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In-House Performance of New Technology Woodstoves

by

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ABSTRACT

Use of wood as a residential heating fuel increased markedly in the United States during the 1970s in response to an increase in fossil fuel costs. Most of the increase represented wood burned in airtight parlor stoves which are generally operated in an air starved condition leading to low combustion efficiency and the release of substantial quantities of unburned organics into the atmosphere. Field studies have been undertaken over the past several years to quantify emission rates from new technology stoves designed to significantly reduce the quantity of unburned organics released. The new stoves, employing either catalytic or noncatalytic secondary combustion features, are currently mandated by the U.S. Environmental Protection Agency. These studies have shown that the new technology stoves, while reducing emissions, do not achieve the emission reduction expected. Studies during the northern winter of 1988-89 showed that emission control was gradually improving but they also showed that some stove models were experiencing degraded emission control performance after only a few months use.

INTRODUCTION

Use of wood as a residential house heating fuel in the United States has been estimated to contribute up to 90% of the polynuclear organic material (POM) attributable to stationary sources and 50% from all sources (40 CFR Ch.1, 1985). POM is known to include numerous carcinogenic compounds. In localities where wood is the predominant house heating fuel, woodstoves have been shown to contribute as much as 80% of the ambient PM10 concentration during winter months.

The U.S. Environmental Protection Agency (EPA) initiated development of regulations for new woodstoves in April 1985 (40 CFR Part 60, 1985). The final rule was promulgated on February 26, 1988 (40 CFR Part 60, 1988). New stoves manufactured after July 1, 1988 were subject to the Phase I particulate emission limits. Stoves manufactured after July 1, 1990 will be subject to the more stringent Phase II particulate emission limits. Prototypes of each model stove must pass an emissions test performed in a laboratory for that model line to be certified for manufacture and sale.

With new technology woodstoves mandated by regulations, there was interest in determining the performance of these stoves in actual domestic use. This paper describes the results of several field studies undertaken in North America since 1985 to establish the emission rates of typical, uncontrolled conventional technology stoves and the degree of emission control achieved by newer stoves designed to reduce emissions.

EXPERIMENTAL PROGRAM

Northeast Cooperative Woodstove Study (NCWS) Phase I

The first major field study of woodstoves in normal consumer use in North America was a 2-year study in 66 houses in Waterbury, Vermont, and Glens Falls, New York, over the 1985-86 and 1986-87 heating seasons as reported by BURNET, P.G. (1987). This study is formally known as NCWS Phase I but is often referred to as the CONEG (Coalition of Northeastern Governors) study after one of the sponsors. Stove performance was closely monitored in 44 of these houses, which included 17 with catalytic models, 11 with noncatalytic low emission models, 10 with add-on or retrofit devices, and 6 with conventional stoves. Of the new technologies, there were in general four houses with each model. Another group of 20 houses switched stoves between seasons; only creosote deposition and wood use were measured. Sponsors of this study included the New York State Energy Research and Development Authority (NYSERDA), the CONEG Policy Research Center, Inc., and the EPA.

Particulate in the woodstove flues in 44 houses was sampled using an automated woodstove emission sampler (AWES) and a data logger, both developed for this project. These samplers, described by HOUCK et al. (1986), collected an integrated 1-week particulate emission sample and recorded the weight of wood added, the time of fueling, and selected temperatures. Wood moisture was measured periodically at each house and the wood species noted. Creosote deposition was gauged by weighing the material removed during periodic chimney cleanings.

The new technology stoves were selected in the fall of 1985, prior to EPA's initiation of the wood heater New Source Performance Standard (NSPS); all met or were judged to meet the State of Oregon's 1986 standards of 15 g/hr for noncatalytic stoves and 6 g/hr for catalytic stoves (OREGON, 1984). Overall results are shown in Table 1.

