A STUDY OF INDOOR ELEMENTAL AND ORGANIC CARBON CONCENTRATIONS IN MISSOULA VALLEY HOMES

By
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A thesis submitted in partial fulfillment of the requirements for the degree of

Industrial Hygiene

Montana Tech of the University of Montana

2006

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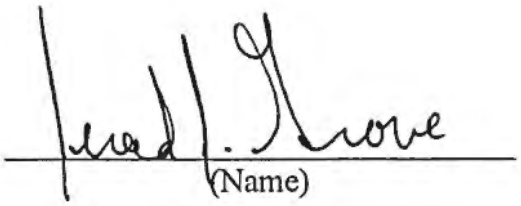

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This thesis has been examined and approved for acceptance by the Department of Industrial Hygiene, Montana Tech of The University of Montana, Butte, Montana, on the thirtieth day of January 2006.

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Abstract

The focus of this study was to identify elemental carbon (EC) and organic carbon (OC) concentrations in homes of pre-selected members of the Missoula community, all whom were asthmatic. Sampling was conducted using a Sioutas Cascade Impacator with all but the first and last stages removed to capture aerosol 2.5 um or less. Samples were taken during heating and non-heating months to capture and compare OC and EC concentrations associated with warm and cold months. Specific indoor activities were recorded during sampling to later correlate indoor activities to the collected OC and EC concentrations.

Twelve homes were sampled during non-heating conditions. The mean EC concentration was 1.79 ug/m^3. The highest EC concentration (8.5 ug/m^3) was found in a location where the resident vacuumed, swept, dusted, cooked, and had open windows as ventilation during the sample period. The mean OC concentration during this sample period was (18.21 ug/m^3). The highest OC concentration (59 ug/m^3) was found in a location where the resident smoked, cooked, and used open windows as ventilation during the sample period.

Seven homes were sampled during heating conditions. The mean EC concentration was .48 ug/m^3. The highest EC concentration (.81 ug/m^3) was found at a location where the residents burned incense during the sample period. The mean OC concentration during this sample period was (17.4 ug/m3). The highest OC concentration (39 ug/m^3) was found at a location where the resident smoked and cooked during the sample period.

Although smoking appeared to be a significant factor in both OC and EC concentrations, a comparison of activities within the home such as smoking, vacuuming, dusting, and using open windows as ventilation revealed no significance ($p > .05$). There was no correlation between EC and OC concentrations during both heating and non-heating conditions ($p > .05$). There was also no significance ($p > .05$) between the OC and EC concentrations captured on the first stage of the impactor (2.5 um cutpoint) and the final stage (<2.5 um) during both heating and non-heating sample conditions.

The ratios of EC and OC to total carbonaceous materials were found to be 8.83% and 89.77% respectively for non-heating conditions. The ratios of EC and OC to total carbonaceous materials during heating conditions were found to be 2.67% and 97.33% respectively. The concentration of OC was significantly greater than the concentration of EC during heating conditions ($p = .009$). This significance was not observed during non-heating conditions ($p = .110$)

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to Julie Hart, Terry Spear, Kumar Ganesan, Tony Ward, Curtis Noonan, and Dan Fitzpatrick. In addition, I would like to thank all study participants for opening their homes and donating their valuable time. Julie Hart, this thesis would have not been possible without your guidance and generosity. Terry Spear, your expert knowledge and leadership were valuable during every step of the study. Thanks for the motivation and continued support. Tony Ward and Curtis Noonan, thanks for giving us the opportunity to spearhead and support your U of M Center for Environmental Health Science study.

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1.0 Introduction

The indoor air quality of a home is an often overlooked health hazard that results from common household activities such as heating, cleaning, cooking, and smoking in the home. These activities introduce and agitate indoor pollutants within the home where they will most likely remain as a result of limited ventilation. If adequate ventilation is achieved within the home, the indoor air quality may improve as long as the ambient air entering the home has a lower concentration of pollutants. Outdoor ambient air quality can be influenced by several factors including forest fires, industrial pollutants, vehicle emissions, and meteorological conditions such as inversions.

The concentration, composition, and the size of particles can affect the health of indoor occupants. Combustion by-products and dusts are very common pollutants found within homes resulting from occupant activities and outdoor materials being carried into the home. Common indoor pollutants include elemental carbon (EC) and organic carbon (OC), which are primary components of both combustion by-products and dust. The size of particles are of significant importance to the potential health effects.

People spend approximately 85% of their time indoors, and as a result it is widely recognized that a major portion of total personal exposure to ambient particulate matter (PM) occurs indoors. The presence of indoor particle sources (i.e. heating systems), can significantly contribute to the overall PM levels indoors (Long, 2000). Indoor particle sources identified in recent studies include household appliances (i.e. gas-fired ranges and ovens, kerosene heaters, wood-stoves, fireplaces, and humidifiers); cooking activities (i.e. frying, sautéing, toasting, and baking) and general activities such as walking (Long, 2000).

As a result of these indoor sources, it can be assumed that indoor particle concentrations are often higher than ambient concentrations.

1.1 Purpose of Research

This research was funded and supported by the University of Montana and Montana Tech. The original scope of this study was to evaluate indoor air quality in Missoula homes during significant forest fire events. Because these events did not occur, the study objective was changed to an evaluation of indoor air quality in Missoula homes during non-heating and heating seasons.

2.0 Background

2.1 Sources and Physical Characteristics of OC/EC

Carbon is one of the most abundant constituents of ambient particulate matter. Carbon can be present as OC, which is volatile, and as EC, which is non-volatile. Carbonaceous particles are composed of solid carbon cores and gaseous organics. The solid carbon cores in the form of EC are released during combustion along with a widely varying array of gaseous organic compounds. As these gaseous organic compounds cool, they tend to form chains of aggregates which attach to the elemental core. OC and EC constitute large fractions of particulate matter $(PM)_{10}$ and $PM_{2.5}$ in ambient air (EPA 2005). EC, sometimes termed black carbon or soot, is usually produced by incomplete combustion of organic gases and particles. Combustion processes, most notably vehicles, emit sooty particles

which contain carbon in the form of a solid core of black EC which is often surrounded by semi-volatile organic compounds which, as stated above, condense from the exhaust gases.

EC, which is not generated by any known atmospheric reactions, is not degraded under atmospheric conditions but is affected by wet and dry depositions. Typically, EC is present in submicron particles with a mass median aerodynamic diameter of less than 1 micron (APACE 2005). This attributes to small amounts being removed from the atmosphere via dry depositions. The life of EC in the atmosphere is on the order of several days to several weeks, depending on meteorology. EC plays an essentially important role in climate considerations, since it is the single most important absorbing species in the atmosphere. EC also provides a good adsorption site for many semi-volatile organic compounds such as Polycyclic Aromatic Hydrocarbons (PAH's) due to its specific surface properties.

OC is of some concern because of possible mutagenic and carcinogenic effects. OC can be directly emitted from primary sources or produced from secondary atmospheric reactions (APACE 2005). OC effectively scatters light and may contribute significantly to visibility degradation. A significant fraction of OC is water soluble, making it important to various aerosol-cloud interactions. Moreover, carbonaceous species have the potential to influence many heterogeneous reactions involving atmospheric aerosols and trace gases. Cigarette smoke has been shown to produce primarily OC (APACE 2005). As a result, OC concentrations can be significantly elevated when cigarettes are burned.

Carbonaceous particulate matter appears black when collected on a filter due to the presence of EC. Ambient PM tends to have a trimodal size distribution by diameter: coarse particles (> 1 um), fine particles (0.1 to 1 um), and ultra fine particles (< 0.1 um)

(Long 2004). The main components of ambient PM are EC and OC, inorganic ions (ammonium sulfate and ammonium nitrate), and trace elements (Allen, 1999). Because of concerns about health effects, the US Environmental Protection Agency (EPA) regulates ambient levels of PM with a diameter of 10 um and 2.5 um or less (PM_{10} and $PM_{2.5}$). EPA PM_{10} standards are 50 ug/m^3 (annual arithmetic mean) and 150 ug/m^3 for a 24 hour period. EPA $PM_{2.5}$ standards are 15 ug/m^3 (annual arithmetic mean) and 65 ug/m^3 for a 24 hour period.

Particle size is usually the critical factor that determines the region of the respiratory tract in which a particle or an aerosol will be deposited. Deposition of particles on the surface of the lung and airways is brought about by a combination of lung anatomy and the pattern of airflow in the respiratory tract. Particles 5-30 um will be deposited by inertial impaction and interception within the nasopharyngeal region. In the average adult, most particles larger than 10 um in aerodynamic diameter are deposited in the nose or oral pharynx and cannot penetrate to tissue distal to the larynx. Particles that penetrate beyond the upper airways are available to be deposited in the bronchial region and the deep-lying airways. The alveolar region has significant deposition efficiencies for particles smaller than 5 um and larger than 0.003 um (Amdur, Doull, Klaassen 2004).

2.2 Health Hazards

$PM_{2.5}$ (fine particulate matter) has been linked to an increase in respiratory symptoms and related hospital visits, aggravated asthma, chronic bronchitis, and premature death. Indoor concentrations of PM are often higher than outdoor concentrations (EPA 2005).

Carbonaceous material often forms the core of fine particulate matter. The organic materials, which can be of a semi volatile or nonvolatile nature, are more often dispersed within the structure of particulate matter, forming layers or sheaths. Estimates of carbonaceous content vary considerably but are nominally considered to be about 30 to 60 percent of total mass of fine particulate matter (EPA, 2005).

