on a non-catalyst stove. It would help you to control the burning rate, but it might also make it easier to burn wetter wood. Certainly routine maintenance around the catalyst, if that maintenance is such that you're not actually potentially replacing the catalyst or to maybe open up or seal a by-pass that wasn't there just by virtue of deposits. Also, interior cleaning to ensure the air ports are not restricted by ash deposit is important.

12.2 *Should the home owner be provided with a maintenance manual or a training course at the time of purchase. Should a maintenance program be part of the purchase price particularly for catalytic stoves?*

Response: Operational yes; the trouble with manuals is they are often a little too long and big and the essential items don't necessarily get followed or even perceived. So yes you should have it, but you should also have a short form of the important things to do. If you have a catalyst, there should be some sort of periodic means of verification and replacement built in to the cost of the unit.   I do not believe that an external (i.e. non-houseowner) maintenance program should be a requirement.

12.3 *What would the key elements of routine maintenance be?*

Response: Other then the verification of the state of the baffle and if it's easily visible, the glowing catalyst operation and the tightness of the door. I think the important things are the ongoing operational checks that a homeowner should do. Obviously the flue pipe and chimney need to be examined and cleaned as required. Air ports should not be blocked.

We recommend the use of sealed double walled flue pipe from the appliance to the chimney to ensure good draft, to reduce likelihood of condensation/deposition in the chimney, and to run the appliance slightly hotter to ensure clean combustion.

An important general comment that I have is that for an advanced combustion (non-catalyst) stove or fireplace, the more attractive and complex the flame, the cleaner the combustion, so there is a good guiding tendency for the user to maintain lower emissions performance (for a woodstove or a fireplace).

Daniel Henry, Vice President -- Aladdin Steel Products, Inc. (Mike Hoteling with Aladdin Steel Products also present during interviews)

1. State-of-the-art of wood stove combustion and emission control technologies.

1.1 *Are in-home emission reductions as compared to conventional stoves shown in Table 1 for catalytic and non-catalytic certified stoves reasonable?*

Response: I think Mike and I agree they are. The consumer can have a major impact on in-situ wood stove performance. I think in some studies they were better trained than in other studies.

1.2 *Are efficiencies shown in Table 2 for catalytic and non-catalytic certified stoves reasonable?*

Response: Were all those stoves using the same method to determine efficiencies? I think, I have a feeling in the back of my mind, or a gut feeling, that the catalytic stoves have a tremendous amount of forgiveness for both g/hr and efficiency as a result of the fact that it's only determined after the by-pass is closed. 72% for catalytic overall seems kind of high. And good clean non-catalytics are kind of low.

1.3 *Can catalytic technology for use in wood stoves be fundamentally improved?*

Response: My opinion is all technology can be improved. The data that I've seen and at all the seminars where data are presented, the catalyst was not necessarily the problem--the stove design was, warping by-passes, combustors located in temperature environments that exceeded their capability. So, my answer is, I think all technology can be improved, be it catalytic or non-catalytic. And I don't believe catalyst technology has reached its peak potential and I don't think non-catalytics have either.

1.4 *Is the use of manufactured fuel (densified and wax logs) a credible emission reduction strategy? See Tables 1 & 2.*

Response: I think so, if they were not too costly. And it would probably be more feasible in an urban environment where people have access to buying their fuel. But in a rural environment where people are cutting their own wood, they are still going to cut kindling.

1.5 *For non-catalytic stoves the heat retention adjustment with refractory material of various densities can reduce particulate emissions. How big an effect can this have?*

Response: It goes both ways. It really is a design criterion that will tend to show that one might be better than the other. We're talking, on a 5 gram stove, a difference of plus or minus a gram between the high and low densities.

1.6 *Approximately one half of the particulate emissions occur during the kindling phase for non-catalytic wood stoves and more than half for catalytic wood stoves. Are there improvements in technology that can mitigate this problem? Can specially designed high BTU wax logs be used to achieve a fast start and reduce kindling phase emissions?*

Response: I agree with that, albeit one of the things that will come up later is that in the emission certification series we were limited to 5 minutes of having the appliance wide open.

In a Northern climate zone, where a homeowner uses a woodstove for a primary heat source, the stove seldom needs to be kindled from a cold start. They just keep the stove going and keep feeding it. It's the cold start kindling, when the mass of the stove is absorbing the majority of the fire's heat that causes increased emissions. And in warmer regions, or during Spring and Fall in colder regions, when the stove is used only at night, it will need to be started cold. It may well be that specially designed wax logs or other products or devices could help reduce emissions, provided they didn't cost too much.

1.7 *Should masonry heaters with tight fitting doors and draft control be classified as a wood stove and be subject to some type of certification even though most weigh more than 800 kg?*

Response: I feel all wood combustion systems should have to meet emissions standards. And, I don't care whether it's a different standard than what woodstoves are currently tested under. Everything should have to prove to be clean burning, if they are going to regulate wood combustion or wood heat, because the wood stove has technically gotten a black eye for many years when there are other wood-burning systems that were emitting emissions.

1.8 *Are the emissions and efficiencies for masonry heaters, based on in-home tests, shown in Tables 1 and 2 reasonable?*

Response: I don't know.

1.9 *The OMNI staff feels the emissions per unit of heat delivered (e.g., lb/MBTU or g/MJ) is a more appropriate way to rank the performance of wood burning appliances than emission factors (lb/ton or g/kg) or emission rates (g/hr). — Comments?*

Response: I agree.

1.10 *Default efficiency values are used for wood stoves. This coupled with the fact that emission factors or rates (not g/MJ) are used to rank wood stoves does not provide an incentive for manufacturers to increase the efficiency of their stoves. — Comments? Should an efficiency test method as described (FR v. 55, n 161, p. 33925, Aug. 20,1990) be required to be used and the results listed?*

Response: That's definitely true, if an accurate method for certifiable products can be developed.

1.11 *Have certified stove design and performance improved since the first certified stoves? If so, how?*

Response: Yes. There's been kind of a laps the last couple of years, because the sales have been low and there hasn't been much incentive. But, I think now that there have been a few disasters as far as weather, wood stove sales are picking up and holding their own. Current technology stoves are more stable and reliable in their performance for emission certification.

2. State-of-the-art of fireplace emission control technology.

2.1 *Are the emission factors and efficiencies for the in-home use of fireplaces and inserts shown in Tables 3 and 4 reasonable?*

Response: They seem to be.

2.2 *There appear to be only a few practical design or technology options for fireplaces that will potentially mitigate particulate emissions. — What designs and technologies are available? What retrofit options are there?*

Response: In 1991 or 1992, I got a call from Majestic to build them a clean burning fireplace. They were moving forward as a manufacturer under the belief that new fireplaces would be regulated, not unlike wood stoves, in the near future.

I developed a single burn rate appliance on which we conducted EPA certification style testing and it came in at, I think, 3.6 grams per hour, and they did two or three runs to confirm it. All I really did was take a fireplace and design a secondary combustion system, with an insulated baffle and secondary tubes and developed the air flow to keep up with the burn rate. And, I think the burn rate, at that time, was in the three kilogram per hour range, which was what we determined, based on the limited amount of data that were available, was where the average fireplace burn rate was, with closed doors--fireplaces that had no doors were generally lower than that. I thought there was a tremendous opportunity to apply non-catalytic woodstove technology to fireplaces. But, the fireplace had limited volume production due to high retail costs.

2.3 *The use of wax fire logs reduces emissions over the use of cordwood. Can the formulation of wax logs be changed to produce even less emissions?*

Response: Don't know.

2.4 *What are the distinctions between a masonry fireplace and a masonry heater?*

Response: A masonry fireplace is a firebox, damper, and essentially a vertical flue. A masonry heater on the other hand is generally a smaller firebox which transfers heat to the massive masonry. A masonry heater is located centrally in the room so little heat is lost to the outdoors.

2.5 *As with wood stoves, the OMNI staff believe that the mass of emissions per unit of heat delivered is a better way to rank the performance of fireplaces than emission factors or emission rates.*

Response: I agree with that.

3. State-of-the-art of wood-fired central heating furnace emission control technology.

3.1 *According to a Department of Energy survey out of the 20.4 million households that used a wood burning appliance in 1993, less than 0.3 million used a wood burning furnace as their primary source of heat. Are there enough wood-fired central heating furnaces in use to merit their closer evaluation? How many commercially available models are there? Are there emissions data for them? Should they be certified?*

Response: I think a lot of these are used in rural areas and considering the fuels that are out there, I don't think they should be regulated. Maybe just a spot check of some sort. I think the only thing that would benefit would be the testing laboratories. If it emits particulate into an air shed where it can have an adverse effect on the industry (my ability to make a living), then yes.

4. State-of-the-art of pellet-fired wood stove technology.

4.1 *Are the emissions and efficiencies for the in-home use of pellet stoves shown in Tables 1 and 2 reasonable?*

Response: They seem to be. Yes.

4.2 *The 35:1 air-to-fuel ratio cut-off for certification has produced two classes of pellet stoves — those that are certified and those that are not. The latter class may have models that are less efficient and have higher emissions than the former. Should the regulations be amended to close the loop-hole and discourage the practice of intentionally designing models with a higher air-to-fuel ratio to avoid certification?*

Response: Well there are six or seven of us left that manufacture pellet stoves. There may be two or three companies that I haven't heard of, but the numbers they are doing at this point are pretty insignificant. There is no data that indicates that even a poorly operating stove is a dirty burning appliance. They are inherently clean, becoming more and more reliable, and don't fix them if they aren't broken.

4.3 *Have pellet stove design and performance improved since the first models were introduced? If so, how?*

Response: Yes, vastly. You go back to the late 80's and early 90's, there were probably sixty pellet stove manufacturers building something and putting a name on it. Field experience problems arrived on the issues of cash flow, poor performance and so on and so forth weeded them out.

5. Ramifications of ISO.

5.1 *The International Organization for Standardization (ISO) has a technical committee for developing emissions, efficiency and safety test standards for wood-fired residential heaters and fireplaces. (See Table 5 for comparison of the draft ISO method 13336 with EPA methods 28, 5G and 5H.) Do you feel that the EPA methods should be replaced* *with or be made comparable to an international standard?*

Response: I would vote for something that would be accepted internationally.

6. Correspondence between in-home and laboratory emission test results.

6.1 *How accurately do certification tests predict in-home performance?*

Response: For some reason we thought that in-home use should be represented in a laboratory number, and in some cases they have been and in some cases they have not been. I believe that a laboratory number, with dimensional lumber and the latitude that we have within the test method, could be an indicator of performance, not what the stove should be able to do with firewood that's got bark and dirt.

We certify our woodstove with 15 feet of pipe, whenever homeowners burn the woodstove it can have anywhere from four to forty feet of pipe on it. That's going to affect the way it burns. There is a real correlation between the height of the stack, static pressure, and the combustion air flowing through the firebox of the appliance that EPA and we in industry didn't think too much about during the development of the standard. But, if we have in the field today an appliance experiencing what we refer to as an "over draft"--you could have a unit that's capable of putting out significant amounts of BTUs into a room, stuck on a 30 foot stack and the guy says, "It burns the wood up in an hour and a half and I'm freezing to death;"--obviously, all the heat is going up the chimney. We've had to come up with solutions for those applications to try and bring the static pressure seen in the firebox back to within parameters that are closer to what was seen during the certification. That can range from a chimney damper to a ring around the top of the chimney that reduces the diameter to, in some cases, putting firebrick up on the baffle to restrict the outlet of the appliance.

6.2 *How would you design research testing in the laboratory to simulate in-home use?*

Question: *So, how would you design a test standard to accommodate all of that? (See paragraph two of response to question 6.1.)*

Response: I don't think we would do it that way. I think you require the manufacturer to give actual static pressure numbers. Build a firebox that has got a static pressure port, and when you run the stove wide-open, require wood pieces that are roughly two inches square and are stacked in there in a crib form (four or five across and four or five left to right and then four or five front to back). Have certification requirements for certified wood installers and they burn the appliance and verify the static pressure is within the allowable parameters--and you'd solve the problem.

7. EPA Method 28 strengths and weaknesses.

7.1 *Method 28 is in part an "art". Fuel loading density, fuel moisture, fuel characteristics (old vs new growth, grain spacing, wood density) and coal bed conditioning can be adjusted within the specification range of the method to influence results. In your experience what things have the most effect on particulate emissions? How much influence can they have?*

Question: *In your experience what things have the most effect on particulate emissions?*

Response: Every one of them. It would be difficult to say that any one or two of those has more effect than one or two of the others. If I was going to make a pick, I would say fuel moisture.

Question: *How much influence do you think that can have? Can you estimate in grams per hour?*

Response: From 40 down to 2. Well if you've got a piece of wood that goes "pop", it blows your low burn out and you've got a 40 gram run. If it doesn't go "pop" and it burns and burns and burns, you've got a 2 gram run. That's the difference. A lot of it depends on if the wood is stable or if it's unstable. You can check that during the pre-burn. You cut a piece of the end and throw it in during the pre-burn. If it goes bang, pop, boom during the pre-burn, you don't use it during your test.

Question: *Do you think that if there were more flexibility during the five minute start-up, that these things would have less influence?*

Response: Absolutely. We write in our owner's manuals: after a new load of firewood, put the draft controls in the wide-open position and run the stove in wide-open condition until you've got all the wood engulfed in flame--and we put a time in there 15, 20 minutes wide-open and then shut the stove down. Well that heats the appliance up and gets the secondary system up to temperature, where it will maintain stable secondary, and it also kindles the new load of wood so that you are getting a release of combustibles that will sustain the secondary combustion. Once you've got that locked in, it's self sustaining and it's going to burn clean until that load of wood is in the char and you lose your secondary. So if the test method could replicate more real world instruction manuals, which the EPA has to approve also, then I think we would have cleaner performing field appliances. It would also allow us to do more things as far as firebox size.

7.2 *Burn rate weighting is based on very limited data and the cities from where the data were* *obtained are not very representative of wood use nationwide (see Table 6). How can the weighting scheme be improved to be more representative of the nation as a whole?*

Response: There are many factors that are going to come into this, but if you can get a region that has 100 wood stoves per square mile and then other places that are going to have none and there're going to be places that are going to be in proximity to wood and it's almost mind boggling to try to figure that one out.

7.3 *The equation for the calculation of the air-to-fuel ratio as in Method 28A is in error. The error produces a small but significant difference in the calculated air-to-fuel ratio. Should the method be corrected or should it be left as a "predictor" of the air-to-fuel ratio?*

Response: I have no objection to proving the accuracy of it.