Table 1. Results of Northeast Phase I Test

Stove Technology	Particulate Emissions, g/hr
Conventional	20.1
Catalytic	17.2
Low Emission Noncatalytic	11.5
Add-on/Retrofit Catalysts	17.6

Somewhat surprising was the lower than expected emission rate for conventional stoves. The emission rate was expected to be on the order of 40 g/hr. Very disappointing was the relatively poor showing of the control technologies. Because of the wide variability in the data, the only technology which gave results statistically different from conventional stoves was the low emission noncatalytic. The add-on/retrofit devices achieved only marginal emission reductions and, in addition, were generally unsatisfactory to the users because of excessive smoke spillage when adding fuel.

Whitehorse Efficient Woodheat Demonstration

During the northern winter of 1986-87, two additional 1-year field studies were undertaken. One of these, the Whitehorse Efficient Woodheat Demonstration, was named after the city in which the test took place, Whitehorse, Yukon, Canada. Funding was provided by the City of Whitehorse and by Energy, Mines and Resources, Canada. This study, reported by SIMONS, C.A. et al. (1987), evaluated new technology stoves in 14 houses over one heating season. Each participant's conventional stove was tested for three 1-week periods during December 1986 and early January 1987. Their new technology stove was then installed and, after 2-3 weeks to get used to the new appliance, tested for five 1-week periods. Sampling equipment and methodology closely paralleled that followed in the NCWS Phase I work.

Results from Whitehorse were similar to those from NCWS Phase I (see Table 2). The study benefitted from the advancement in technology; all of the new technology stoves were certified to the Oregon Phase 2 standard which is equivalent in most respects to the EPA 1988 standard.

One of the catalytic stoves, the Blaze King King Catalytic model, was also used in the NCWS Phase I and in the Northwest Woodstove Study (NWS) (see below). In Whitehorse, the two installations using this stove averaged 15.5 g/hr. The other catalytic stove used in Whitehorse, the Burning Log Turbo 10, averaged 9.0 g/hr in two installations. This stove was not used in any other field studies and is no longer marketed.

Table 2. Results of Whitehorse Efficient Woodheat Demonstration

Stove Technology	Particulate Emissions, g/hr
Conventional	22.5
Catalytic	12.2
Low Emission Noncatalytic	14.3
Add-on Catalyst	19.6

Only one noncatalytic, low emission stove, the Osburn Imperial 2000, was tested in Whitehorse. This stove model was not used in the other studies.

As in the NCWS Phase I, the add-on/retrofit appliances achieved marginal reductions in particulate emissions. In general, users were not pleased with the operation of their stoves when these devices were attached. The additional back pressure caused by the catalyst often result in excessive smoke spillage into the room when adding fuel.

Northwest Woodstove Study

The other field study undertaken during the northern winter of 1986-87 was in the Portland, Oregon, area and consisted of six houses, one each with two different model catalytic, low emission noncatalytic, and conventional technology stoves. The four new technology models were certified to the EPA 1988 standard. Overall average results are presented in Table 3 (SIMONS et al., 1989).

Table 3. Particulate Emission Results for the Northwest Woodstove Study

Stove Technology	Particulate Emissions, g/hr
Conventional	19.7
Catalytic	23.7
Low Emission Noncatalytic	13.4

The Blaze King King Catalytic model stove operated in one of the study houses had an average particulate emissions rate of 4.4 g/hr. The other catalytic stove in the NWS performed very poorly, with an average emission rate of 43.3 g/hr. A followup inspection revealed that the bypass gasket had broken. The broken piece lodged in the seal area, resulting in a 1-2 cm gap with the bypass closed.

Of the two noncatalytic low emission models, one averaged 8.3 g/hr, and the other, 18.6 g/hr. There is no adequate explanation for the discrepancy; mitigating factors for the higher emission house included a shorter, larger cross section chimney which may have resulted in marginal draft.

Extensive laboratory comparison tests between the field particulate emission sampler and regulatory particulate sampling methods were also conducted as part of the NWS. These tests showed that the particulate emission rates measured in the field approximately equaled those using laboratory measurement methods.

Northeast Cooperative Woodstove Study Phase II

Following completion of the 1985-87 field studies, work was initiated to try to understand the factors which caused the advanced technology stoves to perform below expectations. Included in the NCWS Phase II tasks were physical inspections of each stove to look for broken catalysts, degraded gaskets, warped baffles, or any other evidence which could account for the reduced emission control effectiveness. Catalytic stoves were leak- tested to determine the potential for smoke to bypass the catalyst. Catalysts were removed and tested in the laboratory to determine conversion efficiency relative to new ones.