The majority of health studies focused on carbonaceous material are centered on the health effects seen not only from carbon itself, but from organics that attach to the carbon core. The vast majority of OC/EC studies have concentrated on diesel exhaust because it is assumed that 88% of diesel exhaust is carbon, with 50% of the total carbon being EC (WHO, 1996). Diesel exhaust is present in all urban areas and it is likely that it contributes to indoor air quality. As a result, the health data of diesel exhaust can be correlated to the EC/OC found within residential homes. Because of this health data, diesel exhaust will be discussed in this section.

Elemental Carbon particulate matter absorbs genotoxic organic compounds, many of which are carcinogenic. These organic compounds, such as benzo(a)pyrene, quinoline, and 2-Napthylamine attach to particles formed during incomplete combustion. PAH's, such as benzo(a)pyrene, are known carcinogens which may be attached to the elemental carbon core. This has been a focus of health studies in recent years and signifies carcinogenic effects seen with carbonaceous materials.

2.2.1 Non-Carcinogenic Studies

Chronic respiratory effects are the principal non-cancer hazard to humans from long-term environmental exposure to diesel engine exhaust, or emissions (OEHHA, 2005). It has been estimated that diesel contributes about 7 percent of the fine urban PM emissions, which when expressed as an annual U.S. average, are about 2 ug/m^3 (OEHHA, 2005). There have been many studies conducted to evaluate the non-carcinogenic effects of chronic exposure to diesel exhaust emissions. Evidence suggests exposures may impair pulmonary lung functions and show increased occurrence of mostly transient symptoms such as cough, phlegm, and chronic bronchitis.

Other effects (e.g., neurological, growth and survival, neurobehavioral, lowered resistance to respiratory infection, liver effects) are observed in animal studies at higher exposures than those producing the respiratory effects (EPA, 2005). Human and animal immunological effects data of diesel exhaust exposure (i.e., exacerbation of allergenicity, and asthma symptomology) are inadequate for dose-response evaluation at this time. The reproductive toxicity of diesel exhaust has been evaluated in six studies, with no teratogenic, embryotoxic, fetotoxic or female reproductive effects observed in mice, rats, or rabbits at inhalation exposure levels lower than those where respiratory effects were observed. Respiratory effects are considered the "critical effect" for the derivation of a chronic inhalation Reference Concentration (RfC) for diesel exhaust (U.S. EPA, 2005).

Recently, however, carbon in the ultra fine mode (<0.1um) has been suggested to be more toxic than the same substance in the larger fine-mode range (2.5 um), perhaps due to

differences in the surface reactivity or tissue penetration (Amdur, Doull, Klaassen 2004). Particulate matter in the ultra fine range has extremely high surface area but contributes negligible mass to $PM_{2.5}$. As a result there may be more particles in the ultra fine range even though it does not contribute much mass. This is an important issue with regard to diesel PM because it is made up of aggregated ultra fine carbon with small amounts of various combustion-derived complex polycyclic and nitro aromatic compounds. Recent studies of diluted exhaust in humans reveals that the diesel exhaust mix is inflammogenic and to a degree cytotoxic to airway cells. Animal and in vitro cell studies with diesel particles themselves, however, have not shown much acute toxicity (Amdur, Doull, Klaassen 2004).

The American Conference of Governmental Industrial Hygienists (ACGIH) proposed a Threshold Limit Value (TLV) of 0.15 milligrams per cubic meter (mg/m^3) for diesel exhaust in 1996 but later changed the TLV to 0.05 mg/m^3 on evidence that the particle fraction of diesel exhaust may present a risk of causing cancer. These concerns were based upon evidence that the particulate matter (EC/OC) of diesel exhaust, not the organic gases, caused the response. (ACGIH TLV's)

2.2.2 Studies of Carcinogenic Organic Constituents

There are thousands of organic compounds that result from combustion. These organic compounds can vary significantly based upon the type of combustion source. Common organic compounds are PAH's, which can be found in indoor air primarily from the combustion of tobacco, residential heating products such as wood and coal, char-

grilled food, and creosote treated wood products. PAH's attach to the (EC) core and are carried into the body via inhalation. The PAH levels in indoor air usually range from 1 to 50 nanograms per cubic meter (ng/m^3) (OEHHA, 2005). Previous studies have demonstrated that phenanthrene and naphthalene can be the most prominent PAH found indoors, with levels of up to 2300 ng/m^3. One study by Chuang et al., (1991) showed that homes with gas heating systems had higher indoor levels than those with electric heating systems. An additional study by Alfheim & Ramdah, (1984) showed that even higher levels were detected in indoor air near open fireplaces. Airtight residential wood-burning stoves seemed to have a minor effect on the indoor air concentration of PAH's Alfheim & Ramdahl, (1984); Traynor et al., (1987), but in homes with non-airtight wood stoves, 2-46 times higher PAH concentrations were found during heating periods than during periods without heating (Daisey et al., 1989).

Emissions from un-vented kerosene heaters can significantly affect indoor air quality in mobile homes, with a maximum value for naphthalene of 2300 ng/m^3. Four of eight heaters investigated emitted PAH-containing particles at levels that exceeded the USA ambient air standards for airborne particles, with a 50% cutpoint at the aerodynamic diameter of 10 um. When the kerosene heaters were in operation, the concentrations of carcinogenic PAH (with four rings or more) in the mobile homes were increased by 10-fold (Mumford et al., 1991).

PAH's enter the outdoor ambient air primarily from volcanoes, forest fires, burning coal, and automobile exhaust. Industrial sources can also release PAH's into the ambient air. Such industrial sources include coal-tar production plants, coking plants, bitumen and

asphalt production plants, smoke houses, aluminum production plants, waste incinerators, facilities that manufacture or use products of coal, and where wood or other plant materials are burned. People may also be exposed to PAH's in the soil where coal, wood, petrol or other products have been burned (IPCS, 2005).

PAH exposures can irritate the eyes, nose, throat and bronchial tubes. Very high levels can be nephrotoxic, hepatototoxic, damage red blood cells, and cause headaches, nausea, and even cause death (IPCS, 2005). PAH's can be absorbed through the pulmonary tract, the gastrointestinal tract, and the skin. The site and rate of absorption in the lungs depends on the size of the particles on which they are absorbed and type of PAH. In addition, PAH's adsorbed onto particulate matter are cleared from the lungs more slowly than free hydrocarbons (IPCS, 2005). Absorption from the gastrointestinal tract occurs rapidly in rodents, but metabolites return to the intestine via biliary excretion. Studies with ^{32}P-postlabelling of percutaneous absorption of mixtures of PAH's in rodents showed that components of the mixtures reach the alveolar regions of the lungs, where they become bound to DNA (IPCS, 2005).

Several individual PAH's are known carcinogens to animals and may be carcinogenic to humans. There is concern that those PAH's found to be carcinogenic in experimental animals are likely to be carcinogenic in humans. Tumors are produced by PAH's at both contact and at distant sites. It has been documented that exposure to multiple PAH mixtures show an increase in the incidence of cancer in human populations. The carcinogenic potency of PAH's may vary with the route of exposure. The International

Agency for Research on Cancer has cited a number of PAH's as "probably carcinogenic to humans", a number of others are cited as being possibly carcinogenic to humans.

2.2.3 Lung Disease

Studies conducted on the effects of diesel exhaust have linked elevated particle levels in the air to increased hospital admissions, emergency room visits, asthma attacks and premature deaths among those suffering from respiratory problems. Fine particles are associated with increased frequency of childhood illnesses and can also reduce lung function in children (Delfino, 2005). Children are more susceptible to fine particulate matter because of lung development. Increased lung cancer risk has been observed in 8 out of 10 cohort studies, 5 of which were statistically significant. Increased lung cancer risk has also been observed in 10 of 12 case-control studies, 8 of which were statistically significant. Overall, the relative risks (RR) of lung cancer generally range from 1.2 to 1.5, although a few studies show overall RR as high as 2.6 (EPA, 2004). Statistically significant increases in RR, 1.33 to 1.47, are also shown in two independent meta-analyses of epidemiologic studies. The meta-analyses demonstrate the effect of pooling many studies and in this case show the positive relationship between diesel exhaust exposure and lung cancer across a variety of occupations exposed to diesel exhaust (EPA 2004).

Specific studies conducted by Heinrich et al., (1998) suggest that lung cancers in rats exposed to diesel exhaust may be induced by a mechanism that does not require the presence of absorbed organic compounds on the elemental carbon particulate matter. This study does not demonstrate that the only carcinogenic agent is non-soluble elemental

carbon particles. However, genotoxic organics may be masked by diesel particulate lung overload.

2.2.4 Human Studies

Studies have shown that exposure to diesel exhaust can have immediate health effects. DE can irritate the eyes, nose, throat and lungs, and it can cause coughs, headaches, lightheadedness and nausea. In studies with human volunteers, diesel exhaust particles made people with allergies more susceptible to the materials to which they are allergic, such as dust and pollen. Exposure to diesel exhaust also causes inflammation in the lungs, which may aggravate chronic respiratory symptoms and increase the frequency or intensity of asthma attacks (Delfino, 2005).

Over 30 epidemiologic studies published in the literature over the past 40 years have shown a strong association between diesel exhaust exposure and cancer. The majority of the epidemiologic studies evaluate distinct populations of occupational groups, including railroad workers, truck drivers, heavy-equipment operators, farm tractor operators, and professional diesel vehicle drivers. However, a much higher diesel particulate matter concentration would be expected in these occupations than that found inside homes.

