The Alberta Oil Sands Community Exposure and Health Effects Assessment Program:

Technical Report

August 2000

This report is one of a series of published documents:

Pilot Study, 1997
Summary Report, 2000
Methods Report, 2000
Technical Report, 2000

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This report is the result of the efforts of a number of individuals who collaborated to develop a holistic approach to the study of personal exposure and the potential health impact of airborne contaminants.

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1.0 Introduction

Over the past few decades, emphasis has been placed on environmental toxicology and modeling of pollutant fate and transport in the environment to deal with human health concerns. Sources of pollution such as stack emissions, industrial effluents, and toxic wastes are being monitored and are reasonably well understood. However, human exposure to contaminants from all pathways (i.e., air, food, drinking water, and direct skin contact) is largely unknown.

Researchers have been attempting to clarify the relationship between personal exposure and human health outcomes for many years. Beginning in 1979, the United States Environmental Protection Agency (USEPA) developed a strategy for conducting assessments of human exposure to airborne contaminants using a Total Exposure Assessment Method (TEAM). The studies conducted by the USEPA using this method emphasized the necessity of capturing all potential sources of exposure and focused on the added value of measuring a full range of indicators, including personal exposure, biological markers, and measures of health effects. To successfully implement this strategy, TEAM adopted a multi-disciplinary approach to exposure assessment.[1]

Several countries, as well as the World Health Organization (WHO), are implementing exposure and health effects assessment approaches to address human health concerns related to environmental and other (e.g., occupational) factors. This document describes an application of the approach in Alberta, Canada to assess human exposure to contaminants from oil sands industrial activity.

2.0 Context

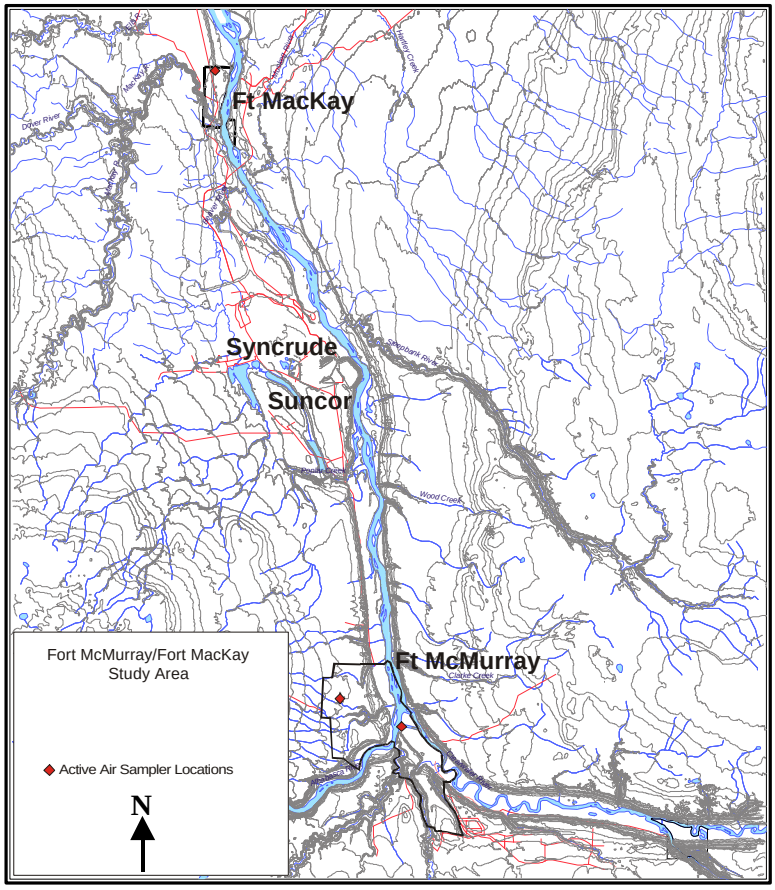
2.1 Alberta

The province of Alberta is located in the prairies of western Canada. The Rocky Mountains and the province of British Columbia border Alberta to the west while the province of Saskatchewan is to the east. The state of Montana lies south of the Canada-U.S.A. international border and to the north are the Northwest Territories. The area of the province is 661,190km^2 (255,291mi^2) with a population of 2,696,826. The population is highly concentrated in the major urban centers, such as Alberta's capital, Edmonton, and Alberta's largest city, Calgary, while the rural areas, especially in northern Alberta are sparsely populated. Alberta's major industries include forestry, oil and gas, agriculture, livestock management, and tourism.