7.4 *The assumed mole fraction of hydrocarbons (Y_{HC}) is defined as a constant in the air-to-fuel ratio calculations in Method 28A. The mole fraction of hydrocarbons in the vapor phase will vary significantly with fuel and combustion conditions. Should hydrocarbon vapors (more appropriately, organic compound vapors) be measured as part of the method?*

Response: I don't think that it's necessary to actually measure hydrocarbon vapor to determine air-to-fuel ratio. It should be possible to determine ranges of values for various hard and soft wood species under typical combustion conditions to come up with a close enough approximation for practical purposes.

8. EPA Methods 5G and 5H correlations.

8.1 *The comparison data to demonstrate the correlation between 5G and 5H are limited. Should the correlation between the two methods be reevaluated?*

Response: I always thought that 5H was right and 5G was corrected to match 5H. Now it appears that 5G is possibly correct and 5H was in error. There was quite a bit of discussion concerning if 5G is correct and the error with 5G is the correction factor and bring it up or down to 5H. I would lobby that if 5G is the correct number, then the problem with 5G is the correction factor. One of the things we have a lot of data on here is the Condar in parallel with 5G. Method 5G and the Condar were very very close, until we hit it with the correction number, and then they got apart and it was always in the negative, not the positive. We got to the point where I stopped using 5G and stayed with the Condar, because when I get certified with 5H it was more realistic data.

I don't have a problem getting rid of 5H and going with 5G. I would hate to voice my opinion or raise my hand to vote on it, if we would have to take a penalty in performance numbers. The industry is now getting used to seeing two to four gram non-catalytic stoves and one and a half to three and a half gram catalytic stoves. If we suddenly come back there with five gram stoves and it's because of a number that we pulled out of our hats to use as the new single test method, then that's going to have some serious ramifications on--Oh, our technology went backward instead of forward, and numbers like the State of Washington's four and a half grams for non-catalytics, there is a potentially serious downside there. So whatever we end up doing, I don't want to see that happen. If 5G is correct, there should be no correction factor, eliminate 5H and leave the standard at 7 ½.

8.2 *It is the general perception that method 5H produces lower numbers than 5G. Method 5G is less costly and more precise than 5H. — Comments? — Should there be just one sampling method?*

Response: 5H produces lower numbers than 5G.

8.3 *The same points regarding flow rate calculations (air-to-fuel ratio) and hydrocarbons as made for Method 28A are applicable to Method 5H. — Comments?*

Response: I think they ought to correct that, it's not going to hurt us as an industry; it's just going to give us a real number.

8.4 *The precision of EPA's Method 5 is estimated as being about 20%. Almost one quarter of the 214 stoves listed as certified by the EPA as of 8/12/97 are within 20% of their respective (catalytic or noncatalytic) emission limits. — Comments?*

Question: *OK, the precision of EPA's Method 5 is estimated as being about 20%.*

Response: I'll buy that.

Question: *Almost one quarter of the 214 stoves listed as certified by the EPA as of 8/12/97 are within 20% of their respective (catalytic or noncatalytic) emission limits. Any comments on that?*

Response: That 20% error factor was discussed during the Reg Neg process. When they turned the number from 9 grams an hour Oregon to 7.5 grams an hour EPA, I always felt like that 20% was accounted for. And another thing, in the Federal Register, No. 38, page 5877, in the rules, they have a different test frequency for people who are within 30% of the standard--so I believe it's accounted for there.

8.5 *Based on practical experience with the 5G and 5H, how can they be improved?*

Response: Covered that already.

9. Performance deterioration of EPA-certified wood stoves in the field.

9.1 *It is the opinion of many in the wood stove industry that catalysts last only five years and that a stove designed for a catalyst operated without a functioning catalyst can produce as much emissions as a conventional stove. — Comments?*

Response: True, I believe a well cared for catalyst can last longer then 5 years.

9.2 *Field studies in Glens Falls, NY, Medford, OR, Klamath Falls, OR and Crested Butte, CO showed that emissions from some catalytic stoves became appreciably worse even after two to three years of use. Inspection of stoves in Glens Falls showed that catalyst deterioration and leaky bypass systems were responsible. Have improvements been made in the design of catalytic stoves to minimize these problems? Is it reasonable to require homeowner training on the proper use of catalytic stoves and/or to incorporate into their costs an inspection and catalyst replacement program?*

Response: Yes, should be up to the manufacturer's discretion.

10. Stress test pros and cons.

10.1 *A short-term laboratory woodstove durability testing protocol was developed to predict the long-term durability of stoves under conditions characteristic of in-home use (see EPA-600/R-94-193). It was concluded in that study that damage occurs during those occasional times when a woodstove is operated in the home at exceptionally high temperatures. The laboratory stress test was designed to operate a woodstove at very high temperatures over a one to two week period to predict long-term durability under in-home use. Is this a reasonable approach?*

Response: See response to 10.2

10.2 *Should a stress test be made part of the certification process?*

Response: I'm not standing for anything that raises the cost of certifying a product before we can go to market. Anything that we use that's going to increase the cost of certification, so that I can go to market with it, it's going to drive up the retail price. You take the top five manufacturers nationwide and only one of them is selling more than 1,750 of any one model currently. But I think a stress test, durability test should be based on real world operations.

11. Feasibility of developing separate emission factors for dry and wet wood and for softwood and hardwood species classes.

11.1 *Optimum wood moisture for low particulate emissions seems to be in the 18% to 20% range. Are you aware of any data that will allow the impact of wood moisture to be isolated from other variables? Could it be different for wood from different tree species?*

Response: I think you've got that data with fuel performance and documenting the moisture content of the firewood pile.

11.2 *Wood from different tree species clearly burns differently. The chemical make-up and density of wood from different tree species is different. For example wood from coniferous trees has more resin than wood from deciduous trees. It is believed that particulate emission factors will be different for wood from different tree species. If this is true different parts of the country may have different emissions factors for residential wood combustion. Are you aware of any data that document different emission factors for wood from different tree species?*

Response: Oak and it burned very very clean.

12. Routine maintenance.

12.1 *Would routine maintenance of stoves once they were in a home reduce particulate emissions? Would this be more relevant for catalytic stoves than non-catalytic stoves? Would this be relevant for pellet stoves with electronic and moving parts?*

Response: Definitely; just like a car, routine maintenance improves the lifetime of anything. Especially with pellet stoves, blowers, heat exchangers, that's common sense. It tends to be far more critical for catalytic technology. They either work or they don't.

12.2 *Should the home owner be provided with a maintenance manual or a training course at the time of purchase? Should a maintenance program be part of the purchase price particularly for catalytic stoves?*

Response: Video format works really well. No.

12.3 *What would the key elements of routine maintenance be?*

Response: Front door gasket.

Dennis Jaasma, Ph.D. - Associate Professor, Department of Mechanical Engineering, Virginia Polytechnic Institute and State University

1. State-of-the-art of wood stove combustion and emission control technologies.

1.1 *Are in-home emission reductions as compared to conventional stoves shown in Table 1 for catalytic and non-catalytic certified stoves reasonable?*

Response: The numbers are a bit too low on pretty much everything. Catalytic and non-catalytic reductions are both listed too high. Whenever we have tested the conventional stoves the numbers have been around 22 g/kg. The estimate that I'm giving is on the Crested Butte data, it was never less than about 20. For catalytics the average is about 21. I don't think things are that bad in general.

1.2 *Are efficiencies shown in Table 2 for catalytic and non-catalytic certified stoves reasonable?*

Response: I didn't have any problems with efficiencies; the numbers weren't that bad.

1.3 *Can catalytic technology for use in wood stoves be fundamentally improved?*

Response: Anything like that can get better.

1.4 *Is the use of manufactured fuel (densified and wax logs) a credible emission reduction strategy? See Tables 1 & 2 .*

Response: It's not the answer to emission control due to the cost of the logs. People aren't going to pay for these, unless they become cheap.

1.5 *For non-catalytic stoves the heat retention adjustment with refractory material of various densities can reduce particulate emissions. How big an effect can this have?*

Response: I don't know.

1.6 *Approximately one half of the particulate emissions occur during the kindling phase for non-catalytic wood stoves and more than half for catalytic wood stoves. Are there* *improvements in technology that can mitigate this problem? Can specially designed high BTU wax logs be used to achieve a fast start and reduce kindling phase emissions?*

Response: Having the dry wood and proper operations goes a long way. For example, kindling the fire and stacking it the right way.

1.7 *Should masonry heaters with tight fitting doors and draft control be classified as a wood stove and be subject to some type of certification even though most weigh more than 800 kg?*

Response: This is a regulatory issue. EPA may or may not have the money to regulate masonry heaters.

1.8 *Are the emissions and efficiencies for masonry heaters, based on in-home tests, shown in Tables 1 and 2 reasonable?*

Response: I can't say, unless I knew how these appliances were operated.

1.9 *The OMNI staff feels the emissions per unit of heat delivered (e.g., lb/MBTU or g/MJ) is a more appropriate way to rank the performance of wood burning appliances than emission factors (lb/ton or g/kg) or emission rates (g/hr). — Comments?*

Response: No, if testing costs are relevant the g/hr approach is OK for now. For masonry heaters, a g/kg standard is a good choice in order to avoid unnecessarily complicated test procedures.

1.10 *Default efficiency values are used for wood stoves. This coupled with the fact that emission factors or rates (not g/MJ) are used to rank wood stoves does not provide an incentive for manufacturers to increase the efficiency of their stoves. — Comments? Should an efficiency test method as described (FR v. 55, n 161, p. 33925, Aug. 20,1990) be required to be used and the results listed?*

Response: It is really up to the EPA. I think it is a good idea.

1.11 *Have certified stove design and performance improved since the first certified stoves? If so, how?*

Response: Larger firebox, cleaner glass, durability (people don't want to have warranty claims), consumer features.

2. State-of-the-art of fireplace emission control technology.

2.1 *Are the emission factors and efficiencies for the in-home use of fireplaces and inserts shown in Tables 3 and 4 reasonable?*

Response: Emission factors for fireplaces were a lot too high.

2.2 *There appear to be only a few practical design or technology options for fireplaces that will potentially mitigate particulate emissions. — What designs and technologies are available? What retrofit options are there?*

Response: Gas logs.

2.3 *The use of wax fire logs reduces emissions over the use of cordwood. Can the formulation of wax logs be changed to produce even less emissions?*

Response: Probably wax logs can be formulated to give reduced emissions.

2.4 *What are the distinctions between a masonry fireplace and a masonry heater?*

Response: Masonry heaters have counter flow arrangements and more restricted air supply .

2.5 *As with wood stoves, the OMNI staff believe that the mass of emissions per unit of heat delivered is a better way to rank the performance of fireplaces than emission factors or emission rates.*

Response: Fireplaces can't compete if a standard is on a g/energy basis. There is more to life then heat. Some could argue that fireplaces should be treated differently.

3. State-of-the-art of wood-fired central heating furnace emission control technology.

3.1 *According to a Department of Energy survey out of the 20.4 million households that used a wood burning appliance in 1993, less than 0.3 million used a wood burning furnace as their primary source of heat. Are there enough wood-fired central heating furnaces in use to merit their closer evaluation? How many commercially available models are there? Are there emissions data for them? Should they be certified?*

Response: Yes, central heaters merit further evaluation. I don't know how many models are available. I think EPA has done some work on them, but I do not know any results. Yes, they should be certified. They are in danger of becoming extinct if they don't wind up with a certification program.

4. State-of-the-art of pellet-fired wood stove technology.

4.1 *Are the emissions and efficiencies for the in-home use of pellet stoves shown in Tables 1 and 2 reasonable?*

Response: OK regarding PM factors. The efficiency numbers are reasonable.

4.2 *The 35:1 air-to-fuel ratio cut-off for certification has produced two classes of pellet stoves — those that are certified and those that are not. The latter class may have models that are less efficient and have higher emissions than the former. Should the regulations be amended to close the loop-hole and discourage the practice of intentionally designing models with a higher air-to-fuel ratio to avoid certification?*

Response: Pellet stoves are inherently clean burning unless there is something very bad about their design. I am not concerned about regulating the currently uncertified units unless their field emissions are bad compared to certified stoves.

4.3 *Have pellet stove design and performance improved since the first models were introduced? If so, how?*

Response: No comment.

5. Ramifications of ISO.

5.1 *The International Organization for Standardization (ISO) has a technical committee for developing emissions, efficiency and safety test standards for wood-fired residential heaters and fireplaces. (See Table 5 for comparison of the draft ISO method 13336 with EPA methods 28, 5G and 5H.) Do you feel that the EPA methods should be replaced with or be made comparable to an international standard?*

Response: The EPA standard should be improved, since it will be a long time before it is replaced by something else. In the long run I hope the ISO effort becomes a standard and the US adopts it.

6. Correspondence between in-home and laboratory emission test results.

6.1 *How accurately do certification tests predict in-home performance?*

Response: Correlation is very poor.

6.2 *How would you design research testing in the laboratory to simulate in-home use?*

Response: Use of reasonable volatility cordwood fuel, reasonable coal bed size, and a range of burn rates.

7. EPA Method 28 strengths and weaknesses.

7.1 *Method 28 is in part an "art". Fuel loading density, fuel moisture, fuel characteristics (old vs new growth, grain spacing, wood density) and coal bed conditioning can be adjusted within the specification range of the method to influence results. In your experience what things have the most effect on particulate emissions? How much influence can they have?*

Response: Coal bed size, can't give a number on that.

7.2 *Burn rate weighting is based on very limited data and the cities from where the data were obtained are not very representative of wood use nationwide (see Table 6). How can the weighting scheme be improved to be more representative of the nation as a whole?*

Response: I think this is a subject for discussion and an open review.

7.3 *The equation for the calculation of the air-to-fuel ratio as in Method 28A is in error. The error produces a small but significant difference in the calculated air-to-fuel ratio. Should the method be corrected or should it be left as a "predictor" of the air-to-fuel ratio?*

Response: (None)

7.4 *The assumed mole fraction of hydrocarbons (Y_{HC}) is defined as a constant in the air-to-fuel ratio calculations in Method 28A. The mole fraction of hydrocarbons in the vapor phase will vary significantly with fuel and combustion conditions. Should hydrocarbon vapors (more appropriately, organic compound vapors) be measured as part of the method?*

Response: No, should calculate the hydrocarbon number, estimate the value from the concentration of carbon monoxide in flue gases.

8. EPA Methods 5G and 5H correlations.

8.1 *The comparison data to demonstrate the correlation between 5G and 5H are limited. Should the correlation between the two methods be reevaluated?*

Response: No.

8.2 *It is the general perception that method 5H produces lower numbers than 5G. Method 5G is less costly and more precise than 5H. — Comments? — Should there be just one sampling method?*

Response: Yes.

8.3 *The same points regarding flow rate calculations (air-to-fuel ratio) and hydrocarbons as made for Method 28A are applicable to Method 5H. — Comments?*

Response: Eliminate 5H.