None of these tasks turned up any one overwhelming factor causing poor performance. Instead, there appeared to be a number of contributing factors. For example, the leak rate tests found substantial variation in leak rate from stove to stove and from model to model, but there seemed to be no correlation between emission rates and bypass leak rates. Nevertheless, one assumes that bypass leakage is fundamentally detrimental to low emissions performance.

A second contributing factor was some catalyst degradation. All of the catalysts showed conversion efficiency degradation in a bench test on a mixture of carbon monoxide and propane, especially on the hydrocarbon. There was also some correlation between the bench test results and in-stove test results; however, there was enough variability to mask catalyst-to-catalyst differences.

Analysis of fueling practices data revealed that most users fired their stoves five or more times each day, adding 5-10 kg of wood at each firing. This is in contrast to the anticipated practice of only one or two firings each day, each firing consisting of 25-50 kg. Particularly for large, catalytic stoves, frequent firing could lead to high emissions due to the need to bypass the catalyst each time wood is added. Also, the catalyst would need several minutes to regain light-off temperature after each firing. If the user forgot to close the bypass right away, the emission rate would be further elevated.

Two more variables uncovered during analysis of the NCWS

Phase I data were that chimney location and type appeared to be major factors affecting emission rate. Stoves venting to masonry chimneys on outside walls resulted, on average, in higher emission rates compared to insulated chimneys constructed within the house envelope. The assumption is that flues on outside walls are subject to greater heat loss, resulting in lower draft. Lower draft reduces combustion efficiency, causing formation of more unburned organics.

As an example of the combined effect of chimney location and firing practice, the Blaze King King Catalytic stove model was tested in all three field studies. In the NWS, it averaged 4.4 g/hr in the one house (P02) using this stove. A followup test 1 year later (March 1988) showed no change in performance. In the two houses in Whitehorse, this model stove averaged 15.5 g/hr while, in four houses in the NCWS Phase I, this model averaged 20.7 g/hr. However, one NCWS Phase I house (V11) averaged 6.5 g/hr over two heating seasons. The major difference between these two "low emission" installations and all other installations of the Blaze King King Catalytic models tested (and most other model installations as well) is that both had chimneys located within the house, not on an outside wall. House P02 had an insulated metal chimney, while House V11 had a masonry chimney. As noted above, this location would result in less thermal loss from the flue gas to the outdoors, resulting in better (higher) draft. It was also noted that the users in these "low emission" houses fired their stoves only once or twice a day, compared to the other users who averaged four to five firings a day. Although one cannot rule out other hidden effects, it seems likely that draft, as affected by chimney heat loss, and firing frequency had major impacts on the emission rate from this model stove. It is suspected that, of the two variables, draft exerts the greater influence.

In summary, Phase II concluded that no single factor caused increased emissions. Chimney location and its effect on heat loss/draft appeared to be a major contributor for all technologies evaluated. It also appeared that less than optimum operator practices combined with reduced catalyst effectiveness and some increase in leakage around the catalysts probably were additional contributors to reduced catalytic stove performance. Differences between stove operation during certification and actual in-house use may also have been a factor for both catalytic and noncatalytic stoves.

Poor performance of add-on/retrofit devices seemed to be attributable to too low temperatures entering the catalyst at the low burn rates commonly encountered in routine consumer use. Under most conditions, the catalyst inlet temperature was below the ignition temperature of the flue gases. In addition, most users found these devices unsuitable because of smoke spillage into the house resulting from the increased back pressure.

Northeast Cooperative Woodstove Study Phase III

The second round of field tests in the NCWS took place during the northern winter of 1988-89. Three catalytic and two low emission noncatalytic model stoves were tested in 25 houses in Glens Falls, New York. Each model stove was tested in five houses. All five stove models were EPA certified to the 1988 standards and were judged capable of meeting the EPA 1990 standards. Samples were collected and analyzed following procedures similar to those used in Phase I. A sensor was added to the bypass handles on the catalytic stoves to record the time of bypass activation and the interval between actions.