2.3 Indoor Air Quality Guidelines

Human activities can be a significant source of indoor air pollution and should be understood and controlled to help eliminate exposures to indoor toxicants. Several daily

indoor activities affect the quality of our breathing air. Such daily activities include cooking, cleaning, utilizing home heating systems, burning candles or incense, and especially smoking. There are many guidelines and suggestions on how to control the level of contaminants released from these activities. These guidelines apply to a broad range of contaminants and will work to control carbonaceous particulate matter liberated from incomplete combustion activities within the home. Specific control guidelines include: source control, ventilation improvements, utilizing air cleaners, installing exhaust fans above combustion sources, reducing wood stove emissions, and cleaning heating systems regularly.

2.4 Previous Studies

A previous study, conducted by Salam, Bauer, and Puxbaux (2000) in the greater Vienna region of Austria between June 1999 and May 2000 evaluated concentrations of elemental carbon (EC) and organic carbon (OC) in aerosol particles. In addition, $PM_{2.5}$ and PM_{10} samples were collected simultaneously at urban Vienna City and a semi-rural regional called Streithofen. Aerosol samples were collected on quartz fiber filters by high volume samplers during a 24 hour sample period.

The reported one-year average concentrations of EC and OC at the Vienna location were 3.3 and 4.0 ug/m^3 for $PM_{2.5}$ and 3.5 and 5.7 ug/m^3 for PM_{10} respectively. The EC and OC concentrations at the Streithofen location were reported to be 1.8 and 3.1 ug/m^3 for $PM_{2.5}$, 2.0 and 4.4 ug/m^3 for PM_{10}. These concentrations are comparable to samples taken at other urban locations in Europe and the USA. The concentrations of EC and OC were

considerably higher in winter than summer. Winter, is defined as heating season (November to February) and summer is defined as outside of the heating season (May to August). Size distribution of EC/OC concentrations in the fine particles mode was around 90% EC and 70% OC at each location. The fraction of carbonaceous material to aerosol mass was roughly 44% at the Vienna location and around 39% at the Streithofen location. Organic material (OM = OC*1.6) contribution to aerosol mass was around 30% at both Vienna and Streithofen sample locations.

An additional study conducted by Long (2000), used continuous $PM_{2.5}$ mass concentration and size distribution measurements as well as the performance of scripted indoor activities, to provide data for the characterization of indoor sources of particles. More than 200 distinct indoor particle events were identified in this study and were used to quantify individual indoor activities. The data collected demonstrated that the impact of indoor activities is especially pronounced in the ultra-fine (< 0.1um) and coarse-mode (10 um) regions. In addition to size selective sampling, EC/OC samples were collected during a 24 hour period. The results suggest that particulate organic carbon is an important constituent of indoor particulate emissions.

Cooking, cleaning, and combustion sources (e.g., candles) were identified as important indoor airborne particle sources. The study indicated that $PM_{2.5}$ and course-mode particle (10 um) concentrations were elevated by both indoor activity sources and suspension events such as walking, dusting, and vacuuming. The mean indoor OC concentration found in this study was 7.7 ug/m^3 (SD = 2.9) and the mean indoor EC concentration was 0.85 ug/m^3 (SD = 0.41). OC comprised 90% of total indoor carbon.

There has been extensive research conducted on emission factors of indoor air pollution sources such as home heating devices. For example, tests conducted by the EPA have shown that conventional wood stoves produce 18.5 g/hr of fine particulate matter, oil furnaces produce 0.07 g/hr of fine particulate matter, and gas furnaces produce 0.04 g/hr of fine particulate matter (New York State Environmental Protection Bureau, 2005).

2.5 Research Hypotheses

The following research hypotheses were developed for this study. The research hypothesis (RH) states the expected outcome of the study. The Null hypothesis (NH) is used to provide reliability and show that there is no difference between what is expected and what is actually found. The following hypotheses have been developed:

RH1

Activities within the home such as smoking, vacuuming, dusting, and using open windows as ventilation will increase airborne OC/EC concentrations.

NH1

Activities within the home such as smoking, vacuuming, dusting, and using open windows as ventilation will not increase airborne OC/EC concentrations.

RH2

There will be a correlation between OC and EC indoor airborne concentrations.

NH2

There will not be a correlation between OC and EC indoor airborne concentrations.

RH3

OC, EC, and total carbon concentrations on both stages A and F of the Sioutas Cascade Impactor will be significantly greater during heating sample periods than non-heating sample periods.

NH3

OC, EC, and total carbon concentrations on both stages A and F of the Sioutas Cascade Impactor will not be significantly greater during heating sample periods than non-heating sample periods.

RH4

The concentration of OC will be greater than the concentration of EC during non-heating and heating sample periods.

NH4

The concentration of OC will not be greater than the concentration of EC during non-heating and heating sample periods.

3.0 Methodology

3.1 Sampling Protocol

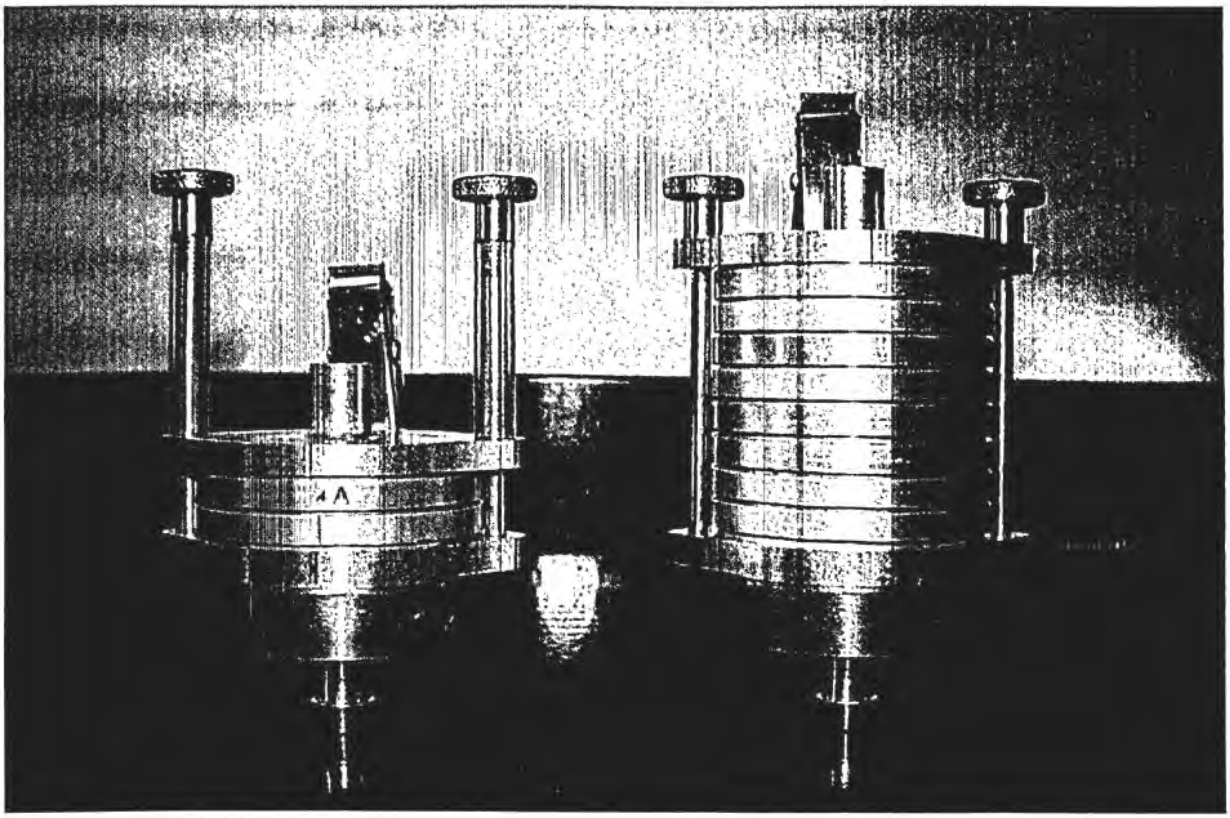
All of the sampling took place within the homes of asthmatics located in the Missoula Valley. These homes were originally selected from a larger asthmatic forest fire smoke study. Participants were contacted through a random digit dialing technique. A two stage procedure was used; in the first stage households were screened to identify potential participants, and in the second stage potential participants were contacted.

The homes were dispersed throughout the Missoula Valley and included single family houses, apartments, assisted living facilities and trailer houses (see Appendix A Figure I). The Institutional Review Board of the University of Montana approved this study and all participants gave informed consent.

A modified Sioutas Cascade Impactor was used to capture size selective EC and OC concentrations. The sample duration within the homes was 24 hours, with samples collected in the primary living area at a height of approximately 3 feet.

The Sioutas Cascade Impactor separates and collects airborne particles in five size ranges: > 2.5 (um), 1.0 to 2.5 um, 0.50 to 1.0 um, 0.25 to 0.50 um, and < 0.25 um. The impactor has four collection plates, where 25-mm filters may be secured and a fifth and final collection plate fitted with a 37-mm filter. For this study, the Sioutas Cascade Impactor was modified, the second through fourth stages of the impactor were removed, leaving stages 1 (A) and the final collection filter (F). As a result of the modification, stage 1 (A) has a cutpoint of 2.5 um with the final collection filter (F) capturing everything < 2.5 um (see figure II). Pre-weighed quartz filters supplied by Data Chem Laboratories were used as the sampling media for all EC and OC concentrations.

Figure II. Modified Sioutas Cascade Impactor



*Left-Modified Sioutas Cascade Impactor Stages A and F. Right-Standard Sioutas Cascade Impactor with Stages A,B,C,D,E, and F.