8.4 *The precision of EPA's Method 5 is estimated as being about 20%. Almost one quarter of the 214 stoves listed as certified by the EPA as of 8/12/97 are within 20% of their respective (catalytic or noncatalytic) emission limits. — Comments?*

Response: The precision of 5G is about +/- 2%. The relatively poor precision of 5H is an additional reason to eliminate 5H.

8.5 *Based on practical experience with the 5G and 5H, how can they be improved?*

Response: 5G, aluminum front filter holders, also dual train approach for 5G should be required for good QA.

9. Performance deterioration of EPA-certified wood stoves in the field.

9.1 *It is the opinion of many in the wood stove industry that catalysts last only five years and that a stove designed for a catalyst operated without a functioning catalyst can produce* *as much emissions as a conventional stove. — Comments?*

Response: Not a good answer for that; could be less then 5 years, could be more.

9.2 *Field studies in Glens Falls, NY, Medford, OR, Klamath Falls, OR and Crested Butte, CO showed that emissions from some catalytic stoves became appreciably worse even after two to three years of use. Inspection of stoves in Glens Falls showed that catalyst deterioration and leaky bypass systems were responsible. Have improvements been made in the design of catalytic stoves to minimize these problems? Is it reasonable to require homeowner training on the proper use of catalytic stoves and/or to incorporate into their costs an inspection and catalyst replacement program?*

Response: Homeowner training is an excellent idea. A paid-for-up-front inspection/replacement program is not a good idea.

10. Stress test pros and cons.

10.1 *A short-term laboratory woodstove durability testing protocol was developed to predict the long-term durability of stoves under conditions characteristic of in-home use (see EPA-600/R-94-193). It was concluded in that study that damage occurs during those occasional times when a woodstove is operated in the home at exceptionally high temperatures. The laboratory stress test was designed to operate a woodstove at very high temperatures over a one to two week period to predict long-term durability under in-home use. Is this a reasonable approach?*

Response: Good idea, if stress test does a good job in predicting failures that actually occur in the field for specific models. The test would need to be confirmed before it is required.

10.2 *Should a stress test be made part of the certification process?*

Response: Yes.

11. Feasibility of developing separate emission factors for dry and wet wood and for softwood and hardwood species classes.

11.1 *Optimum wood moisture for low particulate emissions seems to be in the 18% to 20% range. Are you aware of any data that will allow the impact of wood moisture to be isolated from other variables? Could it be different for wood from different tree species?*

Response: There are much field data that could be looked at. Existing lab and field data could be analyzed, or new data generated.

11.2 *Wood from different tree species clearly burns differently. The chemical make-up and density of wood from different tree species is different. For example wood from coniferous trees has more resin than wood from deciduous trees. It is believed that particulate emission factors will be different for wood from different tree species. If this is true different parts of the country may have different emissions factors for residential wood combustion. Are you aware of any data that document different emission factors for wood from different tree species?*

Response: Field data exist and could be reviewed, but I don't know if anyone has done it.

12. Routine maintenance.

12.1 *Would routine maintenance of stoves once they were in a home reduce particulate emissions? Would this be more relevant for catalytic stoves than non-catalytic stoves? Would this be relevant for pellet stoves with electronic and moving parts?*

Response: Routine maintenance of catalytic stoves will reduce emissions from some models, but have little impact on others. Routine maintenance of non-catalytics will also provide some emissions reductions. Same applies to pellet stoves.

12.2 *Should the home owner be provided with a maintenance manual or a training course at the time of purchase? Should a maintenance program be part of the purchase price particularly for catalytic stoves?*

Response: Yes, definitely yes for the training manual. But a maintenance program should not be part of the purchase price for catalytic stoves. The most effective solution to poor field performance is intelligent local intervention triggered by excessive smoke.

12.3 *What would the key elements of routine maintenance be?*

Response: Inspection, cleaning, and repair.

Robert C. McCrillis - Mechanical Engineer, U.S. Environmental Protection Agency

1. State-of-the-art of wood stove combustion and emission control technologies.

1.1 *Are in-home emission reductions as compared to conventional stoves shown in Table 1 for catalytic and non-catalytic certified stoves reasonable?*

Response: I think they are for new installations, and of course that doesn't account for any degradation. And I suppose it's possible that some of the newer, I mean all these tests were done on stoves that were built in the early 90's. So maybe some of the newer stoves might do a little better.

1.2 *Are efficiencies shown in Table 2 for catalytic and non-catalytic certified stoves reasonable?*

Response: Well I think they are, again for new installations. I have a suspicion and no way to prove it that maybe since the manufacturers use these default efficiencies there is no incentive to make a stove efficient. And I think stoves burn better when you throw a little more heat up the chimney, so the actual efficiencies may have actually gone down.

1.3 *Can catalytic technology for use in wood stoves be fundamentally improved?*

Response: I don't know about the catalyst itself; I just don't know, but there may be some more attention that could be paid to the design of the way the catalyst is installed so that it doesn't get overheated.

1.4 *Is the use of manufactured fuel (densified and wax logs) a credible emission reduction strategy? See Tables 1 & 2 .*

Response: We don't have very much data at all; the only thing that I have seen are the data that you did. It may be reasonable. It may give you some gain or some reduction in the emissions, although the data are showing what, 20 to 30%. It is a more uniform fuel. I don't know if anybody has looked at any other potential pollutants that might be coming out of wax logs. Personally, I wouldn't make a big push to try to get the EPA, lets say, to recognize them as a way to get some emission reduction.

1.5 *For non-catalytic stoves the heat retention adjustment with refractory material of various densities can reduce particulate emissions. How big an effect can this have?*

Response: The little bit of testing that we were able to do here in our lab with that prototype, it seemed like it ran a lot hotter, and in some respects that was good, but then in other respects that was bad. When you threw a load of wood into that stove it retained a lot more heat, so that it tended to drive off volatiles fast and overwhelm the secondary. I'm sure it can have an effect and I suppose the effect could be good or it could be bad.

1.6 *Approximately one half of the particulate emissions occur during the kindling phase for non-catalytic wood stoves and more than half for catalytic wood stoves. Are there improvements in technology that can mitigate this problem? Can specially designed high BTU wax logs be used to achieve a fast start and reduce kindling phase emissions?*

Response: Again, I think the EPA little gas burner would have helped to get that secondary going quicker, especially on the non-catalytic. It probably wouldn't have been applicable to a catalytic stove, unless you could use it to preheat the catalyst or maybe use a catalyst that is preheated electrically. As far as using some kind of a starter fuel, I don't know--I suppose it might if you could get people to do it.

1.7 *Should masonry heaters with tight fitting doors and draft control be classified as a wood stove and be subject to some type of certification even though most weigh more than 800 kg?*

Response: I think it would be a good idea. I wouldn't begin to want to try to develop the test method for it, but I think it would be a good idea.

1.8 *Are the emissions and efficiencies for masonry heaters, based on in-home tests, shown in Tables 1 and 2 reasonable?*

Response: Well I think so, but again, it's a pretty small data set.

1.9 *The OMNI staff feels the emissions per unit of heat delivered (e.g., lb/MBTU or g/MJ) is a more appropriate way to rank the performance of wood burning appliances than emission factors (lb/ton or g/kg) or emission rates (g/hr). — Comments?*

Response: I agree with you.

1.10 *Default efficiency values are used for wood stoves. This coupled with the fact that emission factors or rates (not g/MJ) are used to rank wood stoves does not provide an incentive for manufacturers to increase the efficiency of their stoves. — Comments? Should an efficiency test method as described (FR v. 55, n 161, p. 33925, Aug. 20,1990) be required to be used and the results listed?*

Response: During the wood heater Regulatory Negotiation process, the Committee could not agree on an efficiency method. When the regulation was promulgated, EPA stated that Appendix J, to be proposed separately, was an optional procedure for determining efficiency. Appendix J was proposed (see question) but never promulgated. I wish that the Agency would go ahead and promulgate the method and also do away with those default efficiencies. If a manufacturer wants to quote an efficiency, then he has to have it tested for efficiency by the proposed Federal Register Method.

1.11 *Have certified stove design and performance improved since the first certified stoves? If so, how?*

Response: Yes, I think that is especially true for the non-catalytic technology. I think that the Aladdin type design and as it's been copied and improved on, I think, really made a big improvement on the non-catalytic technology. As far as catalytic technology, I don't really know; I don't have much experience. I have the impression that the life of the catalyst is probably improved since the first stoves, because the earlier ones had the other substrate that crumbled, and you know they did away with that. I don't know about the catalytic stove technology, if that's changed that much. I don't think there has been a lot of change in the catalyst wash coat.

2. State-of-the-art of fireplace emission control technology.

2.1 *Are the emission factors and efficiencies for the in-home use of fireplaces and inserts shown in Tables 3 and 4 reasonable?*

Response: Well, that is hard to say because there is so little data. It's based on field data, but that's such a small data base. You really can't comment on how reasonable it is; there is just so little of it.

2.2 *There appear to be only a few practical design or technology options for fireplaces that will potentially mitigate particulate emissions. — What designs and technologies are available? What retrofit options are there*?

Response: What little bit of testing we did on that Majestic, it seemed to burn quite a bit cleaner.

2.3 *The use of wax fire logs reduces emissions over the use of cordwood. Can the formulation of wax logs be changed to produce even less emissions?*

Response: That I don't know.

2.4 *What are the distinctions between a masonry fireplace and a masonry heater?*

Response: I have always thought of a masonry fireplace as being a regular conventional open fireplace that you burn for the aesthetics, sucks all the heat out of your house. And a masonry heater is one of the European style massive units that stores the heat in the masonry and releases it into the dwelling all day long. I think there is a lot of confusion about those definitions.

2.5 *As with wood stoves, the OMNI staff believe that the mass of emissions per unit of heat delivered is a better way to rank the performance of fireplaces than emission factors or emission rates.*

Response: I agree and it would force the fireplace designs toward a more closed unit with heat recovery.

3. State-of-the-art of wood-fired central heating furnace emission control technology.

3.1 *According to a Department of Energy survey out of the 20.4 million households that used a wood burning appliance in 1993, less than 0.3 million used a wood burning furnace as their primary source of heat. Are there enough wood-fired central heating furnaces in use to merit their closer evaluation? How many commercially available models are there? Are there emissions data for them? Should they be certified?*

Response: In some localities I think these furnaces are a problem; I don't know how many are commercially available. I think I can name off six or eight companies and each one makes several models, but I don't know what the total market is, maybe 10,000 - 15,000 a year. The little bit of testing that we did here, says that they are probably on a par with a conventional wood stove. The way those things work, they have a thermostatically operated draft and when the thermostat shuts off the draft closes, so you get this real smoldering burning situation. Secondary combustion technology probably wouldn't work. Possibly a catalytic technology would, but I just don't think it stays hot enough in there. I guess that really depends on the impact.

4. State-of-the-art of pellet-fired wood stove technology.

4.1 *Are the emissions and efficiencies for the in-home use of pellet stoves shown in Tables 1 and 2 reasonable?*

Response: I assume they are reasonable; I've done a variety of stoves in homes but, how many stoves all together? I don't know, maybe six, eight. Pretty small data base.

4.2 *The 35:1 air-to-fuel ratio cut-off for certification has produced two classes of pellet stoves — those that are certified and those that are not. The latter class may have models that are less efficient and have higher emissions than the former. Should the regulations be amended to close the loop-hole and discourage the practice of intentionally designing models with a higher air-to-fuel ratio to avoid certification?*

Response: Yes, all pellet stoves should be affected facilities and not subjected to that 35:1.

4.3 *Have pellet stove design and performance improved since the first models were introduced? If so, how?*

Response: I don't know because I haven't tested any of them, but it's my impression that they have become more reliable, more bells and whistles on them, automatic lighting and things like that. The reliability thing has probably gone way up. It's good technology. If people want to burn wood, I would like to see more of them choose pellet stoves instead of cordwood stoves.

5. Ramifications of ISO.

5.1 *The International Organization for Standardization (ISO) has a technical committee for developing emissions, efficiency and safety test standards for wood-fired residential heaters and fireplaces. (See Table 5 for comparison of the draft ISO method 13336 with EPA methods 28, 5G and 5H.) Do you feel that the EPA methods should be replaced with or be made comparable to an international standard?*

Response: I think ideally the EPA and the ISO should be the same, or be directly correlatable. But from an economic point of view, I don't think that it's reasonable to ask U.S. manufacturers to retest all their stoves because of a change in procedure. And yet I can see where the international people don't want to just adopt EPA's method.

It's not to say that the EPA rule can't be improved, it certainly can and that's why we're doing what we're doing today. But I don't think it should be done in a way that the stove manufacturers have to retest or redevelop stoves, or go through the development phase again and all that. Well you know a ten year cycle wouldn't be a bad way to bring in a new revised procedure; I don't think that would be too burdensome on the industry.

6. Correspondence between in-home and laboratory emission test results.

6.1 *How accurately do certification tests predict in-home performance*?

Response: It's my impression that it's only in a gross sense, the certified stoves burn cleaner in homes than conventional stoves. But I'm not sure that if you rank the certified stoves from lowest emission rates to highest, I don't think that same ranking would come out in in-home tests. But we don't really have a big enough data base to say that either. You'd have to have 50 homes all burning each stove model, before you get enough statistics to draw a conclusion, because there is so much variation from one home to the next.

6.2 *How would you design research testing in the laboratory to simulate in-home use?*

Response: My only suggestion there is if we could come up with a more typical home use cycle, then that's what we should use in research testing and in certification testing. I don't really know what a more typical home use cycle would be.

7. EPA Method 28 strengths and weaknesses.

7.1 *Method 28 is in part an "art". Fuel loading density, fuel moisture, fuel characteristics (old vs new growth, grain spacing, wood density) and coal bed conditioning can be adjusted within the specification range of the method to influence results. In your experience what things have the most effect on particulate emissions? How much influence can they have?*

Response: You know we did so much testing on that one stove here that we just found that it had enormous effect on emissions, just in what we did in the pre-burn--before we even got to the one hour pre-burn, the regulated one hour. Nobody would run a stove the way we ran it; you wouldn't do that in your home. To me that's just not right. I understand that it gives you good numbers and it's fairly repeatable and all that, but it's just not realistic.

7.2 *Burn rate weighting is based on very limited data and the cities from where the data were* *obtained are not very representative of wood use nationwide (see Table 6). How can the weighting scheme be improved to be more representative of the nation as a whole?*

Response: I don't really have any feel on that. Maybe it should be revised, but I don't know what data to use to do it.

7.3 *The equation for the calculation of the air-to-fuel ratio as in Method 28A is in error. The error produces a small but significant difference in the calculated air-to-fuel ratio. Should the method be corrected or should it be left as a "predictor" of the air-to-fuel ratio?*

Response: I'm not really familiar with that; I know you talked about it. If it's an error, I think it should be fixed. Is it going to make a big difference to the whole certification? I just think that it should be fixed.