The results showed some improvement over the earlier studies. For example, one catalytic model averaged 4.6 g/hr, while the overall catalytic average was 8.6 g/hr compared to the 1990 catalytic standard of 4.1 g/hr. Low emission noncatalytic stoves averaged 11.0 g/hr compared to the 1990 standard of 7.5 g/hr.

Care was taken to select houses with fundamentally good chimney systems. In most cases, chimneys were upgraded to ensure good draft and minimize condensation. There was only one house with a masonry chimney; all others had insulated metal flues sized for the specific stove installed for the study. Mechanical joints in the flue system were sealed to minimize in-leakage.

Detailed inspections of the stoves during the study revealed important information on design and construction which affected the initial performance of these stoves and also physical degradation and its effect on emissions. One of the catalytic models (Blaze King Royal Heir model) showed a marked tendency toward increasing emissions with time (see Fig. 1) over the study due to two factors: (1) the bypass design was susceptible to rapid oxidation and warping of the bypass seat and (2) the catalyst was not protected from flame impingement leading to high catalyst temperatures and loss of catalyst activity. This degradation tendency was particularly evident in house Y01. Users were pleased with the Royal Heir, finding it easy to light and capable of holding a fire overnight. The overall average emission rate for the five houses using the Royal Heir was 10.2 g/hr, or about 2.5 times the 1990 EPA particulate standard of 4.1 g/hr for catalytic stoves.

Another catalytic model (Oregon Woodstove) showed erratic performance (see Fig. 2) due to a poorly designed bypass which did not offer firm tactile feedback on closure. This bypass consisted of two separate dampers welded to a common activating rod which made it susceptible to misalignment during manufacture and use. Users were pleased with the Oregon Woodstove, finding it easy to start and capable of holding a fire overnight. Overall average particulate emission rate for the four houses using the Oregon Woodstove was 11.3 g/hr or nearly 3 times the 1990 EPA particulate standard of 4.1 g/hr. One participant dropped out of the study at the last minute.

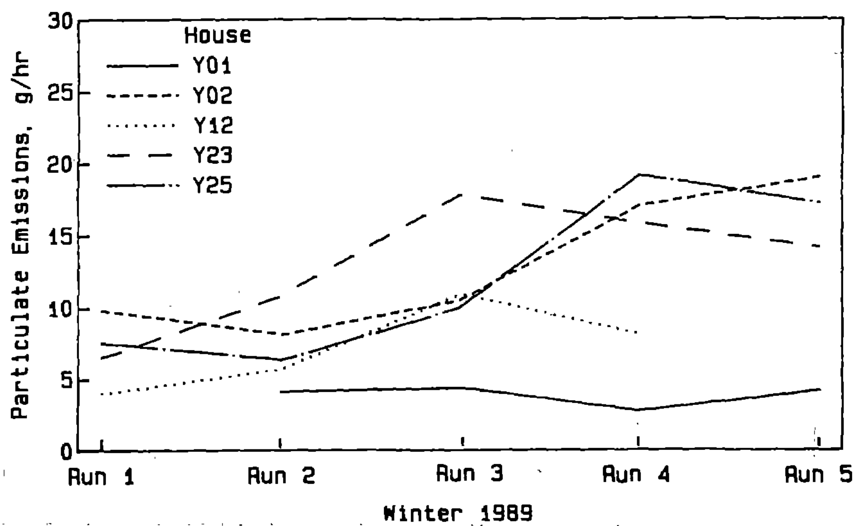

Fig. 1. NCWS Phase III field test particulate emission results for the Blaze King Royal Heir.