2.1.1 Fort McMurray

Participants for the pilot and main study were recruited from the city of Fort McMurray. As shown in Figure 1, Fort McMurray is situated within the Regional Municipality of Wood Buffalo in northeast Alberta, Canada. The site of the world's largest known oil sands deposits, Wood Buffalo is over 67,164km^2 (25,933mi^2) and has an estimated 42,000 residents in 11 communities. Fort McMurray is the largest community with a population of 36,400 (March, 1999 City Census). The nearest metropolitan centre, Edmonton, is located 450km (280 miles) southwest of Fort McMurray, primarily linked by paved, two-lane Highway 63. Lakes, rivers, and creeks carve the landscape of the Wood Buffalo region. Four rivers merge in Fort McMurray: the Horse flows into the Athabasca, the Hangingstone flows into the Clearwater, and the Clearwater flows into the Athabasca. All tributaries flow northward and eventually empty into Lake Athabasca.

Figure 1: Map of Fort McMurray, Fort McKay, Suncor, and Syncrude



The Oil Sands Industry

The oil sands are very different from conventional oil and natural gas deposits. The oil sands are a mixture of bitumen (the thick black raw material extracted from the oil sands), sand, water and clay. The major challenge in developing oil sands is separating the bitumen from the sand, water, clay, and carbon. Once separated, the bitumen is upgraded into high-quality oil called "synthetic crude".

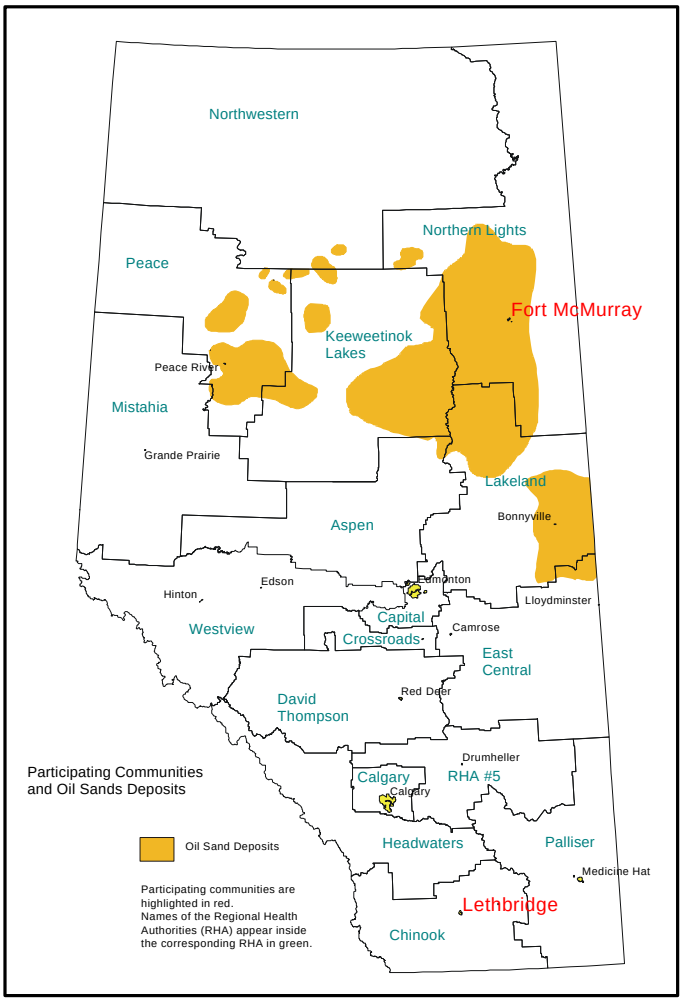
Oil sands and oil shale deposits are found all over the world. There are 16 major oil sands deposits, the largest of which is the Athabasca Oil Sands. There are also major deposits on Melville Island in the Canadian Arctic and three other smaller deposits in northern Alberta: the Peace River, Wabasca, and Cold Lake deposits. Figure 2 shows the location of the Alberta oil sands deposits. These four deposits cover an area of 199,430km^2 (46,113mi^2). The Athabasca Oil Sands alone covers an area of more than 42,000km^2 (16,216mi^2) and contains about 300 billion recoverable barrels of bitumen. In comparison, the Athabasca Oil Sands contain more oil than all the known reserves in Saudi Arabia and represents a third of the world's known petroleum resources.