7.4 *The assumed mole fraction of hydrocarbons (Y_{HC}) is defined as a constant in the air-to-fuel ratio calculations in Method 28A. The mole fraction of hydrocarbons in the vapor phase will vary significantly with fuel and combustion conditions. Should hydrocarbon vapors (more appropriately, organic compound vapors) be measured as part of the method?*

Response: Again, if it is something in error it should be fixed. Do most labs already measure hydrocarbons? So you'd be requiring them to buy a total hydrocarbon instrument.

8. EPA Methods 5G and 5H correlations.

8.1 *The comparison data to demonstrate the correlation between 5G and 5H are limited. Should the correlation between the two methods be reevaluated?*

Response: Yes, we really need to update that correlation. We generated a lot of data here in our lab at a very low emission rate, where we measured both 5G and 5H. And we should redo that equation. At higher rates the Federal Register equation for 5G ends up higher then 5H, but the data show that is not true.

8.2 *It is the general perception that method 5H produces lower numbers than 5G. Method 5G is less costly and more precise than 5H. — Comments? — Should there be just one sampling method?*

Response: Well maybe if the correlation equation was improved or updated then maybe that perception would go away.

8.3 *The same points regarding flow rate calculations (air-to-fuel ratio) and hydrocarbons as made for Method 28A are applicable to Method 5H. — Comments?*

Response: Whatever we said about Method 28A, I think applies to 5H.

8.4 *The precision of EPA's Method 5 is estimated as being about 20%. Almost one quarter of the 214 stoves listed as certified by the EPA as of 8/12/97 are within 20% of their respective (catalytic or noncatalytic) emission limits. — Comments?*

Response: I don't really have a comment on that.

8.5 *Based on practical experience with the 5G and 5H, how can they be improved?*

Response: We did a lot of 5G work here and it seemed that the one variable that we didn't have good control on was the filter temperature. Sometimes, depending on the stove and the burn rate and all that, it would get pretty high and sometimes it would be way down below 90°F. You know that's going to affect how much of the organic condenses. 5H has so many opportunities for error, with tracer gas and all that, it's much more complicated. I think it would be good to standardize, getting away from having to convert 5G to 5H.

9. Performance deterioration of EPA-certified wood stoves in the field.

9.1 *It is the opinion of many in the wood stove industry that catalysts last only five years and that a stove designed for a catalyst operated without a functioning catalyst can produce as much emissions as a conventional stove. — Comments?*

Response: It's certainly my observation that catalysts degrade, and in some stoves they degrade rather quickly and in others they don't; they degrade slowly. I shouldn't say just the stove, but in some home/stove combinations. I don't know how to get at this business with degradation, because it's almost guaranteed that after a few years the stove isn't going to be as clean. And it seems that some sort of maintenance procedures need to be mandated. I think everyone knows that any manufactured thing degrades, so maybe it's something the industry needs to try to advertise and sell. Include something in there about town ordinances. Somehow it seems like this needs to come from the local community level, radio announcements and things and the industry can play their lobbying role about how important this is and kind of work with the regulators and maybe over time it could become a routine practice.

9.2 *Field studies in Glens Falls, NY, Medford, OR, Klamath Falls, OR and Crested Butte, CO showed that emissions from some catalytic stoves became appreciably worse even after two to three years of use. Inspection of stoves in Glens Falls showed that catalyst deterioration and leaky bypass systems were responsible. Have improvements been made in the design of catalytic stoves to minimize these problems? Is it reasonable to require homeowner training on the proper use of catalytic stoves and/or to incorporate into their costs an inspection and catalyst replacement program?*

Response: Catalysts do degrade. At the time of the sale of the wood stove the homeowner or purchaser might be made more aware of what is required in the way of annual maintenance, what's important so the stove would stay burning clean. Maybe include in the purchase price a one year or four year maintenance check, or something like that. Make a big deal out of the maintenance check part. Most people don't want to even think about it, but it needs to be done.

10. Stress test pros and cons.

10.1 *A short-term laboratory woodstove durability testing protocol was developed to predict the long-term durability of stoves under conditions characteristic of in-home use (see EPA-600/R-94-193). It was concluded in that study that damage occurs during those occasional times when a woodstove is operated in the home at exceptionally high temperatures. The laboratory stress test was designed to operate a woodstove at very high temperatures over a one to two week period to predict long-term durability under in-home use. Is this a reasonable approach?*

Response: I always thought that a stress test was a reasonable approach. Maybe the test that the late Skip Burnett (EPA-600/R-94-193) came up with was a little too vigorous. I would like to see it included somehow. You have to break in the catalyst before you test the catalytic stove. Maybe the break in they have to do is the stress test. But then we'd have to agree on what a stress test is.

10.2 *Should a stress test be made part of the certification process?*

Response: I think it should. You could say that the manufacturer has to do this on his own, but is he really going to do it? The homeowner might not even know that something was wrong. If the catalyst isn't working, he's not really going to know that unless he sees the smoke coming out of the chimney and realizes or remembers what it was like two years ago.

11. Feasibility of developing separate emission factors for dry and wet wood and for softwood and hardwood species classes.

11.1 *Optimum wood moisture for low particulate emissions seems to be in the 18% to 20% range. Are you aware of any data that will allow the impact of wood moisture to be isolated from other variables? Could it be different for wood from different tree species?*

11.2 *Wood from different tree species clearly burns differently. The chemical make-up and density of wood from different tree species is different. For example wood from coniferous trees has more resin than wood from deciduous trees. It is believed that particulate emission factors will be different for wood from different tree species. If this is true different parts of the country may have different emissions factors for residential wood combustion. Are you aware of any data that document different emission factors for wood from different tree species?*

Response to
11.1 & 11.2: I don't think this really can be done without a tremendous amount of test data. You can look at existing data statistically and see there is a difference between wet and dry and a difference between oak and pine, but trying to put a number on it would be very difficult.

12. Routine maintenance.

12.1 *Would routine maintenance of stoves once they were in a home reduce particulate emissions? Would this be more relevant for catalytic stoves than non-catalytic stoves? Would this be relevant for pellet stoves with electronic and moving parts*?

Response: Yes; I don't know what routine is, but maybe once a year or every other year. More relevant for catalytic stoves, but there are parts of non-catalytic that can deteriorate and fail too. Yes, I'm sure it would.

12.2 *Should the home owner be provided with a maintenance manual or a training course at the time of purchase? Should a maintenance program be part of the purchase price particularly for catalytic stoves?*

Response: I think they should. I think that should be a more important part of the sale than maybe it is. That might not be a bad idea, if the dealer just includes it in the cost, but then the customer might ask for the cost without the maintenance program. And then if there is no law saying he has to do it, then the dealer will have to bargain.

12.3 *What would the key elements of routine maintenance be?*

Response: Clean the stove inside. Inspect and repair any cracks in the metal. Remove and clean the catalyst following the catalyst manufacturer's practice. Replace door and window gaskets, if they need to be. Replace the bypass gasket, if there is one. Repair any standard damage to the brick or the firebrick lining. Check the bypass seal and hopefully be able to repair it, but there will be times when you can't. Straighten and replace warped parts, again, there're going to be situations where this is just not feasible. Inspect and repair the chimney system. Then run the stove and make sure everything runs right, the catalyst lights up, secondary burn and all those good things.

Ben Myren - President, Myren Consulting, Inc.

1. State-of-the-art of wood stove combustion and emission control technologies.

1.1 *Are in-home emission reductions as compared to conventional stoves shown in Table 1 for catalytic and non-catalytic certified stoves reasonable?*

Response: I think the 18.5 g/kg factor for conventional stoves is low, particularly for the West Coast stoves that we know so well--probably by a factor of 2 to 3.

Question: *What about the blend of conventional stoves that are out there right now--non-catalytics?*

Response: I think some of them have been replaced. One of the things that I ran into when I was down at DRI this year is that they have an old conventional stove, but it had developed a leak and getting it to burn at extremely low airtight burn rates was virtually impossible. I think there are a number of units that are around doing that; how many and which way that affects the emissions is hard to say. Probably with more air it should tend to burn somewhat cleaner, but I don't see the basic inventory changing.

Question: *What about the non-catalytics and catalytics, certified?*

Response: I think those are reasonable. I think, again, we have limited data. Some other data are in that range. I'm kind of ambivalent on that one. I think that if there are reasonable numbers to deal with for the whole population of stoves that are out there, I would like to see it redone only with stoves certified to the State of Washington's 4-1/2 gram standard included to see if that makes a difference. I don't know.

1.2 *Are efficiencies shown in Table 2 for catalytic and non-catalytic certified stoves reasonable?*

Response: I think that those are low. I think that 68%, because of the combustion efficiency necessary for 4-1/2 grams and 1 kg an hour burn rate, I think 70% would be a more real number.

Question: *OK, what about the catalytics--that was the non-catalytics. What about the catalytics?*

Response: I think that is low as well. I think catalytic stoves, if they are done right, should be in the high 70's, 77-78%.

Question: *What about the conventional; do you think that one's on the money?*

Response: I think that one could be all over the map. I think it's a reasonable number. I don't have that much experience with those stoves to really tell you.

1.3 *Can catalytic technology for use in wood stoves be fundamentally improved?*

Response: I believe it can. The problem that I see with catalyst technology is that it doesn't have aesthetic qualities that the consumers tend to be looking for. That's why non-catalytics have sort of garnered the largest share of the market, the major share of the market. And then there is the replacement cost of the catalytic technology. I think the non-catalytic people have oversold that, because what they implied was that if you buy my stove you will never have to do anything to it and it will work forever. The big thing is that you don't have to replace the catalyst. And I would hope that the catalytic manufacturers, themselves, would be hearing what was said here and say, well we got to make our product better so that the replacement cycle is not as frequent. I don't know if that's even possible, but that would be my message to them.

1.4 *Is the use of manufactured fuel (densified and wax logs) a credible emission reduction strategy? See Tables 1 & 2 .*

Response: Yes, what you would get would be EPA appliances. I think that really that issue is kind of a bogus issue--well it's not a bogus issue, because that's the world we live in. But, I think what you are getting out of the wax fuels is a fuel release rate that more closely approaches that and, probably, exceeds it a little bit that of the fuel crib that we are using for EPA testing purposes. We know there are some problems with that, but if you approach that, then you should be clean. Whereas, cordwood tends to run the other way in terms of its air-to-fuel ratio.

1.5 *For non-catalytic stoves the heat retention adjustment with refractory material of various densities can reduce particulate emissions. How big an effect can this have?*

Response: Lots, but it's stove specific. Not even when you have a stove line, you have mama bear, papa bear, and baby bear, you can't make the assumption that by putting a different brick in baby bear it's going to have the same effect as in mama bear or papa bear--it doesn't work that way. There are some advantages to denser bricks. There are some advantages to lighter bricks. It's the mix you have to deal with, from a design point of view. I used to be a real fan of pumice bricks, but I have used them long term now, and they tend to degrade with time as you scoop the ash out and your banging cordwood in them and stuff. They just kind of tend to disintegrate and go away. I don't think anyone has ever talked about that. They are replaceable so the question then becomes, how many people actually do it? I don't know. That would be an interesting study; I think, to do an in-house maintenance check on 100 non-catalytic stoves, generic, and just see how many doors leak, how many baffles are right, etc.--just to see what happens. It would tell you a lot about what's really going on in the real world. That would be great information to feed back into a design situation, in terms of what's going on. And, the manufacturers get some of that through their warranty process--I'm sure.

1.6 *Approximately one half of the particulate emissions occur during the kindling phase for non-catalytic wood stoves and more than half for catalytic wood stoves. Are there improvements in technology that can mitigate this problem? Can specially designed high BTU wax logs be used to achieve a fast start and reduce kindling phase emissions?*

Response: Definitely. I don't know if it's as high as you think it might be. But, I've done some work where I have actually run tests, gases and temperatures, and I measured particulate emissions, using a Condar sampler, from kindling to the first warmup, second warmup, to the third warmup, which was essentially a temperature equilibrium situation at the end of a third warmup. And, this was just using 2 x 4's and watching what happens to emissions--and to no surprise, as the stove got hotter the thermal incineration tended to take over and the emissions went down. I found out that the kindling itself, the way you split it and how you lay it and the size of the kindling pieces themselves can make a huge difference in what happens in terms of emissions. That is something that we need to focus on. I don't know how we put that out. Perhaps something like a HPA thing where we do an informational video, do it in the lab, and then have people watch it; they could take it home. Make the videos available through HPA and they can use it in their store and they can show people how to build fires.

1.7 *Should masonry heaters with tight fitting doors and draft control be classified as a wood stove and be subject to some type of certification even though most weigh more than 800 kg?*

Response: I think that it should be subject to some type of certification, even though they weigh more then 800 kg. This brings me to the overall question. Eventually, the industry is going to have to come to the realization that we don't care from EPA's perspective. EPA should say, "We don't care what you build. We don't care what the burn rates are, as long as they are advertised appropriately. You can't misrepresent what you have, but build whatever you want as long as it burns clean." That creates some real opportunities, particularly for the people in the fireplace industry, to get away from this 5 kg/hr product that is a safety nightmare. I don't think anyone should be exempt, period.

1.8 *Are the emissions and efficiencies for masonry heaters, based on in-home tests, shown in Tables 1 and 2 reasonable?*

Response: I don't know. I have never done any work in that area.

1.9 *The OMNI staff feels the emissions per unit of heat delivered (e.g., lb/MBTU or g/MJ) is a more appropriate way to rank the performance of wood burning appliances than emission factors (lb/ton or g/kg) or emission rates (g/hr). — Comments?*

Response: I agree. The whole process of burning wood is useable heat. At least in my mind it is. These people that talk about aesthetic burning; that's fine, but why bother.

1.10 *Default efficiency values are used for wood stoves. This coupled with the fact that emission factors or rates (not g/MJ) are used to rank wood stoves does not provide an incentive for manufacturers to increase the efficiency of their stoves. — Comments? Should an efficiency test method as described (FR v. 55, n 161, p. 33925, Aug. 20,1990) be required to be used and the results listed?*

Response: True. Particularly for the 4 ½ g/hr stove population. How can they have increased the percent combustion efficiency and not the percent overall efficiency? I don't see how one could happen and not the other, if you know what I'm saying, the inescapable byproduct thereof. I am neutral about the use of an efficiency program.

1.11 *Have certified stove design and performance improved since the first certified stoves? If so, how?*

Response: Yes--and I think emissions have gone down; combustion efficiency and percent overall efficiency have gone up. And I think the other thing that has happened as a better byproduct of the warranty process is we have learned a lot about how to build stoves that can take care of, or handle, over a relatively long period of time, the durability thing. We are not there yet but we've come a long way. We are still learning as we go along. And that's true of everybody. It's true of people who are making plate steel stoves, for people who are making cast iron stoves, and there are a whole range of issues that each has had to deal with.