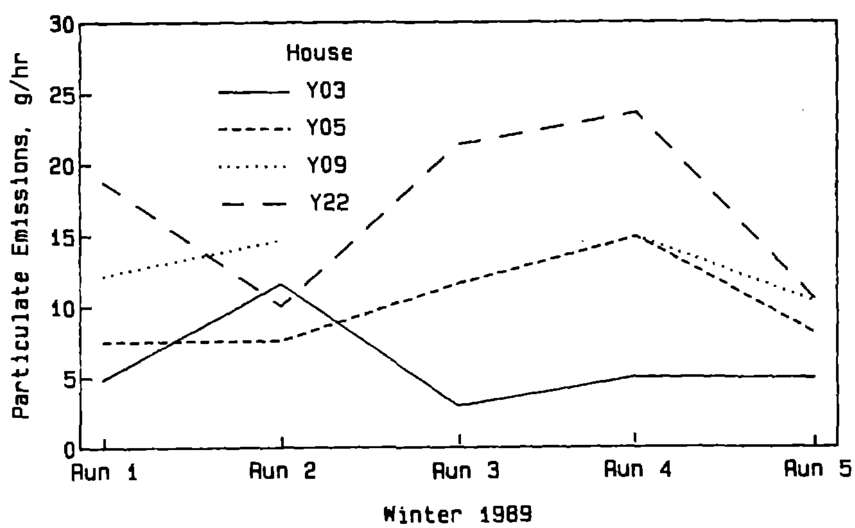

Fig. 2. NCWS Phase III field test particulate emission results for the Oregon Woodstove 1-01.

The best performing catalytic stove (Country Flame BBF-6) incorporates two flame shields to protect the catalyst and enhance mixing of the gases before they enter the catalyst. As shown in Fig. 3, this stove showed little emission performance degradation in four out of the five installations tested. Increasing emissions in house Y13 was felt to reflect catalyst degradation; however, this has not been confirmed. The residents of this house tended to fire the stove hotter than most, leading to higher catalyst temperatures. Users were very pleased with the Country Flame. It was easy to start and would hold a fire overnight. Overall average particulate emission rate for the five houses using the Country Flame was 4.6 g/hr, the lowest for the study. The EPA 1990 particulate standard for catalytic stoves is 4.1 g/hr.

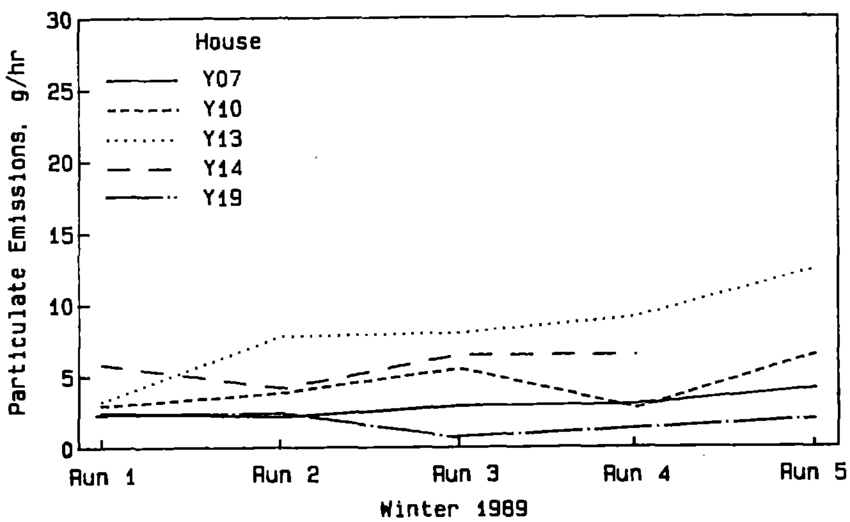

Fig. 3. NCWS Phase III field test particulate emission results for the Country Flame BBF-6.

The noncatalytic low emission stoves also showed physical degradation in some houses. One model (Country Comfort CC150), incorporating a bypass damper, showed heavy oxidation of the damper and damper jamb in one house (Y21) although this did not appear to be reflected in the emission rate (Fig. 4). The emission rate was quite variable. Users found this stove somewhat difficult to start a fire in and to sustain secondary combustion consistently. It would not hold a fire overnight. Overall average particulate emission rate for the five houses in the study was 12.5 g/hr, the highest in the study. The EPA 1990 particulate standard for noncatalytic stoves is 7.5 g/hr.