The recommended flow rate for the Sioutas Cascade Impactor is 9 L/min, which was achieved through the use of a SKC Leland Legacy sample pump. The pump was placed in the near vicinity of the samplers and was plugged into an outlet during the entire sample duration. This was to ensure that the pump did not lose its charge and fault.

A questionnaire created specifically for this study was given to the resident(s) of the home being sampled (see appendix B). This questionnaire contained specific questions regarding household activities that were performed during the 24 hour sample durations. These questions were answered by the resident and reviewed by the researchers when the

samples were picked up after 24 hours. This questionnaire was designed to identify contributing variables to the OC/EC concentrations. Specifically, these events included smoking, vacuuming, sweeping, dusting, cooking, burning substances (i.e. incense), and methods of heating and cooling the home. These factors were used to correlate the EC/OC particulate matter concentrations with the related indoor events. For example, cigarette smoke produces OC, thus we would expect the OC levels to be much higher in the homes of smokers.

SKC Leland Legacy Sample Pumps used in this study were calibrated pre and post sampling at 9L/min (± 2%) using a Gilian Gilibrator with a high flow cylinder. Calibrations were performed with a modified Sioutas Cascade Impactor to mimic filter resistance that would be found during sampling conditions.

3.2 Sample Preparation

Sample preparation and calibration was performed in the Chemistry Building at the University of Montana. The Sioutas Cascade Impactor was cleaned with isopropyl alcohol and clean wipes. It was then allowed time to dry prior to applying filters in the impactor. The researchers wore neoprene gloves and handled the filters with tweezers to prevent contamination. The assembled Sioutas Cascade Impactor was sealed in a plastic zip-lock bag until arriving at the sample location.

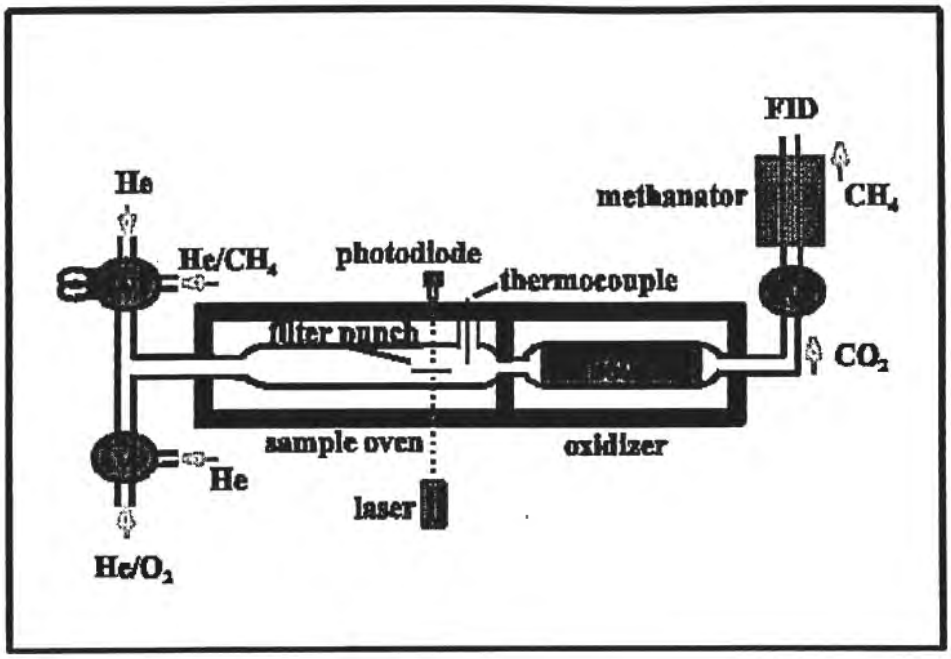
3.3 Sampling Analysis

Samples were analyzed for organic and elemental carbon using NIOSH 5040 evolved gas analysis (EGA) by thermal-optical analyzer. The analysis was performed by Data Chem Laboratories, an American Industrial Hygiene Association (AIHA) accredited laboratory located in Salt Lake City, Utah. Samples were sent in two groups, the first being non-heating data and the second being heating data. Sample blanks were submitted with each sample set. All samples were frozen until shipped.

3.3.1 NIOSH 5040 Analytical Method

In the thermal-optical analysis of carbonaceous aerosols, speciation of organic and elemental carbon is accomplished through temperature and atmosphere control, and by continuous monitoring of filter transmittance. A schematic of the instrument is given below (Figure III). An optical feature corrects for pyrolytically generated elemental carbon (EC), or "char," which is formed during the analysis of some materials (e.g., cigarette and wood smokes, pollen). Laser light passed through the filter allows continuous monitoring of filter transmittance. Because temperatures in excess of 850°C are employed during the analysis, quartz-fiber filters are required. A punch from the sample filter is taken for analysis, and organic and elemental carbon are reported in terms of ug per cm^2 of filter area. The total OC and EC on the filter are calculated by multiplying the reported values by the deposit area. In this approach, a homogeneous sample deposit is assumed. Just prior to the end of the analysis (i.e., after EC is evolved), calibration is achieved through injection of a known volume of methane into the sample oven. (NIOSH 5040)

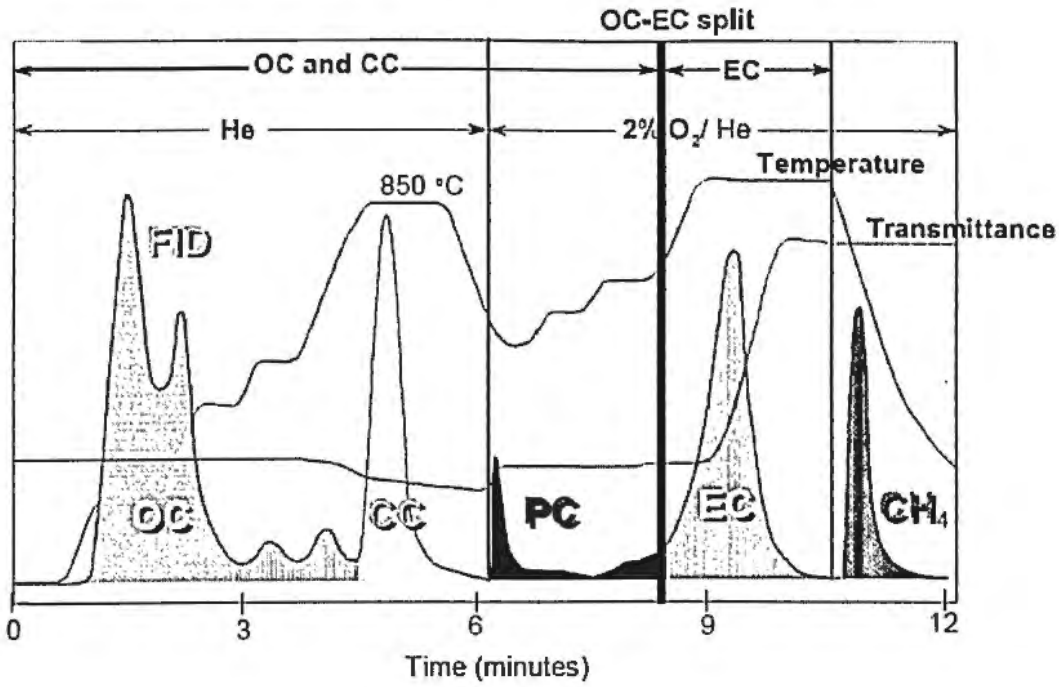
Figure III. Schematic of Thermal-Optical Instrument (NIOSH 5040)



Thermal-optical analysis proceeds essentially in two stages. In the first, organic and carbonate (if present) carbon are evolved in a helium atmosphere as the temperature is stepped to about 850 °C (750 °C if EC loss is evident). The evolved carbon is catalytically oxidized to CO_2 in a bed of granular MnO_2, and then reduced to CH_4 in a Ni/firebrick methanator. CH_4 is quantified by a Flame Ionization Detector (FID). In the second stage, the sample oven temperature is reduced, an oxygen-helium mix is introduced, and the temperature is increased (to about 940 °C). As oxygen enters the oven, pyrolytically generated carbon (PC) is oxidized and a concurrent increase in filter transmittance occurs. The point at which the filter transmittance reaches its initial value is defined as the "split" between OC and EC. Carbon evolved prior to the split is considered OC (including

carbonate), and carbon volatilized after the split is considered elemental (EC). The presence of carbonate is verified by exposing a second punch from the filter to HCl vapor prior to analysis. A dessicator containing concentrated HCl (added to dessicator or a petri dish placed at the bottom of it) can be used to acidify the punches. The dessicator, or alternative vessel, should be used in a well ventilated hood. Punches are placed on the desiccator tray, transferred into the dessicator and covered with lid. Wetted pH indicator sticks inserted between the dessicator lid and base can be used to check acidity and should give a pH near 2. Punches are exposed to vapor for about 1 hour (large particles can require more time). After acidification, the tray is removed and placed on a clean surface inside a hood. The residual acid on the punches is allowed to volatilize in hood for at least one hour before analyzing. When the acidified sample is analyzed, a much-reduced (or absent) peak is indicative of carbonate in the original sample. (NIOSH 5040)

Figure IV. Thermogram for Filter Sample Containing Organic Carbon and Elemental Carbon (NIOSH 5040)



4.0 Results and Discussion

4.1 Elemental, Organic, and Total Carbon Results

Samples were collected from twelve randomly selected homes of asthmatics in the Missoula Valley during non-heating and heating conditions. During this sample period, several participants smoked, burned incense or candles, used windows as ventilation (non-heating conditions), and performed cleaning operations (sweeping, vacuuming, and dusting). Indoor activities varied at each sample location, but a few remained the same such as smoking (see Table I).