With the advancement of technology, the economic viability of oil sands development has increased. Full-scale development of the oil sands in the Fort McMurray region began when Suncor and Syncrude started operations in the 1960's and 1970's. Fort McMurray has experienced tremendous growth and opportunity in the last three decades due to the abundance of natural resources in the area, including oil, gas, and forestry. The main industry is oil sands extraction and upgrading at Syncrude Canada, 44km (27 miles) north of the townsite, and Suncor Energy, 34km (21 miles) north of the townsite. The locations of these two industries in relation to Fort McMurray are shown in Figure 1. Combined, these two major industries employ about 7,000 people or approximately one-third of the labor force in the community and immediate surrounding area, while providing about 20% of Canada's energy needs. In addition to Syncrude Canada and Suncor Energy, there are a number of other oil extraction plants that also have employees living in the community. The gas industry has also played an increasingly important role in this region during the past several years. There are approximately 15 gas companies operating in the region. Employment in the forestry sector is growing with the development of the Athabasca Pulp and Paper Mill (ALPAC) and general development of the forestry sector across northeast Alberta.

Syncrude Canada and Suncor Energy are currently in the process of expanding their industries. Syncrude Canada has construction underway on three major projects simultaneously: the second train in the North Mine area, the first train at Aurora, and the second phase of the Upgrader Debottleneck. All of these projects will be completed and commissioned by July 1, 2000. This will lead to an additional 15 million barrels of Syncrude Sweet Blend a year, bringing a projected total of 94 million barrels produced by 2001. Meanwhile, Suncor Energy has designed Project Millennium. The first phase of the project, called the Production Enhancement Phase (PEP), is designed to improve processes and increase plant capacity to reach 135,000 barrels per day by the year 2001. The second phase calls for further development of the Steepbank Mine, expansion of the extraction and upgrading plants, and increased requirements for steam, water, and electricity. The projected end result would be to expand production to 220,000 barrels of oil per day by 2002, doubling current production.

There are many other industries in the Fort McMurray region. Gulf Canada Resources Ltd. is investing in a pilot project in the Surmount area near Fort McMurray. Gulf, which owns or manages a 20.77% stake in the Syncrude plant, is planning to develop a commercial plant at Surmount. In 1997, Shell Canada Ltd. announced plans for a new major oil sands surface mine and extraction plant, located about 70km (43 miles) north of Fort McMurray. The proposed Muskeg River Mine will produce up to 150,000 barrels per day of bitumen starting in 2002. It will be linked to a new bitumen upgrader at Shell's Scotford Refinery near Fort Saskatchewan, Alberta, by the proposed 496km (308 miles) Corridor Pipeline. Koch Canada Ltd. has a 78% interest in the proposed 90,000 barrels per day Fort Hills bitumen mine project. Koch is expecting a significant increase in its workforce in the next few years. First Oil from the Fort Hills mine project is anticipated in 2005. Mobil Oil Canada plans to develop an oil sands mine, extraction facility, and related infrastructure. The mine will be designed to produce an estimated 130,000 barrels a day of bitumen and will be built and operated 70km (43 miles) north of Fort McMurray, Alberta. Projected construction is 2000 with First Oil anticipated in 2003.

Figure 2: Oil Sands Deposits in Alberta



2.1.2 Lethbridge

Participants were recruited from the city of Lethbridge to act as a control group for comparison with the main study sample from Fort McMurray. As shown by Figure 2, Lethbridge is situated in south-central Alberta. Lethbridge is 217km (134 miles) south of Calgary, 518km (321 miles) south of Edmonton, and 105km (65 miles) north of the Montana border. The population of Lethbridge is 68,712 (April, 1999 City Census). The Oldman River flows through the city of Lethbridge, before heading northeast towards Hudson Bay. Table 1 shows other demographics for the city of Lethbridge with comparable data for Fort McMurray and Edmonton. Although Lethbridge is considerably larger than Fort McMurray, both cities are considered medium-sized within the province of Alberta. Winter temperatures are colder in Fort McMurray due to its more northern proximity and also due to the warm chinooks that are characteristic in Lethbridge during the winter months.