The other noncatalytic model (Regency Medium) showed a more consistent emission rate within a given house but substantial variation between houses (Fig. 5). In house Y20 the baffle separating the primary and secondary combustion chambers was oxidized and warped more severely than in the other houses using the Regency, indicating Y20 occupants operated their stove hotter. Emission rates for Y20 were relatively constant throughout the study. Y20 had a taller chimney (8.8 m) than most, resulting in higher draft pressure.

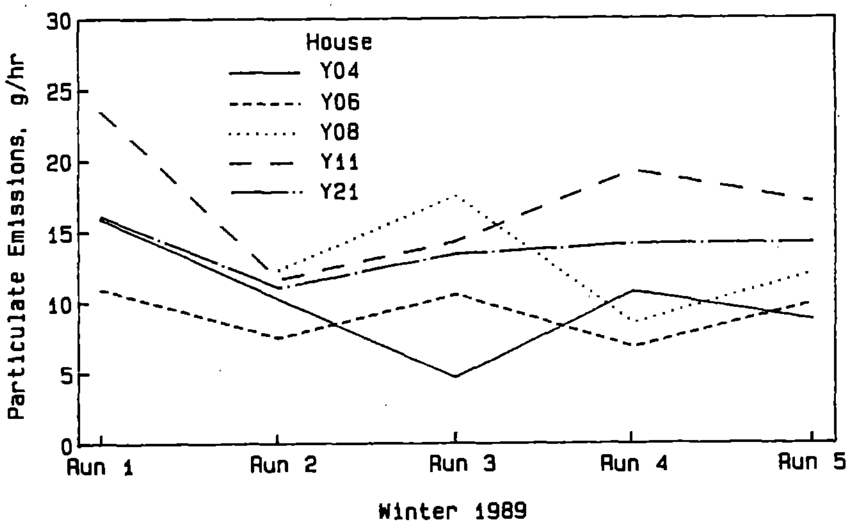

Fig. 4. NCWS Phase III field test particulate emission results for the Country Comfort CC150.

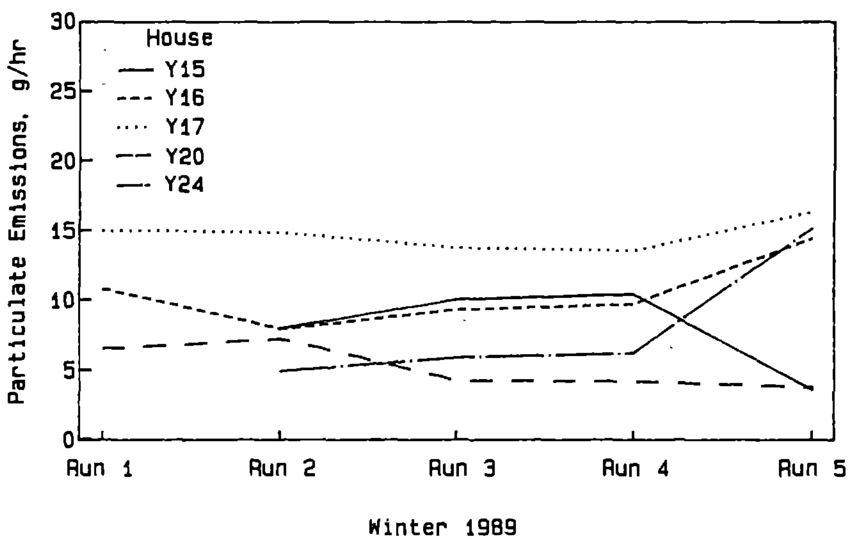

Fig. 5. NCWS Phase III field test particulate emission results for the Regency Medium.

This resulted in higher burn rates, even at the lowest draft setting. In general, users found this stove easy to use and were pleased with its operation, although it was difficult to hold a fire overnight, especially in Y20. Overall average emission rate for the five houses using the Regency Medium was 9.3 g/hr, compared to the 1990 EPA particulate standard for noncatalytic stoves of 7.5 g/hr.