Table I. Identification of Sample Population and Related Indoor Activity Variables

	Non-Heating Conditions n=	Percentage	Heating Conditions n=	Percentage
Locations Sampled	12	100.00%	7	100.00%
Smokers	3	25.00%	2	28.57%
Used Candles or Insence	2	16.67%	1	14.29%
Vacuumed	3	25.00%	1	14.29%
Swept	3	25.00%	1	14.29%
Dusted	2	16.67%	1	14.29%
Cooked	5	41.67%	4	57.14%
Had Open Windows or Door	9	75.00%	1	14.29%

A total of nineteen EC and OC samples were collected from homes in the Missoula valley. Twelve of these samples were collected during non-heating conditions and seven were collected during heating conditions. Samples were collected between July of 2004 and April 2005. Two stages of the modified Sioutas Cascade Impactor (Stage A and F) were used to collect EC and OC. The EC, OC, and total carbon concentrations of stage A and F for non-heating and heating conditions are presented in Table II and Table III respectively. In order to perform statistical analysis on masses that were less than the limit of detection (LOD), a value of 70% of the LOD was used (Mulhausen and Damiano, 1998). These locations are C, D, E, and H for Non-Heating and locations B, D, and F for heating sampling conditions.

Table II. Elemental and Organic Carbon Concentrations for Non-Heating Conditions

Non-Heating Sample Results							
Sample Location	EC Stage A	EC Stage F	Total EC	OC Stage A	OC Stage F	Total OC	Total Carbon
	(ug/m3)	(ug/m3)	(ug/m3)	(ug/m3)	(ug/m3)	(ug/m3)	(ug/m3)
A	0.29	0.81	1.10	9.20	11.00	20.20	21.30
B	0.09	0.45	0.54	3.90	6.70	10.60	11.14
C	$7.7xE^{-5}$	8.50	*8.5	4.70	6.60	11.30	19.80
D	$7.7xE^{-5}$	$7.7xE^{-5}$	$*1.54xE^{-4}$	0.73	1.60	2.33	2.33
E	$7x10^{-5}$	$1.4xE^{-4}$	$*2.1xE^{-4}$	1.50	0.00	1.50	1.50
F	0.20	1.20	1.40	6.00	53.00	59.00	60.40
G	0.09	4.70	4.79	5.30	9.00	14.30	19.09
H	$6.65xE^{-6}$	$6.65xE^{-6}$	$*1.33xE^{-5}$	0.93	2.60	3.53	3.53
I	0.07	0.76	0.83	4.20	17.00	21.20	22.03
J	0.12	1.20	1.32	6.80	11.00	17.80	19.12
K	1.60	0.37	1.97	7.30	8.80	16.10	18.07
L	0.06	1.00	1.06	4.70	36.00	40.70	41.76
Mean	0.21	1.58	1.79	4.61	13.61	18.21	19.11

* Indicates Locations Reported at 70% of the LOD

The four highest EC and four highest OC concentrations during non-heating sample conditions are presented with the lightest shade in columns 4 and 7 of Table II. The highest EC concentration was found in location C where the resident vacuumed, swept, dusted, cooked, and had open windows as ventilation during the sample period. The other three locations (F, G, and K) had only open windows, with the exception of location F where the resident was a smoker. The highest OC concentration was found in location F where the resident smoked, cooked, and used open windows as ventilation during the sample period. The second and third highest OC concentrations, found at locations L and I, also came from homes where residence smoked. Location A, the fourth highest OC concentration, came from a location where incense was burned.

Table III. Elemental and Organic Carbon Concentrations for Heating Conditions

Heating Sample Results							
Sample Location	EC Stage A	EC Stage F	Total EC	OC Stage A	OC Stage F	Total OC	Total Carbon
	(ug/m3)	(ug/m3)	(ug/m3)	(ug/m3)	(ug/m3)	(ug/m3)	(ug/m3)
A	0.05	0.76	0.81	7.20	20.00	27.20	28.01
C	$2.59x10^{-5}$	0.14	*0.14	2.60	4.50	7.10	7.24
D	0.07	0.42	0.49	2.20	6.50	8.70	9.19
E	$2.59x10^{-5}$	0.77	*0.77	6.10	10.00	16.10	16.87
F	0.10	0.51	0.61	6.10	33.00	39.10	39.71
H	$2.94x10^{-5}$	$7.7x10^{-5}$	$*1.06x10^{-4}$	3.60	9.40	13.00	13.00
K	0.05	0.47	0.52	3.00	7.40	10.40	10.92
Mean	0.04	0.44	0.48	4.40	12.97	17.37	17.85

*Indicates Locations Reported at 70% of the LOD

The four highest EC concentrations from heating sample conditions were found at locations A, E, F, and K as illustrated with the lightest shade in columns 4 and 7 of Table III. The four highest OC concentrations from heating sampling conditions were found at locations A, E, F, and H. The highest EC concentration was found at location A where the resident burned incense and used open window as ventilation during the sample period. The other locations (E, F, and K) had residence that cooked, with location F having cooked and smoked during the sample period. The highest OC concentration was found at location F where the resident smoked and cooked during the sample period. The second highest OC concentration was found at location A where the resident burned incense during the sample period. The two remaining locations (E and H) had residence that smoked during the sample period.

Stages A and F Heating vs. non-heating elemental, organic, and total carbon concentration comparisons are found in Tables IV, V, and VI. Because more samples

were taken during non heating conditions, comparisons were made using only those locations that were sampled during both non heating and heating conditions.

Table IV. Non-Heating vs. Heating Elemental Carbon Levels from Stages A and Final

Location	EC Stage A (ug/m3) Non-heating	EC Stage A (ug/m3) Heating	EC Stage F (ug/m3) Non-heating	EC Stage F (ug/m3) Heating
A	0.29	0.053	0.81	0.76
C	*$7.7x10^{-5}$	*$2.59x10^{-5}$	8.5	0.14
D	*$7.7x10^{-5}$	0.066	*$7.7x10^{-5}$	0.42
E	*$7x10^{-5}$	*$2.59x10^{-5}$	*$1.4x10^{-4}$	0.77
F	0.2	0.1	1.2	0.51
H	*$6.65x10^{-6}$	*$2.94x10^{-5}$	*$6.65x10^{-6}$	*$7.7x10^{-5}$
K	1.6	0.048	0.37	0.47
Mean	0.30	0.04	1.55	0.44

*Indicates Locations Reported at 70% of the LOD

Table V. Non-Heating vs. Heating Organic Carbon Levels from Stages A and Final

Location	OC Stage A (ug/m3) Non-heating	OC Stage A (ug/m3) Heating	OC Stage F (ug/m3) Non-heating	OC Stage F (ug/m3) Heating
A	9.20	7.20	11.00	20.00
C	4.70	2.60	6.60	4.50
D	0.73	2.20	1.60	6.50
E	1.50	6.10	0.00	10.00
F	6.00	6.10	53.00	33.00
H	0.93	3.60	2.60	9.40
K	7.30	3.00	8.80	7.40
Mean	4.34	4.40	11.94	12.97

Table VI. Non-Heating vs. Heating Total Carbon Levels from Stage A and Final

Location	TC Stage A (ug/m3) Non-heating	TC Stage A (ug/m3) Heating	TC Stage F (ug/m3) Non-heating	TC Stage F (ug/m3) Heating
A	9.40	7.25	12.00	20.76
C	4.70	2.60	7.40	4.64
D	0.73	2.27	1.60	6.92
E	1.50	6.10	3.40	10.77
F	6.20	6.20	54.20	33.51
H	0.93	3.60	2.60	9.40
K	7.50	3.05	9.20	7.87
Mean	4.42	4.44	12.91	13.41

4.2 Daily Temperature Data

Temperature data averages were obtained daily during both heating and non-heating sample periods (Table VII Appendix A). The high, low, and overall average temperatures for non-heating and heating conditions are presented in Table VIII.

Table VIII. High, Low, and Overall Average Temperature for Non-Heating and Heating Sample Periods

Non-Heating	Heating
Low--50 degrees F	Low--5 degrees F
High--79 degrees F	High--40 degrees F
Average--67 degrees F	Average--31 degrees F

4.3 Ratio of EC and OC to Total Carbon (TC)

The ratios of EC/OC to total carbon (TC) were calculated for non-heating and heating conditions.

In addition, ratios were developed for both stage A and F. These values can be seen in Table IX. The ratio of OC to TC was significantly higher on both stage A and F during heating and non-heating sample conditions.

Table IX. Ratios of EC and OC to TC for Non-Heating and Heating Conditions

Ratios Non-Heating	
EC A to TC A	OC A to TC A
4.24%	92.95%
EC F to TC F	OC F to TC F
10.32%	88.74%
EC Total to TC Total	OC Total to TC Total
8.83%	89.77%

Ratios Heating	
EC A to TC A	OC A to TC A
0.86%	99.14%
EC F to TC F	OC F to TC F
9.88%	99.14%
EC Total to TC Total	OC Total to TC Total
2.67%	97.33%

4.4 Statistical Analysis of Data

Statistical analysis was performed on the collected EC, OC, and total carbon (TC) data using Minitab 14® statistical software. Statistics were used to test the research hypotheses presented earlier. A significance level of 0.05 was used for all statistical analyses.