Agriculture is the main industry of southern Alberta. It plays an important role in the Lethbridge's retail, wholesale, and service sectors. Service and trade industries comprise over one half of all the occupations in Lethbridge, the largest employer being the Chinook Health Region.

Lethbridge served as an appropriate control community for Fort McMurray due to the contrast of industries between the two cities. The role of petroleum-based industries in and surrounding Lethbridge is minimal (oil sands mining is non-existent) compared to the crucial role of these industries in the Fort McMurray region. Both cities are relatively isolated from any major urbanized cities (i.e., Edmonton or Calgary) that may influence the quality of air and types and levels of environmental contaminants.

Table 1: Comparison of Fort McMurray, Lethbridge, and Edmonton[2,3,4]

	Fort McMurray	Lethbridge	Edmonton
Population	36,400	68,712	616,306
Area	60.7km^2 (15,000 acres)	127.1km^2 (31,415 acres)	671km^2 (165,811 acres)
Temperature	Jan.: -25.3°C (-13.5°F) July: 23.2°C (73.8°F)	Jan.: -14.2°C (6.4°F) July: 25.9°C (78.6°F)	Jan.: -17.0°C (1.4°F) July: 23.0°C (73.4°F)
Precipitation	Rain: 335mm (13.2") Snow: 172cm (67.7")	Rain: 263mm (10.4") Snow: 160cm (63.0")	Rain: 349mm (13.8") Snow: 130cm (51.2")
Elevation	369m (1211')	929m (3048')	668m (2192')

3.0 Study Rationale

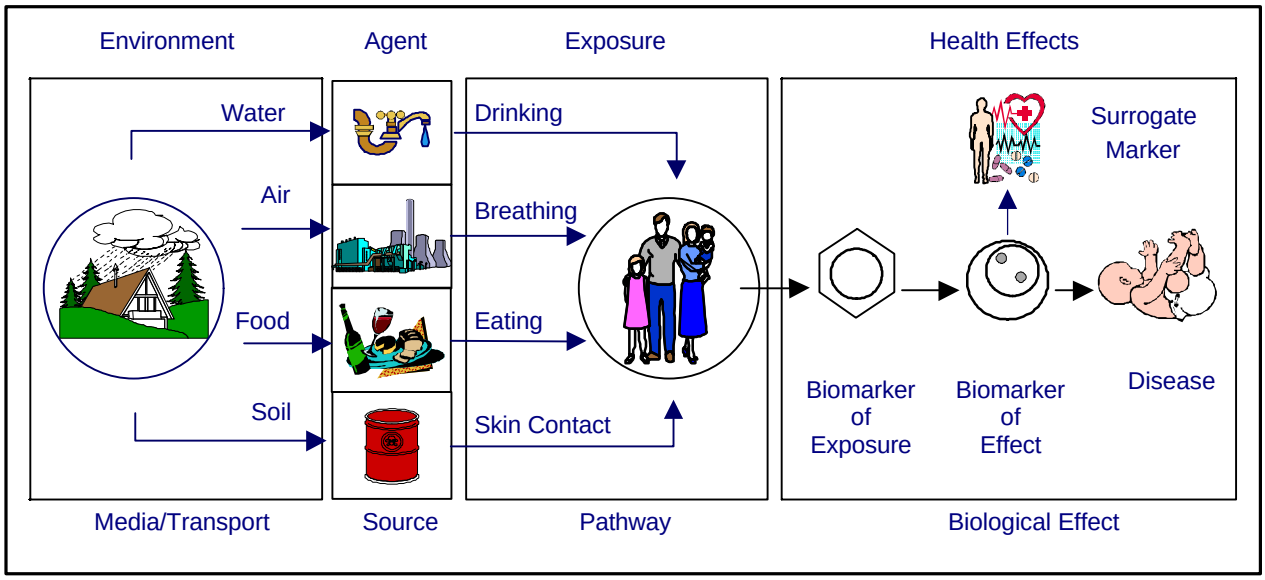
In general, exposure is any contact between a substance, biological agent or radiation and an individual or community. We are all exposed to low-levels of contamination in the air we breathe, the food we eat, the water we drink, and the consumer products we use. Contaminants can interfere with the normal biological functions, causing effects ranging from subtle biochemical changes to clinical disease and even death.