2. State-of-the-art of fireplace emission control technology.

2.1 *Are the emission factors and efficiencies for the in-home use of fireplaces and inserts shown in Tables 3 and 4 reasonable?*

Response Here again, I think the fireplace emission rate is low. I remember numbers that were slightly higher than what you guys show. When you show it on a kg/hr burn rate, or g/kg, that's somewhat deceiving, because if you have a fireplace where your burning 5 kg/hr of wood in the fireplace versus 2 or 3, it really changes the emission rate. And I think that fueling thing with fireplaces is kind of a hard one to grab hold of, because they vary so much in size and everything else. I don't see any reason to doubt the data, but my gut intuition tells me it's low.

2.2 *There appear to be only a few practical design or technology options for fireplaces that will potentially mitigate particulate emissions. — What designs and technologies are available? What retrofit options are there?*

Response: You bet. I think fireplace needs to be redefined. Looking ahead to where we have to go as an industry, fireplace is a definite category product. Masonry fireplaces are one thing, zero clearance fireplaces are another. The reason that I say it needs to be redefined is they need to have a very simple definition, so if they ever do set an emissions standard for it at a national level, we know exactly what it is that we're talking about as far as product. To me fireplaces are units where the burn rate is based upon the fueling rate; there's no air control in it.

2.3 *The use of wax fire logs reduces emissions over the use of cordwood. Can the formulation of wax logs be changed to produce even less emissions?*

Response: No comment.

2.4 *What are the distinctions between a masonry fireplace and a masonry heater?*

Response: I think the big thing there is the masonry heater has some sort of heat exchange, physical apparatus built into it, a longer smoke path, etc. Where fireplaces are, generally, up and through the throat and up the chimney and away she goes, with no thought to heat exchange. There's probably gray in there somewhere, but very little.

2.5 *As with wood stoves, the OMNI staff believe that the mass of emissions per unit of heat delivered is a better way to rank the performance of fireplaces than emission factors or emission rates.*

Response: I agree. To me what they should say is it's so many g/hr, at such and such an efficiency, which translates into so many g/MJ, or kW. Pick your number or your unit. I don't care what it is, but that would give an intelligent consumer the ability to understand all the numbers. Advertise whatever they want, as long as it is true numbers--none of this hokus pokus stuff.

3. State-of-the-art of wood-fired central heating furnace emission control technology.

3.1 *According to a Department of Energy survey out of the 20.4 million households that used a wood burning appliance in 1993, less than 0.3 million used a wood burning furnace as their primary source of heat. Are there enough wood-fired central heating furnaces in use to merit their closer evaluation? How many commercially available models are there? Are there emissions data for them? Should they be certified?*

Response: I don't think they should be exempt for any reason. As to the rest of it--are there emissions data for them? I suspect there are. Should they be certified? Yes they should be certified. Nobody should be exempt from the process.

4. State-of-the-art of pellet-fired wood stove technology.

4.1 *Are the emissions and efficiencies for the in-home use of pellet stoves shown in Tables 1 and 2 reasonable?*

Response: I think there is a difference for stoves just based upon their air-to-fuel ratio, whether they are an affected facility, certified product or a non-certified product--I think, breaking it into two groups would provide more accurate numbers.

4.2 *The 35:1 air-to-fuel ratio cut-off for certification has produced two classes of pellet stoves — those that are certified and those that are not. The latter class may have models that are less efficient and have higher emissions than the former. Should the regulations be amended to close the loop-hole and discourage the practice of intentionally designing models with a higher air-to-fuel ratio to avoid certification?*

Response: I agree, no more loop-holes. The new technology stoves that are coming on the market are going to be totally new critters. I don't think that turning down the air-to-fuel ratio, to make it whatever it is, should get you out of the loop. Some of those suckers have got to be just filthy. I mean you look at the flame. I've seen them burn at the trade show; you know, the glass is sooting up on the edges. You can just see it.

4.3 *Have pellet stove design and performance improved since the first models were introduced? If so, how?*

Response: I think technology has improved, is improving and will continue to improve. I think the efficiency thing drives it, because the cost of pellets is going up, and I think the warranty thing drives it, because nobody wants the headache of a pellet stove that doesn't work right.

5. Ramifications of ISO.

5.1 *The International Organization for Standardization (ISO) has a technical committee for developing emissions, efficiency and safety test standards for wood-fired residential heaters and fireplaces. (See Table 5 for comparison of the draft ISO method 13336 with EPA methods 28, 5G and 5H.) Do you feel that the EPA methods should be replaced with or be made comparable to an international standard?*

Response: I don't want to see it go to a calorimeter room. I think that's a horrendous mistake, in terms of cost and complexity. Should the EPA methods be replaced by, or made comparable to an international standard? I would hope so. That would give everyone a level playing field on which to compete in different markets. I would not object to that happening.

(Additional response submitted 12/01/98): I do want to add some additional comments to my response to question 5.1 on the ramifications of ISO 13336. When I originally responded, I had read the ISO standard but hadn't worked on any stoves that had passed it. Since then I have had the opportunity to work on three different units from two different manufacturers that had passed the ISO test. None of these units would come close to passing the EPA test without substantial modifications. However, I have been told by manufacturers (clients who have taken EPA certified stoves to Australia to be tested) that the EPA certified stoves have little or no trouble in passing the ISO test.

I have also been told that units can be taken to the test lab without any prior R&D testing and made (or helped) to pass the test by varying the air flow through the calorimeter room. I do not know of one EPA certified unit that made it through testing without substantial R&D testing prior to the trip to the lab for certification testing.

The units I worked on all had a forced air (fan driven) secondary air supply. You vary the fan speed with the burn rate setting, i.e., off for low, on high for high. Since there is no Fan Confirmation test, one has no idea if the unit will burn cleanly with the fan off, particularly on high. Furthermore, they are allowed to burn off 20% of the test fuel weight at the start of the test before they shut the unit down to the run setting. This results in minimum burn rates that are in our medium high category, which is much too fast of a "low burn" for a lot of the US market. And the fuel load does not have to be loaded parallel to the longer dimension of the firebox (e.g., if the box is 20" wide and 16" deep, you can load the test fuel parallel to the shorter dimension). This, in my opinion, runs counter to what would happen in the field, because very few people are going to spend the extra time to cut 16" fuel when they can cut 20" fuel and get it in the stove. Thus, the air flow would be wrong.

The one thing I do like about the ISO test is that it uses cord wood. However, since the test fuel is hardwood, there would probably be some changes in the combustion air supply ratios, amounts and distribution.

Having said all of that, I guess my major comment would be that we need to approach the adoption of the ISO standard very carefully and knowledgeably. It is not necessarily the panacea that we might think. But I do support the idea and effort that there should be one standard emission certification test used world wide. The same is true for overall efficiency.

6. Correspondence between in-home and laboratory emission test results.

6.1 *How accurately do certification tests predict in-home performance?*

Response: I think it's stove dependent. We always tend to compare in-home performance with the weighted average, which is really not an apples to apples comparison. We need to compare the in-home burn rate number with a sort of a weighted average or a comparable burn rate, based upon stove emissions in the lab.

6.2 *How would you design research testing in the laboratory to simulate in-home use?*

Response: Eventually we're going to have to open up the NSPS and deal with some substantive issues in it. And I think the two big ones that I see right now are: a.)

the fuel crib, and b.) the freely communicated stack in a warm enclosure. Those two are the major ones I think that upset the real world--make what we do in the lab less real world.

7. EPA Method 28 strengths and weaknesses.

7.1 *Method 28 is in part an "art". Fuel loading density, fuel moisture, fuel characteristics (old vs new growth, grain spacing, wood density) and coal bed conditioning can be adjusted within the specification range of the method to influence results. In your experience what things have the most effect on particulate emissions? How much influence can they have?*

Response: It's stove dependent and it's also burn rate dependent, on that same stove. And it is an art. It is a black art, unfortunately. I think while we may be able to eliminate some of that, I think the fact that wood is a non-uniform product that you are dealing with, and you have a wide range of variables that you are dealing with, so that that's always going to be there to some degree. I don't think you will ever be able to get rid of it. I think you can eliminate some of it, but never totally get rid of it.

7.2 *Burn rate weighting is based on very limited data and the cities from where the data were obtained are not very representative of wood use nationwide (see Table 6). How can the weighting scheme be improved to be more representative of the nation as a whole?*

Response: Here, I think some more data would be helpful. I would think that we would need to be population weighted. By that I mean, if you base everything upon Montana and North Dakota, where nobody lives, versus the I-5 corridor, where a lot of people live, I think you would be producing stoves that would be great for 1% of the population and not so good for the rest of the world. I think you need to look where the people live. Not only does it need to be a heat demand thing, but it needs to be population density weighted too. The East Coast is much more populated then the West, particularly the Great Plains, Northern Mid-West versus the Southern States. It needs to be looked at, but it needs to be addressed intelligently. That would be the only way to do it. That would just take some design work up front, and then you could do it. A lot of that information, I'm sure, is available. To me this is a number crunching exercise. You've got a lot of information and you put it into the computer and you come up with whatever it is you are looking for. The input will, of course, determine the output.

7.3 *The equation for the calculation of the air-to-fuel ratio as in Method 28A is in error.*

The error produces a small but significant difference in the calculated air-to-fuel ratio. Should the method be corrected or should it be left as a "predictor" of the air-to-fuel ratio?

Response: That should be corrected. Nothing should be left uncorrected. If you know something is wrong, then it should be fixed. To me that is a given in life.

7.4 *The assumed mole fraction of hydrocarbons (Y_{HC}) is defined as a constant in the air-to-fuel ratio calculations in Method 28A. The mole fraction of hydrocarbons in the vapor phase will vary significantly with fuel and combustion conditions. Should hydrocarbon vapors (more appropriately, organic compound vapors) be measured as part of the method?*

Response: Yes, yes. I don't know where EPA came up with the numbering in the first place, but I don't think it would be that difficult to do some work on some 4.5 gram stoves and figure out what the correct HC mole faction of EPA stoves really is. Do the same for the 7 ½ gram stoves and then use it accordingly, and I think you're going to find it's going to be burn rate specific. If you are under 1 kg/hr you're going to have this, at 1.25 to 1.9 you are going to have that. I don't think there is a number that you could apply as an average to each burn rate, because the HC fraction is dependent upon the emission rate. Just look at emissions and M5H back half catches. I think that it's that burn rate and emission specific. I suppose we could use FID's, but that would be tough--I would not want to do it.

8. EPA Methods 5G and 5H correlations.

8.1 *The comparison data to demonstrate the correlation between 5G and 5H are limited. Should the correlation between the two methods be reevaluated?*

Response: Yes.

8.2 *It is the general perception that method 5H produces lower numbers than 5G. Method 5G is less costly and more precise than 5H. — Comments? — Should there be just one sampling method?*

Response: Yes, that would be fine if it was excepted internationally. I think we have to talk about the room setup and all of that, the full picture of what we're proposing to do before we decide upon what to do. I think one of the things about 5H, it's a tougher method to run. We know there's an error in the hydrocarbon thing, if that were corrected the error might go away. That might take care of itself, because from a laboratory point of view, everyone would automatically go to 5G. But, 5H is more appropriate for other reasons.

8.3 *The same points regarding flow rate calculations (air-to-fuel ratio) and hydrocarbons as made for Method 28A are applicable to Method 5H. — Comments?*

Response: It should be corrected

8.4 *The precision of EPA's Method 5 is estimated as being about 20%. Almost one quarter of the 214 stoves listed as certified by the EPA as of 8/12/97 are within 20% of their respective (catalytic or non-catalytic) emission limits. — Comments?*

Response: How many of those stoves that are within 20% are product lines that are still being made? A lot of people have products on the list, but they aren't making them anymore.

8.5 *Based on practical experience with the 5G and 5H, how can they be improved?*

Response: There's a ton of stuff that could be done there. EPA, they could take anything and make it hard to do. How, what and why they do that is beyond me, but some of the stuff that they require, calibration and documentation, are utterly and totally nonsense. That's the kind of requirements that should be ejected. Focus on what really counts.

9. Performance deterioration of EPA-certified wood stoves in the field.

9.1 *It is the opinion of many in the wood stove industry that catalysts last only five years and that a stove designed for a catalyst operated without a functioning catalyst can produce as much emissions as a conventional stove. — Comments?*

Response: I think that's true. Since most catalytic stoves were designed to be "creosote " cookers, which was what the old conventional air tight stove was. I would say they are probably just as bad when the catalytic combustor doesn't work.

9.2 *Field studies in Glens Falls, NY, Medford, OR, Klamath Falls, OR and Crested Butte, CO showed that emissions from some catalytic stoves became appreciably worse even after two to three years of use. Inspection of stoves in Glens Falls showed that catalyst deterioration and leaky bypass systems were responsible. Have improvements been made* *in the design of catalytic stoves to minimize these problems? Is it reasonable to require homeowner training on the proper use of catalytic stoves and/or to incorporate into their costs an inspection and catalyst replacement program?*

Response: I would say there were designs available that did not seem to have a problem and those designs still around today. I think the same is true for non-catalytics. I don't see any reason to exempt non-catalytics from inspection and maintenance, or make it any less rigorous for them. You just have to look at different things. Baffle warping, leaking air wash. The air wash gap is critical. Anything that moves through the use of improper steel or welding or whatever. All bets are off, emissions wise and I've been through that personally.

Question: *Let's see; is it reasonable to require homeowner training?*

Response: I don't see any reason why that shouldn't happen. I guess my question would be to the dealers, I hope they are doing it. When you are selling stoves to some place like Home Depot and you get a sales guy back there who knows anything about a wood stove, you're lucky. I don't know how to go about reaching those people who, other than, it's part of their operating permit they have to go to a two hour night class where people talk to them about how to run a stove properly. If the dealer could do it through the inspection and maintenance program, so much the better. We should try to keep the government out, if we can, and have the industry guys do it.

Question: *What about incorporating the costs of an inspection and catalyst replacement program?*

Response: I don't have a problem with that. I would think that could be left to the local people. I wouldn't have a problem with it as long as it was across the board, played off fairly. I think that people should try it — fiddling around with that and see what happens from an airshed to airshed point of view, in terms of improvement and find out what works. I think that is one distinct possibility.

10. Stress test pros and cons.

10.1 *A short-term laboratory woodstove durability testing protocol was developed to predict the long-term durability of stoves under conditions characteristic of in-home use (see EPA-600/R-94-193). It was concluded in that study that damage occurs during those occasional times when a woodstove is operated in the home at exceptionally high temperatures. The laboratory stress test was designed to operate a woodstove at very high temperatures over a one to two week period to predict long-term durability under in-home use. Is this a reasonable approach?*

Response: I think there are two kinds of stress. I want to call them acute and chronic. What acute is is what you'd get with what the late Skip Burnett (EPA-600/R-94-193) did. Chronic is more what happens to a stove, due to a large number of cycles of warming up and cooling off, warming up, cooling off that happens during normal operation. I think you'll get some of the chronic effects with an acute kind of a test, but I think it maybe overkill in some instances and it may not even come close to documenting what really happens in the real world. How you'd balance that out is tough.