Analysis was conducted to determine if there were correlations between the EC and OC concentrations and contributing factors such as smoking, sweeping, and vacuuming. Due to the limited sample size and number of contributing factors (variables), the only statistical test suitable was the 2-sample-t test. In these tests, EC and OC concentrations were

compared to each individual contributing factor, with a 0 representing a negative value and 1 representing a positive value. These tests showed no significance ($p > .05$) between the contributing factors (see table I) and the level of EC and OC found within the home. The small sample size is the limiting factor when trying to compare the large number of contributing factors to the limited EC and OC data.

Because of the limited sample size and lack of significance shown for the 2-sample-t-tests, the means for the number of negative (0) and positive (1) outcomes were compared for each contributing factor. This provided information that may suggest that certain contributing factors would have more significance if a larger sample size would have been taken. For example, when looking at the mean OC concentrations in the homes of smokers vs. non-smokers during non-heating conditions, mean values of 40.3 and 10.8 were found respectively. This clearly shows that smokers had a higher mean OC value. The mean values for each contributing factor for EC and OC during non-heating and heating conditions are found in Appendix C. Contributing factors with substantially different means may indicate significance with a large sample size.

2-sample-t tests were also used to compare EC, OC, and TC levels in the first and final stages of the Sioutas Impactor. These values were compared using sample data collected from the same homes during heating and non-heating conditions. The 2-sample-t tests were used to determine significance for the following:

1. If OC, EC, and TC stages A and F concentrations would be significantly greater during heating sample periods than non-heating sample periods.

2. If the concentration of total OC will be greater than the concentration of total EC during non-heating and heating sample periods.

The results for the above 2-sample-t tests are found in tables X through XVII respectively.

Table X. 2-sample-t test OC stage A non-heating vs. OC stage A heating for homes A, C, D, E, F, H, and K

	N	Mean	StDev	SE Mean
OC Stage A (Non-	7	4.34	3.37	1.3
OC Stage A (Heat	7	4.40	2.01	0.76

Difference = mu (OC Stage A (Non-heating)) - mu (OC Stage A (Heating))
Estimate for difference: -0.062857
95% CI for difference: (-3.416220, 3.290505)
T-Test of difference = 0 (vs not =): T-Value = -0.04 P-Value = 0.967
DF = 9

Table XI. 2-sample-t test OC stage F non-heating vs. OC stage F heating for homes A, C, D, E, F, H, and K

	N	Mean	StDev	SE Mean
OC Stage F (Non-	7	11.9	18.5	7.0
OC Stage F (Heat	7	13.0	10.1	3.8

Difference = mu (OC Stage F (Non-Heating)) - mu (OC Stage F (Heating))
Estimate for difference: -1.02857
95% CI for difference: (-19.09453, 17.03739)
T-Test of difference = 0 (vs not =): T-Value = -0.13 P-Value = 0.900
DF = 9

Table XII. 2-sample-t test EC stage A non-heating vs. EC stage A heating for homes A, C, D, E, F, H, and K

	N	Mean	StDev	SE Mean
EC Stage A (Non-	7	0.299	0.586	0.22

EC Stage A (Heat	7	0.0382	0.0393	0.015

Difference = mu (EC Stage A (Non-Heating)) - mu (EC Stage A (Heating))
Estimate for difference: 0.260450
95% CI for difference: (-0.282672, 0.803572)
T-Test of difference = 0 (vs not =): T-Value = 1.17 P-Value = 0.285 DF = 6

Table XIII. 2-sample-t test EC stage F non-heating vs. EC stage F heating for homes A, C, D, E, F, H, and K

	N	Mean	StDev	SE Mean
EC Stage F (Non-	7	1.55	3.10	1.2
EC Stage F (Heat	7	0.439	0.289	0.11

Difference = mu (EC Stage F (Non-Heating)) - mu (EC Stage F (Heating))
Estimate for difference: 1.11574
95% CI for difference: (-1.76153, 3.99300)
T-Test of difference = 0 (vs not =): T-Value = 0.95 P-Value = 0.379 DF = 6

Table XIV. 2-sample-t test TC stage A non-heating vs. TC stage A heating for homes A, C, D, E, F, H, and K

	N	Mean	StDev	SE Mean
TC Stage A (Non-	7	4.42	3.46	1.3
TC Stage A (Heat	7	4.44	2.02	0.76

Difference = mu (TC Stage A (Non-Heating)) - mu (TC Stage A (Heating))
Estimate for difference: -0.015296
95% CI for difference: (-3.442071, 3.411478)
T-Test of difference = 0 (vs not =): T-Value = -0.01 P-Value = 0.992 DF = 9

Table XV. 2-sample-t test TC stage F non-heating vs. TC stage F heating for homes A, C, D, E, F, H, and K

	N	Mean	StDev	SE Mean
TC Stage F (Non-	7	13.0	18.9	7.1
TC Stage F (Heat	7	13.4	10.3	3.9

Difference = mu (TC Stage F (Non-Heating)) - mu (TC Stage F (Heating))
Estimate for difference: -0.381439
95% CI for difference: (-18.758894, 17.996016)
T-Test of difference = 0 (vs not =): T-Value = -0.05 P-Value = 0.964 DF = 9

Table XVI. 2-sample-t test Total OC vs. Total EC during non-heating conditions for homes A, C, D, E, F, H, and K

	N	Mean	StDev	SE Mean
Total OC	7	16.3	20.2	7.6
Total EC	7	1.85	3.04	1.1

Difference = mu (Total OC) - mu (Total EC)
Estimate for difference: 14.4271
95% CI for difference: (-4.4365, 33.2906)
T-Test of difference = 0 (vs not =): T-Value = 1.87 P-Value = 0.110 DF = 6

Table XVII. 2-sample-t test Total OC vs. Total EC during heating conditions for homes A, C, D, E, F, H, and K

	N	Mean	StDev	SE Mean
Total OC_2	7	17.4	11.7	4.4
Total EC_1	7	0.477	0.305	0.12

Difference = mu (Total OC_2) - mu (Total EC_1)
Estimate for difference: 16.8947
95% CI for difference: (6.0874, 27.7020)
T-Test of difference = 0 (vs not =): T-Value = 3.83 P-Value = 0.009 DF = 6

2-sample-t tests were also used to compare values for certain contributing factors; this was done by isolating each contributing factor and by comparing carbon data for the homes that did have a contributing factor vs. those homes that did not have a contributing factor. 2-Sample-t tests were used to determine significance for the following:

1. The concentration of OC in homes of smokers vs. non-smokers during non-heating and heating conditions

The results for the above 2-sample-t tests are found in tables XVIII and XIX respectively.

Table XVIII. 2-sample-t test OC in homes of smokers vs. non-smokers during heating conditions

N Mean StDev SE Mean
Smokers Total OC 3 40.3 18.9 11
Non-Smokers Tota 9 10.92 7.03 2.3

Difference = mu (Smokers Total OC) - mu (Non-Smokers Total OC)
Estimate for difference: 29.3822
95% CI for difference: (-18.6469, 77.4114)
T-Test of difference = 0 (vs not =): T-Value = 2.63 P-Value = 0.119 DF = 2

Table XIX. 2-sample-t test OC in homes of smokers vs. non-smokers during non-heating conditions

	N	Mean	StDev	SE Mean
Smokers Total OC	2	26.1	18.5	13
Non-Smokers Tota	5	13.90	8.17	3.7

Difference = mu (Smokers Total OC_1) - mu (Non-Smokers Total OC_1)
Estimate for difference: 12.1500
95% CI for difference: (-160.0486, 184.3486)
T-Test of difference = 0 (vs not =): T-Value = 0.90 P-Value = 0.535 DF = 1
A Pearson Correlation was performed to determine the degree of linear association between the total OC and total EC concentrations during both heating and non-heating conditions

(see Table XX). This analysis showed no significance (p = .901) and (p =.238) for heating and non-heating conditions respectively.

Table XX. Correlation between and increase in OC and an increase in EC

Correlations: Total OC, Total EC Heating

Pearson correlation of Total OC and Total EC = 0.058
P-Value = 0.901

Correlations: Total OC, Total EC Non-Heating

Pearson correlation of Total OC_2 and Total EC_1 = 0.514
P-Value = 0.238

5.0 Conclusion

Samples were collected at 12 locations during non-heating conditions and at 7 locations during heating conditions. When non-heating and heating EC, OC, and TC samples were compared, it was observed that there was no statistical difference between the carbon concentrations (p >.05). Several factors may have influenced both heating and non-heating data including inconsistencies in indoor activities during non-heating and heating sample conditions.

The EC, OC, and TC concentrations were also compared via stage A and F of the modified Sioutas Cascade Impactor for heating and non-heating conditions. This was performed to determine what stage and during what sample period most EC/OC was

collected. Stage (A) had a cutpoint of 2.5 um with the final collection filter (F) capturing everything < 2.5 um. There was no statistical difference between these values ($p > .05$).

Previous studies have shown that a higher concentration of OC than EC is typically found within homes. As a result, the OC concentrations were compared to the EC concentrations for both non-heating and heating conditions. During non-heating conditions there was no significant difference in the OC and EC concentrations ($p = .110$). However, a significant difference in OC and EC concentrations was found during heating sample periods ($p = .009$). The ratio of OC to TC was significantly higher on both stage A and F during heating and non-heating sample conditions. This outcome is similar to previous studies where 90% of indoor carbonaceous particulate matter is comprised of OC (Long, 2005). This is expected because heating sources contribute to OC. The difference between non-heating and heating conditions many be similar to those disparities seen in the study conducted by Long in which the quartz filters not only collected particulate organic carbon but also absorbed gaseous carbon. There also exists the possibility that a portion of semi-volatile organic carbon was lost from the samples explaining lack of significance in the non-heating data.