Another aspect of the NCWS Phase III field study was the comparison of products from two catalyst manufacturers. All of the catalytic stoves were fitted with either a Corning Longlife or Panasonic catalyst. Most of the stoves of a given model were fitted with the brand of catalyst normally sold with that model. Since there were five of each model, three were fitted with one brand, and two with the other. Because of the limited number of data points, one must be cautious in drawing conclusions. Looking only at the overall average for each catalyst brand across all three stove models, the stoves with the Corning product gave a particulate emission rate of 5.5 g/hr compared to 9.7 g/hr for the Panasonic-equipped stoves.

Crested Butte Woodstove Replacement Project

The last woodstove field study to be discussed in this paper is the Crested Butte Woodstove Replacement Project, which is now in the second year of intensive field measurements. Crested Butte is a small town of about 800 year-round residents in the southwestern part of Colorado. Located in the Rocky Mountains at an altitude of 2710 m, Crested Butte is a popular winter ski resort. Alarmed by the thick, low level haze hanging over the town on clear winter days, the town council initiated a program to replace existing conventional woodstoves with new, certified units. All new woodstove installations must also be certified. The program also encouraged installation of gas-fired "logs" in fireplaces.

Baseline stack and ambient particulate measurements were made during the 1988-89 northern winter (JAASMA and CHAMPION, 1989). These data showed peak ambient PM10 concentrations greater than 110 ug/m^3, well above the EPA standard. In-stack measurements showed conventional stove average emission rates of 28 g/hr, very close to the values measured in the other field studies. Source apportionment of the ambient particulate indicated woodstoves accounted for about 75% of the PM10.

During the northern summer and fall of 1989 over 90% of the conventional stoves in Crested Butte were removed and new technology units installed. Many fireplaces were equipped with propane-fired gas logs. The residents were offered approved stoves at substantial discount to encourage the changeover. For those who chose not to replace their old stoves, the town is levying a fee of $30.00(U.S.) per month for the next 2 years, starting September 1, 1989. After the 2-year grace period, old technology stoves will be banned from Crested Butte.

The field study is now in its second year. Ambient measurements are being made as they were last year. In-stack measurements are focusing on the new technology stoves. To date, the results are encouraging. The highest ambient PM10 reading so far this winter is 39 ug/m^3. In-stack measurements show that several of the new stoves are performing in the 6-8 g/hr range, but there are also some in the 10-15 g/hr range. A complete report of the results is scheduled for completion by September 1990. It is hoped that there will be some long-term monitoring to assess the degree of emission control performance degradation.

SUMMARY AND CONCLUSIONS

Several field studies, completed during the 1985-87 heating seasons, showed that catalytic stoves subsequently certified to the EPA Phase I standard released average particulate emissions of 16.9 g/hr in routine domestic use compared to the standard of 5.5 g/hr and average certification test results of 1.1 g/hr. Corresponding results for low emission noncatalytic stoves were 12.3 g/hr in the field versus 6 g/hr in laboratory certification tests and a Phase I standard of 8.5 g/hr. Conventional stoves in these studies showed average emissions of 21.6 g/hr.

Follow-on field studies performed during the 1988-89 northern winter and continuing this winter show that some certified stove models can achieve emission rates in the 4-6 g/hr range over their first heating season. At the same time, these studies also show that many certified stove models do not achieve that level of emission control even when new and that some models are prone to rapid particulate emission control performance degradation after one heating season.

Further research is required to identify the causes of the poor initial performance; there is some thought that the laboratory test burn is not representative of real life use. Further research would also help identify the causes and cures of the rapid degradation seen in some stove models.

Wood is a desirable domestic heating fuel from a global warming perspective if burned cleanly. For wood to be a viable alternative for house heating, technology must be in place which results in substantial emission reduction, compared to conventional, uncontrolled stoves, over the life of the appliance. This may mean that the conventional, stick wood burning designs must give way to inherently cleaner burning alternatives such as pellet fueled appliances.

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Dennis Jaasma, of Virginia Polytechnic Institute and State University, is directing the source sampling field work in Crested Butte.

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NOTICE

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17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Stoves	Stationary Sources	13A
Wood	Woodstoves	11L
Combustion		21B
Residential Buildings		13M
Organic Compounds		07C

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