When we have stoves come through our lab, if we see anything that might be a potential durability problem for that particular stove and that manufacturer, we start talking to them about it right up front right then. In the way we run our R and D program with my clients, is that hopefully, by the time we are through developing a stove, that stove has been cycled enough times that if there is something blatantly obvious that would show up, like in the kind of work that Skip Burnett was doing, we've kind of gotten through that. What we do everyday is we run the stove up to, basically, maximum heat storage and then we start our test from that. We've got a warmup period that is anywhere from 3 to 4 hours a day that's wide open. Then we shut down and cool it off. Well, if you cycle a stove like that (to do an R&D project on a wood stove is probably a minimum of 90 days, more like 6 months, if you want to know the truth), you've really put that stove through its hoops.

So to make a stress test part of the certification process, you'd have to convince me that that kind of a development process was not sorting things out, as far as durability is concerned. We know for a fact that one thing or another, can or cannot happen, and once the manufacturers are well aware of those issues and they don't want to get into a certification series and suddenly find that their air wash gap has changed because of one thing or another, or so it goes. In some ways I would like to see some good 4.5 gram stoves, non-catalytic stoves be put into the field and monitored in the same way that the early stove studies where done. And do it for a number of years.

10.2 *Should a stress test be made part of the certification process?*

Response: Only if you could demonstrate through the field studies that we haven't got our basics covered. If you took some brand new stoves out into the field that were current products, 4.5 grams or better, and looked at what they did. Cast iron stoves should be included in that field study to see if they, because of the nature of cast, do better or worse. My gut reaction is they should do better.

11. Feasibility of developing separate emission factors for dry and wet wood and for softwood and hardwood species classes.

11.1 *Optimum wood moisture for low particulate emissions seems to be in the 18% to 20% range. Are you aware of any data that will allow the impact of wood moisture to be isolated from other variables? Could it be different for wood from different tree species?*

Response: Given the EPA thing, when most of our fuel loads are somewhere between 17 and 18%, that's just where we tend to be. Can it be isolated from other variables? That be a tough one. I think you could do it, but it would take repeated tests, because I don't know how you would dial out barometric pressure. And we all know that can have a tremendous impact. Could it be different for wood from different species? You bet it would. Pine has a totally different emission profile than fir, larch or oak. Having said that, how do we deal with it? I haven't got an answer for that.

11.2 *Wood from different tree species clearly burns differently. The chemical make-up and density of wood from different tree species is different. For example wood from coniferous trees has more resin than wood from deciduous trees. It is believed that particulate emission factors will be different for wood from different tree species. If this is true different parts of the country may have different emissions factors for residential wood combustion. Are you aware of any data that document different emission factors for wood from different tree species?*

Response: Yes, I don't know of any data, other then some work that EPA's Robert C. McCrillis did, that would document emission factors from different tree species.

12. Routine maintenance.

12.1 *Would routine maintenance of stoves once they were in a home reduce particulate emissions? Would this be more relevant for catalytic stoves than non-catalytic stoves? Would this be relevant for pellet stoves with electronic and moving parts?*

Response: I think it would and I don't think it's more relevant for either stove type; I think it's across the board. Catalysts probably have the most potential for having emissions sky rocket particularly, if the catalyst doesn't work; non-catalyst stoves, if something happens if the door leaks. If you upset the airflow inside a non-catalytic stove by very much, things go downhill very quickly. I think pellet stoves should be kicked in there too.

12.2 *Should the home owner be provided with a maintenance manual or a training course at the time of purchase? Should a maintenance program be part of the purchase price particularly for catalytic stoves?*

Response: Yes, I think here the stove stores should really, as part of the sale for sure, you take them over and say hey got a few things that I'd like to show you about how to make this stove really work. It's part of the sales pitch. I think it needs to be done, I'd like to see the local stove shops do it. If they give tickets out for smoky stoves that might be part of the penalty to get your ticket fixed you have to have someone come out and go through your stove to make sure something isn't wrong with it and be told and shown how to run it properly.

12.3 *What would the key elements of routine maintenance be?*

Response: Bypass gap, outside air kits installed properly, air wash gap, window glass seal, ash door seal, secondary combustion stoves that have tubes (or any other way of doing it), secondary system mounting system is intact, good baffle, no warpage, insulation, no wear, bricks are all there, baffle is not scaled. The list goes on & on.

As for the rest of the testing issue, I see the need to do a high, low and perhaps a mid range run on each stove being tested. Problems always seem to occur at the margins, rather than in the middle. At the same time, I would eliminate all reciprocal certifications and the fan confirmation test. If a stove has a fan as an option, then you would do a high & low with the fan on and with the fan off. A fireplace insert would be treated the same way as would the change from a leg to a pedestal model.

Michael Van Buren - Technical Director, Hearth Products Association

1. State-of-the-art of wood stove combustion and emission control technologies.

1.1 *Are in-home emission reductions as compared to conventional stoves shown in Table 1 for catalytic and non-catalytic certified stoves reasonable?*

Response: There are differences in catalytic and non-catalytic stoves. The conventional stove is probably low; the pounds per gram or pounds per ton were probably a lot higher then that. You can see dramatic reductions using densified logs in EPA certified appliances in the field.

1.2 *Are efficiencies shown in Table 2 for catalytic and non-catalytic certified stoves reasonable?*

Response: I think that there is a variation from stove to stove. That is a hard number to give, since there hasn't been a lot of efficiency testing. What would you put down here for a conventional fireplace? I think what we will see in the future is more outdoor air being used and less indoor air, and how that would affect the efficiency of the product.

1.3 *Can catalytic technology for use in wood stoves be fundamentally improved?*

Response: I would imagine that there are a lot of things that can be done, but a lot of those things fall outside the realm of the EPA standards (i.e., natural and propane gas secondary combustion). The increased use of electronic control and larger catalysts could help, but all of these would also impact the cost of the stove.

1.4 *Is the use of manufactured fuel (densified and wax logs) a credible emission reduction strategy? See Tables 1 & 2 .*

Response: I think it is especially for the fireplaces. I think that it is something that has been overlooked in a lot of areas, particularly Phoenix. I don't think it was looked at as an option, or it wasn't conveyed as clearly as it could have been. More testing needs to be done to prove this.

1.5 *For non-catalytic stoves the heat retention adjustment with refractory material of various* *densities can reduce particulate emissions. How big an effect can this have?*

Response: It does make a difference. How much of a difference, as far as better emission values, varies from stove to stove. I have limited experience with this at Hearthstone, we did do some work on a side loading door. Small modifications to a stove can have a major effect on emissions. Modifying the geometry of the stove, such as changes in the baffle or the baffle angle, can make a difference in emissions. Just changing the baffle insulation can affect emissions.

1.6 *Approximately one half of the particulate emissions occur during the kindling phase for non-catalytic wood stoves and more than half for catalytic wood stoves. Are there improvements in technology that can mitigate this problem? Can specially designed high BTU wax logs be used to achieve a fast start and reduce kindling phase emissions?*

Response: I'm sure using some type of fire starter would reduce emissions. Anything that touches off at a lower temperature is going to help. I think the two things that we run up against there is that's basically a usage strategy of the homeowner, and how do you control that? From a regulatory viewpoint, is using a wax fire starter considered a dual fuel action? It's a petroleum base product. Would EPA accept that under the present regulations? If they accept that, what other dual fuel options would they accept? And then whenever we start talking about electronic controls, we have to think about the actual market environment out there and purchasing stoves and what it does to the price of the stove.

1.7 *Should masonry heaters with tight fitting doors and draft control be classified as a wood stove and be subject to some type of certification even though most weigh more than 800 kg?*

Response: I don't think they should be classified as wood stoves, because of their usage. I think they could be potentially tested to some certification. The other thing is to look at how many of them are being sold and is it worth it? The answer may be no, because it's not a large volume product. I think there needs to be some proof of those usage patterns.

1.8 *Are the emissions and efficiencies for masonry heaters, based on in-home tests, shown in Tables 1 and 2 reasonable?*

Response: No comment.

1.9 *The OMNI staff feels the emissions per unit of heat delivered (e.g., lb/MBTU or g/MJ) is a more appropriate way to rank the performance of wood burning appliances than emission factors (lb/ton or g/kg) or emission rates (g/hr). — Comments?*

Response: You are now rating efficiencies and emissions. The question then becomes: should there be some type of control on a woodstove that's sensitive to room temperature? More work needs to be done on efficiency testing of wood burning appliances.

1.10 *Default efficiency values are used for wood stoves. This coupled with the fact that emission factors or rates (not g/MJ) are used to rank wood stoves does not provide an incentive for manufacturers to increase the efficiency of their stoves. — Comments? Should an efficiency test method as described (FR v. 55, n 161, p. 33925, Aug. 20,1990) be required to be used and the results listed?*

Response: Manufacturers have an incentive to build stoves that have good combustion efficiency through the EPA emission standard. Lowering emissions requires raising the combustion efficiency. Thermal (sometimes referred to as heat transfer) efficiency should go hand-in-hand with combustion efficiency. An accurate method for measuring overall efficiency (combustion x thermal) needs to be developed before implementing an efficiency standard.

1.11 *Have certified stove design and performance improved since the first certified stoves? If so, how?*

Response: Without a doubt, the certified stoves have improved dramatically. All you have to do is look at the emissions that are coming out of the stove now. Almost all the stoves on the market meet the Washington standard versus the EPA standard, as far as I know. And I think the durability of the stoves has improved. The warranty times are longer. It used to be a one year warranty on products, now it's three or five years, and that is a very good example of how they have improved.

2. State-of-the-art of fireplace emission control technology.

2.1 *Are the emission factors and efficiencies for the in-home use of fireplaces and inserts shown in Tables 3 and 4 reasonable?*

Response: No comment.

2.2 *There appear to be only a few practical design or technology options for fireplaces that will potentially mitigate particulate emissions. — What designs and technologies are available? What retrofit options are there?*

Response: I think this comes down to a financial issue and what the market will pay for, but I have seen electric afterburners that can go on fireplaces to lower emissions. I've seen designs that lower emissions, some type of secondary combustion through the same method as is used in non-catalytic stoves. I think there are plenty of things that can be done to lower emissions, secondary air in stoves; glass doors certainly help. It's just a matter of what is financially feasible on the market.

2.3 *The use of wax fire logs reduces emissions over the use of cordwood. Can the formulation of wax logs be changed to produce even less emissions?*

Response: I understand that wood wax logs produce less emissions than cordwood. I am not sure what can be done to further reduce emissions from today's wood wax logs. The other thing to mention here is that the material used to manufacture all-wood logs is generally cleaner than ordinary cordwood, so it burns cleaner and that can lower emissions.

2.4 *What are the distinctions between a masonry fireplace and a masonry heater?*

Response: Masonry heaters have a method of storing heat. They have longer passages. Some have downflow in them to give the flue gas a longer path before it actually exits, so you have a mass inside the home that can be heated. A masonry fireplace does not have these features.

2.5 *As with wood stoves, the OMNI staff believe that the mass of emissions per unit of heat delivered is a better way to rank the performance of fireplaces than emission factors or emission rates.*

Response: Given the study that was mentioned, 7% of the fireplaces are used as a primary source of heat in a limited area, I don't know if g/MJ is a reasonable way of measuring the emissions. I think maybe g/kg is a better way of doing it for a fireplace, because the usage is completely different than a wood stove. I think there is a distinct difference between fireplaces and wood stoves and their reasons for being used. I think their testing methods should be completely different. They are not used probably 99% of the time as a source of heat; they are used for aesthetic purposes. And therefore they should be tested accordingly, in g/kg.

3. State-of-the-art of wood-fired central heating furnace emission control technology.

3.1 *According to a Department of Energy survey out of the 20.4 million households that used a wood burning appliance in 1993, less than 0.3 million used a wood burning furnace as their primary source of heat. Are there enough wood-fired central heating furnaces in use to merit their closer evaluation? How many commercially available models are there? Are there emissions data for them? Should they be certified?*

Response: I think there are a lot of products that fall into that category, including probably masonry heaters. How many are being used, and is it worth regulating a small number across the country? I think there is good reason to have some testing. I don't think they should fall under the same test standard as a wood stove, because the way they operate and the way they are used are completely different. I think there are under 10 different manufacturers and there are probably less then that, and they probably have one or two models each being a different size. There is one pellet burner; that's all I know of at this point. I think there should be some type of testing on them.

4. State-of-the-art of pellet-fired wood stove technology.

4.1 *Are the emissions and efficiencies for the in-home use of pellet stoves shown in Tables 1 and 2 reasonable?*

Response: I'd say they are probably pretty reasonable, as an average. I think the question that comes up is, what stoves are above 35:1 air-to-fuel ratio? What do they emit versus a cleaner one?

4.2 *The 35:1 air-to-fuel ratio cut-off for certification has produced two classes of pellet stoves — those that are certified and those that are not. The latter class may have models that are less efficient and have higher emissions than the former. Should the regulations be amended to close the loop-hole and discourage the practice of intentionally designing models with a higher air-to-fuel ratio to avoid certification*?

Response: I don't know what that loop-hole does, whether it really affects the operation of the stove and the efficiency of the stove.

4.3 *Have pellet stove design and performance improved since the first models were introduced? If so, how?*

Response: Absolutely. I think some of the stoves on the market have improved dramatically, since the first stoves. Just in reliability, pellet stoves are much more reliable today compared to 10 years ago. The basic materials used, the equipment used within the stoves have improved. Some now use microprocessors to control them.

5. Ramifications of ISO.

5.1 *The International Organization for Standardization (ISO) has a technical committee for developing emissions, efficiency and safety test standards for wood-fired residential heaters and fireplaces. (See Table 5 for comparison of the draft ISO method 13336 with EPA methods 28, 5G and 5H.) Do you feel that the EPA methods should be replaced with or be made comparable to an international standard?*

Response: I don't feel that the EPA method should be replaced with the ISO standard. I do, however, feel that the United States has to become involved in that ISO standard, if it starts to gain any strength. But I don't see the ISO standard having any effect on us at the present time. I don't think it's refined enough. If we get involved, then we could help shape it. If we wait, what's going to happen is we're going to get something imposed on us by the ISO that we don't like, and I think that is a bad alternative.

6. Correspondence between in-home and laboratory emission test results.

6.1 *How accurately do certification tests predict in-home performance?*

Response: I have not seen any information that shows anything between the two, so I can only speculate. I hope there is some correlation between a clean burning stove in the lab and a cleaner burning stove in the field. Are the numbers going to be close to the same? Absolutely not. There should be no assumption along those lines. But is the cleanest burning tested stove going to be the cleanest burning stove in the field?