Previous studies have also shown that cigarette smoke liberates primarily OC. Because of this, it was assumed that OC levels within the homes of smokers would be greater than in the homes of non-smokers during both heating and non-heating conditions. Statistical analysis performed on this data did not show significance when comparing OC/EC data during non-heating ($p = .119$) and heating ($p = .535$) conditions. However, the highest

concentrations of EC and OC were found in the homes where residence smoked and burned incense (see tables II and III). Only 3 out of the 12 samples collected during non-heating conditions were from the homes of smokers. Only 2 out of 7 were collected from homes of smokers during heating conditions. The small sample size and other contributing variables (cooking, open windows, vacuuming, and dusting) were most likely limiting factors in this comparison

A Pearson's correlation was performed to determine if EC concentrations increased as the related OC concentrations increased in heating and non-heating conditions. The results of the correlation showed no significance between these concentrations. ($p = .901$) and ($p = 2.38$) for non-heating and heating respectively.

5.1 Hypotheses

Based on the statistical analysis performed, the following conclusions can be made about the research hypotheses:

1. When 2-sample-t tests were used to determine if activities within the home such as smoking, vacuuming, dusting, and using open windows as ventilation will increase airborne OC/EC concentrations, all p-values showed no significance. Thus we fail to reject NH1.

   NH1: Activities within the home such as smoking, vacuuming, dusting, and using open windows as ventilation will not increase airborne OC/EC concentrations.

2. When a correlation was performed to determine if EC levels increased as OC levels increased, p-values of .901 and .238 were found for non-heating and heating conditions. Correlation Coefficients (CC) of .058 and .514 were found for non-heating and heating conditions respectively. Thus we fail to reject NH2.

   NH2: There will not be a correlation between OC and EC indoor airborne concentrations

3. When 2-sample-t tests were used to determine if the OC, EC, and TC concentrations collected on stages A and F would be significantly higher during heating sample periods than non-heating sample periods, p-values of .967, .900, .285, .379, .992, and .964 were found respectively. Thus we fail to reject NH3.

   NH3: OC, EC, and total carbon concentrations on both stages A and F of the Sioutas Cascade Impactor will be significantly greater during heating sample periods than non-heating sample periods.

4. When 2-sample-t tests were used to determine if the concentration of OC will be greater than the concentration of EC during non-heating and heating sample periods p-values of .110 and .009 were found respectively. Thus for non-heating (.110) we fail to reject NH4 and for heating (.009) we reject NH4.

NH4: The concentration of OC will not be greater than the concentration of EC during non-heating and heating sample periods.

5.2 Limitations of Research

The limitations of research encountered during this study include limited sample size, concentrations reported < the limit of detection (LOD) with 70% of the LOD being used, and continuous data logging instrumentation was not used to identify EC/OC contributions by specific indoor activities at measurable time intervals. In addition, it was difficult to pinpoint the contribution specific contributing activities (smoking, cooking, dusting, vacuuming, and open windows) had on the overall EC/OC levels collected within the home. Outdoor ambient sampling near the home was not performed, thus infiltration of carbonaceous particulate matter from outside of the home was not measurable.

5.3 Recommendations for Future Research

The purpose of this study was to identify if heating and non-heating conditions along with certain indoor activities influence EC, OC, and TC levels within the home. The outcome of the results were influenced by many factors and living conditions found within each specific sample site. In order to precisely capture and record data resulting from indoor activities, continuous and time-integrated sampling instrumentation would be recommended. This would allow for specific indoor activities to be isolated and analyzed for specific contributions to elevated EC, OC, and TC levels.

This study was specifically focused on capturing particulate indoors. If further research was performed, outside ambient EC, OC, and TC data should be collected to correlated ambient concentrations to indoor concentrations. This would help determine if open windows and doors have an affect on the carbon levels within the home. Certain meteorological and environmental events, such as inversions and vehicle emissions, can elevate carbon levels found in ambient air.

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APPENDIX A: Figure I and Table VII

Figure I: Sample Locations

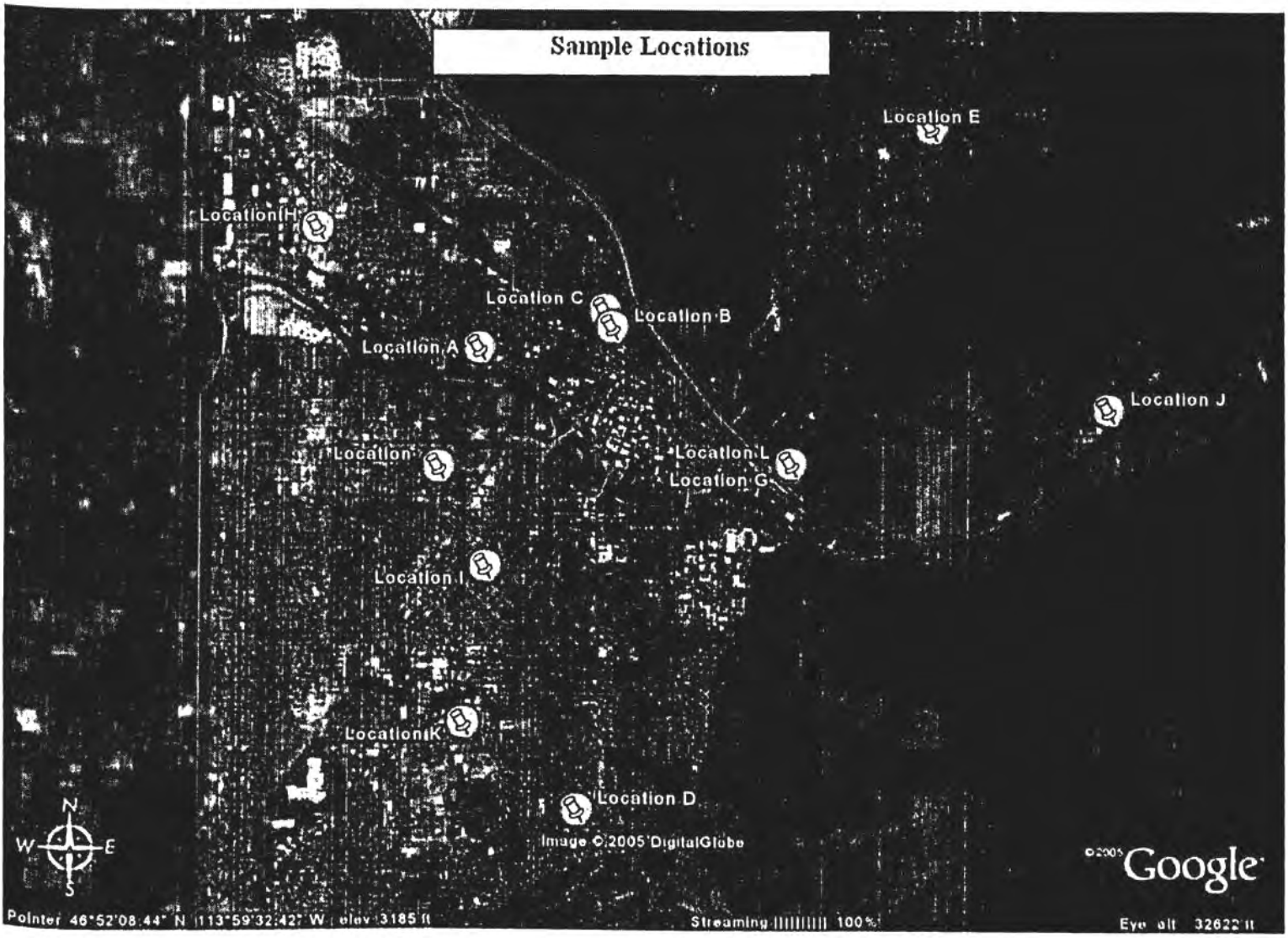

Table VII. Temperature Data during Sampling Conditions

Temperature DATA (Non-Heating)						
Month	Day	Max 24 hr. temp	Min 24 hr temp.	Average 24 Temperature	Smoke or Haze	Blowing dust of Sand Visibility 1/2 mile or less
July	14	98	56	77	no	no
	15	99	58	79	no	no
	20	80	58	69	no	no
	21	84	52	68	no	no
	22	86	51	69	yes	no
August	4	88	53	71	no	no
	5	90	52	71	no	no
	30	85	47	66	no	no
	31	86	47	67	no	no
September	14	58	47	53	no	no
	15	55	45	50	no	no
Temperature DATA (Heating)						
Month	Day	Max 24 hr. temp	Min 24 hr temp.	Average 24 Temperature	Smoke or Haze	Blowing dust of Sand Visibility 1/2 mile or less
January	4	23	1	12	yes	no
	5	13	-3	5	no	no
March	22	40	26	33	no	no
April	14	47	32	40	no	no

*January 4th and 5th and April 12th were day when samples were taken at two locations

Appendix B:
House Activity Questionnaire

The University of Montana
Title of Study Here
Indoor Air Sampling Residence Questionnaire

Address: _____

Thank you for your participation in the _____ study. A portion of this study pertains to monitoring exposures to indoor and outdoor particulates. In order to accomplish this, we will be placing two Leland® Legacy air sampling pumps in your home for a 24 hour period. The air sampling pumps will be drawing air into filters. These filters will be analyzed for the total weight gained during the sample period (mass) as well as for the elemental and organic carbon collected during the sampling period.

In order to accurately assess the air sampling results from your home prior to the forest fire season and during the forest fire season, it is important to consider the many variables that may contribute to particulate exposures. Please take a moment and read through this questionnaire, noting any of the events that occurred during the 24 hour sampling period. The researchers will complete this questionnaire with your assistance at the end of the sampling duration.

If you have any further questions about this study or if you need to contact the researchers for any reason during the sampling period, please contact _____ at _____.

Event, Activity or Home Condition	Frequency	Duration	Total Duration	Comments
Smoking				
Vacuuming Type of vacuum and filter:				
Sweeping				
Dusting				
Remodeling or renovation Activities:				
Pets in the Home: and #s				
Dog				
Cat				
Bird				
Other				
Cooking: and type				
Frying				
Deep fat frying				
Baking				
Grilling indoor				
Grilling outdoor				
Other				
Home HVAC: Systems				
Air Conditioner				
Heating System				
Cooling Fans				
Open Windows				
Other:				
Outdoor Activities				
Lawn Mowing				
Other				

Appendix C:
Mean Values of Contributing Factors for EC and OC during Non-Heating and Heating Sample Conditions

EC Mean Values for Non-Heating Sample Condtions

By Smoke	Mean Smoke	By Burning Incense	Mean Burning Incense	By Vacuum	Mean Vacuum	By Sweep	Mean Sweep	By Dust	Mean Dust	By Cook	Mean Cook	By Open Windows	Mean Open Windows
0	2.02	0	1.96	0	1.26	0	1.18	0	1.19	0	1.72	0	0.42
1	1.10	1	0.97	1	3.38	1	3.64	1	4.80	1	1.87	1	2.07

OC Mean Values for Non-Heating Sample Condtions

By Smoke	Mean Smoke	By Burning Incense	Mean Burning Incense	By Vacuum	Mean Vacuum	By Sweep	Mean Sweep	By Dust	Mean Dust	By Cook	Mean Cook	By Open Windows	Mean Open Windows
0	10.85	0	17.72	0	19.61	0	18.81	0	18.71	0	20.52	0	11.77
1	40.30	1	20.70	1	14.03	1	16.43	1	15.75	1	15.91	1	19.50

EC Mean Values for Heating Sample Condtions

By Smoke	Mean Smoke	By Burning Incense	Mean Burning Incense	By Vacuum	Mean Vacuum	By Sweep	Mean Sweep	By Dust	Mean Dust	By Cook	Mean Cook	By Open Windows	Mean Open Windows
0	0.55	0	0.42	0	0.53	0	0.53	0	0.53	0	0.43	0	0.37
1	0.31	1	0.81	1	0.14	1	0.14	1	0.14	1	0.51	1	0.56

OC Mean Values for Heating Sample Condtions

By Smoke	Mean Smoke	By Burning Incense	Mean Burning Incense	By Vacuum	Mean Vacuum	By Sweep	Mean Sweep	By Dust	Mean Dust	By Cook	Mean Cook	By Open Windows	Mean Open Windows
0	13.90	0	15.73	0	19.08	0	19.08	0	19.08	0	16.30	0	20.27
1	26.05	1	27.20	1	7.10	1	7.10	1	7.10	1	18.18	1	15.20

Appendix D: Raw Sample Data

DATA CHEM LABORATORIES
A Sorenson Company

ANALYTICAL REPORT

Form ARF-AL
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09300414035004RX

SEP 30 2004

Date

Laboratory Group Name 04I-3026-02

Account No. 07003

Montana Tech
Attention: Julie Hart
1300 W. Park Street
Butte, MT 59701

FAX (406) 496-4650
Telephone (406) 496-4792
E-mail jhart@mtech.edu

Sampling Collection and Shipment

Sampling Site Missoula Homes Date of Collection

Date Samples Received at Laboratory September 23, 2004

Analysis

Method of Analysis NMAM 5040

Date(s) of Analysis September 27, 2004 - September 28, 2004

Analytical Results

Field Sample Number	Laboratory Number	Sample Type	Organic Carbon µg/sample	Elemental Carbon µg/sample	Total Carbon µg/sample	Organic Carbon mg/m³	Elemental Carbon mg/m³	Total Carbon mg/m³	Air Volume L		
714A	04I28775	FILTER	120	3.8	130	0.0092	0.00029	0.0094	13280		†
714F	04I28776	FILTER	150	11.	160	0.011	0.00081	0.012	13280		†
715A	04I28777	FILTER	51.	1.2	52.	0.0039	<0.00010	0.0040	12990		†
715F	04I28778	FILTER	87.	5.9	93.	0.0067	0.00045	0.0072	12990		†
A04-300	04I28779	FILTER	20.	ND	20.	0.0015	<0.00010	0.0015	12900		†
A04-301	04I28780	FILTER	44.	ND	44.	0.0034	<0.00010	0.0034	12900		†
804A	04I28781	FILTER	75.	2.5	77.	0.0060	0.00020	0.0062	12410		†
804F	04I28782	FILTER	660	15.	680	0.053	0.0012	0.055	12410		†
805A	04I28783	FILTER	68.	1.2	69.	0.0053	<0.00010	0.0054	12770		†
805F	04I28784	FILTER	120	6.0	120	0.0090	0.00047	0.0091	12770		†
1304A	04I28785	FILTER	7.8	ND	7.8	0.00062	<0.00010	0.00062	12500		†
1304F	04I28786	FILTER	7.1	ND	7.1	0.00057	<0.00010	0.00057	12500		†
083003A	04I28787	FILTER	13.	ND	13.	0.00093	<9.5E-5	0.00093	13740		†

† See comment on last page.
ND Parameter not detected above LOD.
NR Parameter not requested.
NA Parameter not applicable.

** See comment on last page.
( ) Parameter between LOD and LOQ.

Analyst: Penny A. Foote

Reviewer: Robert B. Copenhafer

DATA CHEM LABORATORIES
A Sorenson Company

ANALYTICAL REPORT

Form ARF-BL
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Part 1 of 1
09300414035004RX

SEP 30 2004

Date _____

Laboratory Group Name 04I-3026-02

Analytical Results

Field Sample Number	Laboratory Number	Sample Type	Organic Carbon µg/sample	Elemental Carbon µg/sample	Total Carbon µg/sample	Organic Carbon mg/m³	Elemental Carbon mg/m³	Total Carbon mg/m³	Air Volume L		
083004F	04I28788	FILTER	35.	ND	35.	0.0026	<9.5E-5	0.0026	13740		†
043004C	04I28789	FILTER	55.	0.87	55.	0.0042	<0.00010	0.0043	12940		†
043004P	04I28790	FILTER	210	9.8	220	0.017	0.00076	0.017	12940		†
0831A	04I28791	FILTER	90.	1.6	92.	0.0068	0.00012	0.0069	13300		†
0831F	04I28792	FILTER	150	15.	160	0.011	0.0012	0.012	13300		†
091404Z	04I28793	FILTER	100	2.3	110	0.0073	0.00016	0.0075	14050		†
09140401	04I28794	FILTER	120	5.1	130	0.0088	0.00037	0.0092	14050		†
0915A	04I28795	FILTER	63.	0.83	64.	0.0047	<9.7E-5	0.0048	13400		†
ZFA04-100	04I28796	FILTER	79.	10.	90.	0.0066	0.00085	0.0074	12060		†
ZFA04-101	04I28797	FILTER	57.	ND	57.	0.0047	<0.00011	0.0047	12060		†
0915F	04I28798	FILTER	480	14.	490	0.036	0.0010	0.037	13400		†
ZFA04102	04I28799	FILTER	8.8	ND	8.8	0.00073	<0.00011	0.00073	12060		†
ZFA04104	04I28804	FILTER	19.	ND	19.	0.0016	<0.00011	0.0016	12060		†
Reporting Limit			**	**							

DATA CHEM LABORATORIES
A Sorenson Company

ANALYTICAL REPORT

Form ARF-AL
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10270510360031RX

OCT 27 2005

Date _____
Laboratory Group Name 05I-4350-03
Account No. 07003

Montana Tech
Attention: Julie Hart
1300 W. Park Street
Butte, MT 59701

FAX (406) 496-4650
Telephone (406) 496-4792
E-mail jhart@mtech.edu

Sampling Collection and Shipment

Sampling Site Missoula Homes-RC/OC Date of Collection _____

Date Samples Received at Laboratory October 21, 2005

Analysis

Method of Analysis NMAM 5040

Date(s) of Analysis October 25, 2005

Analytical Results

Field Sample Number	Laboratory Number	Sample Type	Organic Carbon µg/sample	Elemental Carbon µg/sample	Total Carbon µg/sample	Organic Carbon mg/m³	Elemental Carbon mg/m³	Total Carbon mg/m³	Air Volume L		
108 A	05I41416	QFF	13.	0.91	14.	0.0010	0.000072	0.0011	12600		†
1322 A	05I41355	QFF	85.	0.63	86.	0.0072	0.000053	0.0073	11800		†
215 A	05I41356	QFF	29.	0.85	30.	0.0022	0.000066	0.0023	12800		†
909 A	05I41357	QFF	39.	0.63	40.	0.0030	0.000048	0.0031	13000		†
1612 A	05I41358	QFF	78.	1.3	79.	0.0061	0.00010	0.0062	12800		†
32205 A	05I41359	QFF	41.	ND	41.	0.0036	<4.2E-5	0.0036	11380		†
41405 A	05I41360	QFF	34.	ND	34.	0.0026	<3.7E-5	0.0026	12900		†
104 A	05I41361	QFF	80.	ND	80.	0.0061	<3.7E-5	0.0061	13100		†
Reporting Limit			1.9	0.48							

† See comment on last page.
ND Parameter not detected above LOD.
NR Parameter not requested.
NA Parameter not applicable.

** See comment on last page.
( ) Parameter between LOD and LOQ.

Analyst: Mei Qi Huang

Reviewer: Penny A. Foote