6.2 *How would you design research testing in the laboratory to simulate in-home use?*

Response: I would get away from using dimensional lumber. I would try to use more of a cord wood and I would give more flexibility as to how the operator can work with the stove.

7. EPA Method 28 strengths and weaknesses.

7.1 *Method 28 is in part an "art". Fuel loading density, fuel moisture, fuel characteristics* *(old vs new growth, grain spacing, wood density) and coal bed conditioning can be adjusted within the specification range of the method to influence results. In your experience what things have the most effect on particulate emissions? How much influence can they have?*

Response: There are a lot of things that affect emissions. And the first thing we come to is the low burn rate, and getting the stove to start up quickly, get flaming quickly and then once you get it burning that it doesn't burn too fast. Moisture content has a big effect, picking the wood, where you put it. It is an "art", and lots of different people will give you lots of different answers.

7.2 *Burn rate weighting is based on very limited data and the cities from where the data were obtained are not very representative of wood use nationwide (see Table 6). How can the weighting scheme be improved to be more representative of the nation as a whole?*

Response: I think that the weighting just continues the art of having the stove pass. Where your burn rates come in and do you make another run to try to get rid of that burn rate and what's the weighting factor, is what makes it more of an art than a science.

7.3 *The equation for the calculation of the air-to-fuel ratio as in Method 28A is in error. The error produces a small but significant difference in the calculated air-to-fuel ratio. Should the method be corrected or should it be left as a "predictor" of the air-to-fuel ratio?*

Response: No comment.

7.4 *The assumed mole fraction of hydrocarbons (Y_{HC}) is defined as a constant in the air-to-fuel ratio calculations in Method 28A. The mole fraction of hydrocarbons in the vapor phase will vary significantly with fuel and combustion conditions. Should hydrocarbon vapors (more appropriately, organic compound vapors) be measured as part of the method?*

Response: No comment.

8. EPA Methods 5G and 5H correlations.

8.1 *The comparison data to demonstrate the correlation between 5G and 5H are limited. Should the correlation between the two methods be reevaluated?*

Response: You can't look at just 5H and 5G; you have to look at its entirety. Should you really have two methods?

8.2 *It is the general perception that method 5H produces lower numbers than 5G. Method 5G is less costly and more precise than 5H. — Comments? — Should there be just one sampling method?*

Response: Having a single method makes sense.

8.3 *The same points regarding flow rate calculations (air-to-fuel ratio) and hydrocarbons as made for Method 28A are applicable to Method 5H. — Comments?*

Response: No comment.

8.4 *The precision of EPA's Method 5 is estimated as being about 20%. Almost one quarter of the 214 stoves listed as certified by the EPA as of 8/12/97 are within 20% of their respective (catalytic or noncatalytic) emission limits. — Comments?*

Response: I have looked at the list of 214 stoves and a lot of those stoves I did not recognize, and I don't know how many of those are still on the market. What are the factors that EPA built into the original test method to take that 20% into account?

8.5 *Based on practical experience with the 5G and 5H, how can they be improved?*

Response: Any way of taking it out of an art in order to make it a science would help.

9. Performance deterioration of EPA-certified wood stoves in the field.

9.1 *It is the opinion of many in the wood stove industry that catalysts last only five years and that a stove designed for a catalyst operated without a functioning catalyst can produce as much emissions as a conventional stove. — Comments?*

Response: Catalytic stoves need regular maintenance; are the operators keeping track of how the catalytic is performing and are they checking the stove properly?

9.2 *Field studies in Glens Falls, NY, Medford, OR, Klamath Falls, OR and Crested Butte, CO showed that emissions from some catalytic stoves became appreciably worse even* *after two to three years of use. Inspection of stoves in Glens Falls showed that catalyst deterioration and leaky bypass systems were responsible. Have improvements been made in the design of catalytic stoves to minimize these problems? Is it reasonable to require homeowner training on the proper use of catalytic stoves and/or to incorporate into their costs an inspection and catalyst replacement program?*

Response: Stoves have become more user friendly; they are easier to use. They are now vertical instead of horizontal, so the ashes fall out. It is unreasonable to require training. There should be instructions, but not attached to the stove.

10. Stress test pros and cons.

10.1 *A short-term laboratory woodstove durability testing protocol was developed to predict the long-term durability of stoves under conditions characteristic of in-home use (see EPA-600/R-94-193). It was concluded in that study that damage occurs during those occasional times when a woodstove is operated in the home at exceptionally high temperatures. The laboratory stress test was designed to operate a woodstove at very high temperatures over a one to two week period to predict long-term durability under in-home use. Is this a reasonable approach?*

Response: No.

10.2 *Should a stress test be made part of the certification process?*

Response: No.

11. Feasibility of developing separate emission factors for dry and wet wood and for softwood and hardwood species classes.

11.1 *Optimum wood moisture for low particulate emissions seems to be in the 18% to 20% range. Are you aware of any data that will allow the impact of wood moisture to be isolated from other variables? Could it be different for wood from different tree species?*

Response: ISO doesn't take into effect the species of the tree. I don't know

11.2 *Wood from different tree species clearly burns differently. The chemical make-up and density of wood from different tree species is different. For example wood from coniferous trees has more resin than wood from deciduous trees. It is believed that particulate emission factors will be different for wood from different tree species. If this* *is true different parts of the country may have different emissions factors for residential wood combustion. Are you aware of any data that document different emission factors for wood from different tree species?*

Response: I don't know of any data available.

12. Routine maintenance.

12.1 *Would routine maintenance of stoves once they were in a home reduce particulate emissions? Would this be more relevant for catalytic stoves than non-catalytic stoves? Would this be relevant for pellet stoves with electronic and moving parts?*

Response: Regular maintenance should be done, especially when there are moving parts.

12.2 *Should the home owner be provided with a maintenance manual or a training course at the time of purchase? Should a maintenance program be part of the purchase price particularly for catalytic stoves?*

Response: An owner's manual should be provided. No training should be required unless this same training was also required for gas and oil products, such as water heaters, furnaces, boilers. Everything needs regular maintenance.

12.3 *What would the key elements of routine maintenance be?*

Response: It should be looked at once a year to see if cleaning or maintenance needs to be done. The flue should also be cleaned.

Other unsolicited comments not in response to prepared questions:

1.) People [government regulators] who review the reports should be able to qualitatively assess them: does this make sense?
2.) They need to enforce the regulation to ensure that all players continue to abide by the rules.
3.) They need to welcome new technology and be willing to allow for changes in the methods as long as the results show that the product burns cleanly. Forcing everybody into the square or rectangular firebox fuel load configuration may eliminate some very viable technologies. In short, the NSPS should be technology enhancing rather than technology limiting. Right now EPA is preventing some very viable technologies from being developed.

Appendix C

Solid Fuel Committee of the Hearth Products Association (HPA) Comments on Review Topics

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Attendees to Solid Fuel Technical Committee Meeting

- Dan Henry, Vice President, Aladdin Steel Products
- Bill Sendelback, President & CEO, Breckwell
- David Johnson, DSJ Technical Services
- Prasad Deshmukh, Electronic Engineer, Duraflame
- Thao Huynh, Chemist One, Duraflame
- Paul Lynch, New Business Dev. Manager, Duraflame
- Lohit Tutupalli, Research Scientist, Duraflame
- Dennis Jaasma, President, EECI
- Jim Kovacs, Mgr. Engineering R & D, FPI
- Ken Maitland, Director of Engineering, FMI
- Walter Moberg, President, Firespaces
- John Crouch, Director of Government Relations, HPA
- Michael Van Buren, Technical Director, HPA
- Denny Kingery, Product Engineer, Heatilator
- Wayne Terpstra, Vice President of Technical Services, Heatilator
- Rick Curkeet, Chief Engineer, Intertek Testing Services
- Ben Myren, President, Myren Consulting
- James E. Houck, Vice President, OMNI
- David McClure, Vice President, OMNI
- Paul Tiegs, President, OMNI
- John Francisty, R &D Manager, Pacific Energy
- Jerry Whitfield, President, Pyro Industries
- Eric Dufour, Director of R & D, Security Chimneys
- Tim French, Mgr. of Eng. Wood Products & Drafting, Superior Fireplace
- Steven Plass, Product Manager, Superior Fireplace
- Erkki Jarvinen, Technical Director, Tulikivi
- Bill Bradberry, President of Sales, Vestal Mfg.

Hearth Products Association Solid Fuel Technical Committee Meeting
Friday January 9, 1998

Review of questions from OMNI Laboratories
Residential Wood Combustion Technology Review
EPA Purchase Order no. 7C-R285-NASX

1. State-of-the-art of woodstove combustion and emission control technologies.

1. l Are in-home emission reductions as compared to conventional stoves shown in Table 1 for catalytic and non-catalytic certified stoves reasonable?

Dr. Houck explained that the values in Table 1 are from in-situ studies, they are not laboratory test results. Dr. Houck reviewed data taken from the mid 1980's through 1996.

Dr. Houck explained that some of these numbers are best guess. The greatest uncertainty is with the conventional stoves - this data is optimistic. Rick Curkeet thought the emissions for conventional stoves are actually much worse. There was a question of how many of the convention stoves used in-situ had been developed to meet the Oregon standard. This would imply that the conventional stoves used for in-situ studies had improved emissions compared to those stoves that did not meet the Oregon standard.

The EPA data is based on 30 conventional stoves. A vote was taken in the room as to whether 18.5 g/kg was too low, the consensus was that it was too low. Rick Curkeet suggested that a range of 20-200 g/kg be used. Everyone agreed. Dr. Houck told the group that EPA wanted a specific number. All attendees agreed that there was not just one specific number. The comparison was made of fuel economy with different vehicles. It would depend on the vehicle and how it was driven.

Dan Henry mentioned that he had seen some EPA approved appliances tested with densified fuels that had very low emissions, below 1 g/hr and that should be reflected in this table.

1.2 Are efficiencies shown in Table 2 for catalytic and non-catalytic certified stoves reasonable?

Rick Curkeet stated that the efficiencies of conventional stoves range from 20 to 50% efficient. The efficiencies for non-catalytic stoves go by EPA default efficiencies, which takes away the motivation to improve the efficiencies of non-catalytic stoves. There are two different types of non-catalytics, those that pass Washington State standards and those that do not.

Conventional, catalytic and non-catalytic stoves go by default numbers for efficiencies, whereas pellet, masonry and densified fuel are calculated. 68% efficiency is more accurate than 63% for non-catalytic stoves. The default efficiency for pellet stoves is 78%.

The group agreed that single numbers are misleading; a range of efficiencies should be used for each type of stove. Erkki, from Tulikivi questioned the efficiencies of the masonry heaters; use patterns have to be considered.

There were concems on the efficiencies given to conventional stoves however, it is difficult to prove or disprove this number without additional in-situ data.

1.3 Can catalyst technology for use in woodstoves be fundamentally improved?

Yes, microprocessors could be added to stoves to monitor and control the stove, preheating of the catalyst could be done with propane or electric resistance heat. However, EPA's current standards are design restrictive and do not allow these types of improvements. In addition, catalytic stoves have lost their market share over the last four years, in part due to their initial cost. Any modification to the stove that would drive up the cost of the stoves would probably end sales of these stoves altogether.

1.4 Is the use of manufactured fuel (densified and wax logs) a credible emission reduction strategy? See Tables 1 & 2.

The committee does not look at this as an emission reduction strategy, but rather as a technological possibility. Yes, manufactured logs are an option for cleaning up woodstove emissions, both conventional and EPA approved. Whether or not they are a credible strategy would depend on the EPA State Implementation Plan.

1.5 For non-catalytic stoves the heat retention adjustment with refractory material of various densities can reduce particulate emissions. How big an effect can this have?

Refractory materials and the type chosen can make a difference with light off in the first five minutes of a test burn. This can make the difference between a 5g/hr run and a 25g/hr run. This is fundamental, but very stove specific. There are other design characteristics that also make just as much of a difference. These types of "tricks" to make a stove perform better in an EPA emissions test may or may not make a difference on how stoves perform in the field. No one at the meeting had seen conclusive data to prove or disprove this correlation. There was general agreement that for some stoves, this can have a very large effect, both in the lab and in the field.

1.6 Approximately one half of the particulate emissions occur during the kindling phase for non-catalytic woodstoves and more than half for catalytic woodstoves. Are there improvements in technology that can mitigate this problem? Can specially designed high BTU wax logs be used to achieve a fast start and reduce kindling phase emissions?

Dan Henry told the group how EPA and Aladdin Steel were working on a system with very stable secondary combustion. The system used a gas pilot light. Dan wanted to certify the stove using the pilot light. At first EPA approved this and later revoked it stating the appliance had to be tested without the pilot light running because this would be considered a dual fuel. The system was considered dual fuel and therefore could not be certified. An in-situ study was done in Spokane and Dennis Jaasma was going to perform an in-situ study in Virginia prior to EPA revoking this concept.

There have been similar other products. Ben Myren told of a product that used an electric combustion enhancement and emissions reduction technology that also was rejected by EPA.

High Btu wax logs can be used to achieve a fast start and therefore lower emissions of woodstoves, however EPA would probably consider this a dual fuel system.

> *1.7 Should masonry heaters with tight fitting doors and draft control be classified as a wood stove and be subject to some type of certification even though most weigh more than 800 kg?*

Walter Moberg stated there are advantages for masonry heaters to be listed and tested to EPA standards, however the industry suffers because there is no fair way to do this at the present time under the existing standard. Erkki stated that those masonry heaters that are not built on site should have some type of certification, but masonry heaters should not be tested the same way a woodstove is tested. There was agreement that masonry heaters need to be certified, but not as woodstoves, but rather to their own masonry heater standard.

> *1.8 Are the emissions and efficiencies for masonry heaters, based on in- home tests, shown in Tables 1 and 2 reasonable?*

The thought was these numbers given are generally fair values, although efficiencies are difficult to measure.

> *1.9 The OMNI staff feels the emissions per unit of heat delivered (e.g., lb/MBTU or g/MJ) is a more appropriate way to rank the performance of wood burning appliances than emission factors (lb/ton or g/kg) or emission rates (g/hr). Comments?*

Dan Henry brought up the point that to go from g/hr to g/kg would mean re-educating the public and the state and local regulators. Historically, the industry initially wanted g/kg but the environmental community wanted g/hr. Neither g/hr nor g/kg motivates manufacturers to increase efficiencies.

> *1.10 Default efficiency values are used for woodstoves. This, coupled with the fact that emission factors or rates (not g/MJ) are used to rank woodstoves, does not provide an*

incentive for manufacturers to increase the efficiency of their stoves. -Comments? Should the efficiency test method as described (FR v. 55, n 1611 p. 33925, Aug. 20,1990) be required to be used and the results listed?

Rick Curkeet commented that almost all EPA approved stoves have higher efficiencies than the EPA default efficiency. Grams/hr and efficiency are two separate parts of the equation. If woodstove manufacturers also were required to test for efficiency, this would drive up the cost of testing stoves.

Grams/MJ vs. g/hr - g/hr makes an appliance that stores heat (such as a masonry heater) look bad. Another thing to consider is that g/MJ should take into account transmission losses, for instance, if the unit is outside the house.

Jerry Whitfield stated that if you were to go to a g/MJ measurement, there would be more regulation, due to the fact that g/MJ is very difficult to define.

1.11 Have certified stove design and performance improved since the first certified stoves? If so, how?

Yes - John Francisty pointed out that the stoves today are more durable, and more user friendly. Proof of this is the longer warranty periods on the stoves today. Manufacturers are more confident in the durability of their stoves.

2. State-of-the-art of fireplace emission control technology.

2.1 Are the emission factors and efficiencies for the in-home use of fireplaces and inserts shown in Tables 3 and 4 reasonable?

EPA standards all look at emissions on a mass per mass source basis.

Use patterns are critical and the purpose for an appliance is also critical. Are you talking about a heater such as a stove or a fireplace that is used for aesthetics?

Grams/MJ should not be used to measure emissions from a fireplace. The problem is what do you do about the products in between a heater and a fireplace such as masonry heaters? There may in fact need to be three different test methods.

Grams/kg may be the best way to test an appliance, but regulators wanted g/hr because they wanted emissions based on time. The thought of the group was that no-burn-days covers incidents such as the example given of fireplaces being used at Christmas time. Dr. Houck mentioned that 28% of cordwood is burned in fireplaces and 7% of those are used as a primary source of heat according to studies in the Southeastern U.S.

It was also mentioned when looking at fireplaces, glass doors can make a difference in efficiency of 30-40%.

2.2 There appear to be only a few practical design or technology options for fireplaces that will potentially mitigate particulate emissions. - What designs and technologies are available? What retrofit options are there?

Walter Moberg mentioned that there have got to be options that have not been explored. Fireplaces are significantly under developed from an emissions standpoint. Glass doors in themselves can lower emissions.

2.3 The use of wax fire logs reduces emissions over the use of cordwood. Can the formulation of wax logs be changed to produce even fewer emissions?

Duraflame log representatives informed the committee that there are ways of lowering emissions from wood/wax logs that are being explored by some manufacturers.

2.4 What are the distinctions between a masonry fireplace and a masonry heater?

The big differences between fireplaces and heaters are the hearth opening size, heating ability and efficiency. Masonry heaters have smaller openings, more heating ability, and higher efficiencies, but it is a matter of drawing a line in efficiencies to separate the two. Colorado has a masonry heater standard.

2.5 As with woodstoves, the OMNI staff believe that the mass of emissions per unit of heat delivered is a better way to rank the performance of fireplaces than emission factors or emission rates.

See question 1.10

3. State-of-the-art of wood-fired central heating furnace emission control technology.

3.1 According to a Department of Energy survey, out of the 20.4 million households that used a wood burning appliance in 1993, less than 0.3 million used a wood burning furnace as their primary source of heat. Are there enough wood-fired central heating furnaces in use to merit their closer evaluation? How many commercially available models are there? Are there emissions data for them? Should they be certified?

Rick Curkeet pointed out that the lack of EPA regulations on wood fired central boilers has killed R&D on central heating furnaces. Outdoor furnaces could potentially give the wood burning industry a black eye. It is however a viable technology and is used in Europe. More automation could be developed.

There is a need for a separate central furnace standard as opposed to a modified woodstove standard. The Canadian standard CSA B415 committee started a furnace standard but sales of the product did not warrant it, so it was never finished. CanMet did some work on this.

CSA B415 is a consensus standard, which allows for modifications, unlike the EPA standard, which has no method of modification or industry participation once it is set up.

4. State-of-the-art of Pellet-fired woodstove technology.

4.1 Are the emissions and efficiencies for the in-home use ofpellet stoves shown in Tables 1 and 2 reasonable'?

Table 1 information comes from Klamath Falls and Medford, as well as estimates by OMNI staff.

Jerry Whitfield stated that comparing particulate from cordwood and pellet stoves is apples and oranges. From pellet stoves, larger particles are being captured instead of smaller ones that are more of a health risk. There are no data that show this at the present time. Pellet burning in the field is more controllable and definable. For this reason pellet stoves should not be tested by the same method as a cordwood stove.

4.2 The 35:1 air-to-fuel ratio cut-off for certification has produced two classes of pellet stoves - those that are certified and those that are not. The latter class may have models that are less efficient and have higher emissions than the former. Should the regulations be amended to close the loophole and discourage the practice of intentionally designing models with a higher air-to-fuel ratio to avoid certification?

Jerry Whitfield stated that it is not necessarily true that "The latter class may have models that are less efficient and have higher emissions than the former". Dan Henry stated that it is very difficult to meet or exceed the 35:1 ratio.

4.3 Have pellet stove design and performance improved since the first models were introduced? If so, how?

Yes, they have improved, but we are on the brink of a third generation of stoves that could be just as clean as gas or oil.

5. Ramifications of ISO.

5.1 The International Organization for Standardization (ISO) has a technical committee for developing emissions, efficiency and safety test standards for wood-fired residential heaters and fireplaces. (See Table 5 for comparison of the draft ISO Method 13336 with EPA Methods 28, 5G and 5H.) Do you feel that the EPA methods should be replaced with or be made comparable to an international standard?

It was the feeling of the group that the ISO standard has very little relevance at this time. It is being used mainly in New Zealand and Australia. The group felt that the Canadian standard CSA B415 should be looked at more closely. The question is, should the U.S. get involved in the ISO standard so that it is a standard that the U.S. can agree with? At the present time manufacturers have very little interest in dedicating any resources to this effort.

6. Correspondence between in-home and laboratory emission test results.

6.1 How accurately do certification tests predict in-home performance?

We don't know what the correlation is if any. Dan Henry stated that it is unlikely that a lab test would mirror in-home performance given the fuel alone used in the lab is different from cordwood. The original purpose of the test was to rank stoves given a standard test procedure. Also, given that the accuracy of the lab test is plus or minus 20% makes it difficult.

Ben Myren brought up the Klamath Falls study where the cleanest lab stove was the cleanest stove in the field. The same held true for the dirtiest stove in the lab. The EPA test protocol may be very accurate at predicting relative field performance.

It was also brought up that the EPA test should not designate a low burn, but allow the manufacturer to choose a low burn rate for its appliance.

6.2 How would you design research testing in the laboratory to simulate in-home use?

This would be very difficult due to the variations in use patterns and fuel types in the field.

7. EPA Method 28 strengths and weaknesses.

7.1 Method 28 is in part an "art ". Fuel loading density, fuel moisture, fuel characteristics (old vs. new growth, grain spacing, wood density) and coal bed conditioning can be adjusted within the specification range of the method to influence results. In your experience what things have the most effect on particulate emissions? How much influence can they have?

There are many little things that affect emissions during a test burn and they vary with every stove.

John Francisty stated that this industry has spent literally millions of dollars trying to get their appliances to reach a 1 kg/hr burn rate, which is unnecessary. There does not need to be a certain low burn rate. The low burn rate has the largest impact on the emissions of the stove.

Everyone agreed that the low burn rate and the high burn rate were critical in the test procedure and the two middle burn rates were academic.

7.2 Burn rate weighting is based on very limited data and the cities from where the data were obtained are not very representative of wood use nationwide (see Table 6). How can the weighting scheme be improved to be more representative of the nation as a whole?

Don't use 1 kg/hr as an artificial minimum burn rate requirement.

Plus the EPA rule is design restrictive. An example of this is in the late 1980's EPA stopped regulating wood burning furnaces and R&D stopped almost immediately.

Historically, we ended up with a test method using conventional lumber because there was a database using conventional lumber. The 1 kg/hr low burn rate was imposed because regulators thought the industry would be getting away with something if an artificial low burn weren't imposed. As a note, there was an ASTM standard at the time that was repeatable and reliable.

The question was asked if question 7 is irrelevant. Dr. Dennis Jaasma pointed out that most stoves in the field burned at the low burn rate category. However, burn rates with cordwood vary more than that of dimensional lumber. Users know that to get a longer burn, you use a larger piece of wood.

It was also mentioned that the industry is not making or selling many woodstoves and that everything discussed is going to cost a lot of money for the industry to comply with. This should be considered with any possible change made to the present test methods.

Ben Myren pointed out that with the new air quality standards, improvements would need to be made.

7.3 The equationfor the calculation ofthe air-to-fuel ratio in Method 28A is in error. The error produces a small but significant difference in the calculated air-to-fuel ratio. Should the Method be corrected or should it be left as a "predictor" of the air-to-fuel ratio?

Dr. Jim Houck pointed out that the calculation is flawed due to the volume occupied by hydrocarbon gas being considered a constant. What this error does is have a negative effect on stove efficiencies as well as measured air-to-fuel ratios. Stoves have to be well over the 35:1 ratio to actually meet the exemption.

CSA B415 gives a solid basis for calculating efficiencies.

It was brought up that there should be only one test if the tests do not give the same answers.

7.4 The assumed molefraction of hydrocarbons (Y_{HC}) is defined as a constant in the air-to-fuel ratio calculations in Method28A. The mole fraction of hydrocarbons in the vapor *phase will vary significantly with fuel and combustion conditions. Should hydrocarbon vapors (more appropriately, organic compound vapors) be measured as part of the Method?*

The committee as a whole had no strong opinion on this issue.

8. EPA Methods 5G and 5H correlation.

8.1 The comparison data to demonstrate the correlation between 5G and 5H are limited. Should the correlation between the two Methods be re-evaluated?

No, just eliminate Method 5H. There should not be two methods in one standard that do not produce identical results. One method should be eliminated. The perception is that 5H gives lower results even though theoretically it should give a higher result.

The correlation between the two methods has never been tested, but they do not converge to zero, as they should with the correction. There is also a problem at higher burn rates.

8.2 It is the general perception that Method 5H produces lower numbers than 5G. Method 5G is less costly and more precise than 5H. - Comments? - Should there be just one sampling method?

There should be one Method 5G, however the correction multiplier in 5G that is supposed to make 5G and 5H equal would have to be removed.

8.3 The same points regarding flow rate calculations (air-to-fuel ratio) and hydrocarbons as made for Method 28A are applicable to Method 5H. -- Comments?

They are wrong and should be changed. This is a modification of Method 5.

8.4 The precision of EPA's basic Method 5 is estimated as being about 20%. Almost one quarter of the 214 stoves listed as certified by the EPA as of 8/12/97 are within 20% of their respective (catalytic or noncatalytic) emission limits. -Comments?

How many of the 214 are still being sold? The safety factor is already built into the Phase II appliances by dropping Phase I from 9 g/hr to 7.5 g/hr.

8.5 Based on practical experience with the 5G and 5H, how can they be improved?

There are many improvements that are needed. An example of this are the calibration requirements. The test methods are also very susceptible to barometric pressure, especially at the low burn rate.

Correct 5G and 5H so that the results match or get rid of 5H and get rid of the correction factor on 5G. This may mean changing the pass/fail number. 5G was designed for variable flow rates, which better represents wood stoves.

9. Performance deterioration of EPA-certified woodstoves in the field.

9.1 It is the opinion of many in the woodstove industry that catalysts last only five years and that a stove designed for a catalyst operated without a functioning catalyst can produce as much emissions as a conventional stove. -Comments?

The thought was that the life of the catalyst was dependent upon the operator as well as the stove design so it is very difficult to say. Also the emissions from a catalytic stove without a functioning catalyst are very much a function of the stove design.

9.2 Field studies in Glens Falls, NY, Medford, OR, Klamath Falls, OR, and Crested Butte, CO, showed that emissions from some catalytic stoves became appreciably worse even after only two to three years of use. Inspection of stoves in Glens Falls showed that catalyst deterioration and leaky bypass systems were responsible. Have improvements been made in the design of catalytic stoves to minimize these problems? Is it reasonable to require homeowner training on the proper use of catalytic stoves and/or to incorporate into their costs an inspection and catalyst replacement program?

The Glens Falls stoves were "cooked" by overdrafting chimneys. Woodstoves are the only type of residential heating appliance that do not have some type of overdraft protection. This needs to be changed.

Education of consumers would be helpful, but how would this be done? Would you require a stove owner to be licensed? This is not reasonable.

10. Stress test pros and cons.

10.1 A short-term laboratory woodstove durability testing protocol was developed to predict the long-term durability of stoves under conditions characteristic of in-home use (see EPA-600/R-94-193). It was concluded in that study that damage occurs during those occasional times when a woodstove is operated in the home at exceptionally high temperatures. The laboratory stress test was designed to operate a woodstove at very high temperatures over a one to two week period to predict long-term durability under in-home use. Is this a reasonable approach?

One manufacturer mentioned that his stove failed the stress test even though they have had very little problems with them in the field. This would indicate that the test was much too severe.

10.2 Should a stress test be made part of the certification process?

The feeling was that a stress test should not be made a part of the certification test.

11. Feasibility of developing separate emission factors for dry and wet wood and for soft-wood and hardwood species classes.

11.1 Optimum wood moisture for low particulate emissions seems to be in the 18% to 20% range. Are you aware of any data that will allow the impact of wood moisture to be isolated from other variables? Could it be different for wood from different tree species?

No one present knew of any data that were not already available to OMNI.

11.2 Wood from different tree species clearly burns differently. The chemical makeup and density of wood from different tree species is different. For example wood from coniferous trees has more resin than wood from deciduous trees. It is believed that particulate emission factors will be different for wood from different tree species. If this is true different parts of the country may have different emissions factors for residential wood combustion. Are you aware of any data that document different emission factors for wood from different tree species?

The committee generally agreed that testing with different wood species made more sense than at four burn rates on the same species.

12. Routine maintenance.

12.1 Would routine maintenance of stoves once they were in a home reduce particulate emissions? Would this be more relevant for catalytic stoves than noncatalytic stoves? Would this be relevant for pellet stoves with electronic and moving parts?

The committee agreed that routine maintenance was very relevant and that training of chimney sweeps, who perform much of the routine maintenance, is important.

12.2 Should the homeowner be provided with a maintenance manual or a training course at the time of purchase? Should a maintenance program be part of the purchase price particularly for catalytic stoves?

Homeowners are provided with maintenance instructions at the time of purchase. A maintenance program for catalytic stoves would likely make these stoves even less popular in the market than they already are.

12.3 What would the key elements of routine maintenance be?

This varies from model to model, and is covered in each individual owner's manual.