The concept of a continuum from source of contamination to the final health effect is a basic feature of all contemporary risk models (see Figure 3). Determining the risk posed by environmental contaminants to populations requires knowledge about the following fundamental components:

- source(s) of contaminants;
- transport of agents in the environment;
- exposure of individuals and communities to chemicals;

- dose received by those exposed (biological markers of exposure);
- early biological effects resulting from the dose (biological markers of effect);
- overt health effects (clinical disease, death).

Figure 3: Continuum of Exposure



The output of each component in the chain of events serves as input to the next. Thus, the lack of information on any one component impairs our ability to make accurate assessments of the associated population health risks. Our knowledge about the source and transport of chemicals and other agents in the ambient environment is fairly well established as the result of environmental monitoring programs. However, there is a need to integrate these data with information on population exposure, biological markers and associated health effects or conditions. This is very important in achieving new, health-based protection levels.

In dealing with population health outcomes that may be attributable to exposures to low levels of contaminants, we are confronted with the difficult and complex problem of chronic health effects. A number of conditions, such as cancers, disorders of the cardiovascular system, neurological diseases, chronic respiratory ailments, and many other diseases have important environmental, behavioral, social, and genetic links. Other characteristics such as multistage development, long induction time, and the absence of information on individual and population exposure, make progress in chronic disease prevention slow and tenuous. In order to be able to address these issues, more than ever, there is a need to look beyond one-time epidemiologic studies.

3.1 Literature Review

In the past, assessments of human exposure to air-borne contaminants and the associated health effects have relied on two sources: 1) evaluation of occupational exposure and the associated health effects; and 2) comparison of hospitalization or mortality rates with fixed site measurements of ambient air, considered proxies for estimates of personal exposure. Ambient monitoring was implemented to determine overall air quality and to estimate the quantity of specific contaminants in the airshed; the

outdoor pollutant levels measured at these monitoring stations were then used as an estimate of personal exposure for people living in that region. However, scientific understanding of the links between ambient measures of air pollution, personal exposure, and associated health outcomes is incomplete. Further, it has become increasingly recognized that indirect measurement of exposure does not account for variation in personal exposures to these contaminants.

In the past few decades, a number of studies have found a significant difference between measurements of pollutants taken at the individual exposure level and ambient measurements from the geophysical carrier media.[5] Information about the correlation between fixed site concentrations and measurements of personal exposure are necessary to adequately investigate the validity of ambient concentrations at a fixed site as a measure of exposure to air pollutants. In response to this gap in knowledge, the USEPA developed a more precise and accurate method of determining the exposures of the general population to certain pollutants. The new approach was an innovative way of working backward from the individual toward the polluting industry. Its use in a USEPA study that evaluated air quality criteria for carbon monoxide[6] influenced other researchers to adopt the same approach, thereby developing new scientific methodologies to investigate other pollutants.[7, 8] USEPA's Total Exposure Assessment Methodology (TEAM), emphasizes the necessity of measuring individual human exposure to the target pollutants. The TEAM approach embodies four fundamental characteristics:

1. direct measurement of all routes of exposure (breathing, ingestion, and skin contact);
2. direct measurement of biomarkers;
3. daily logs of a participant's activities; and
4. a representative probability sample.

Initially, this concept was tested in three small pilot studies measuring VOCs.[9, 10, 11] Following the pilot studies' success, large scale TEAM studies were applied in New Jersey.[12, 13] These studies found that personal exposure measures for VOCs were consistently higher than the measured outdoor concentrations; indoor sources appeared to be responsible for much of the difference.

With a history of effectiveness, application of the TEAM approach was expanded to include measurement of exposure to inhalable and respirable particles – referred to as the Particle Total Exposure Assessment Methodology (PTEAM). This revised method was adopted by the Research Triangle Institute for a study measuring indoor and outdoor phthalates and polycyclic aromatic hydrocarbons (PAHs) in Riverside, California.[14] The TEAM approach has evolved and has been adapted for use by various researchers with the underlying goal of improving health risk assessment. More importantly, this method of assessment focuses its resources towards what environmental regulatory programs primarily exist to protect the human population.

The assessment of the effects of exposure to airborne pollutants on human health depends on obtaining reliable estimates of exposure. Personal exposure monitors play an integral part of the TEAM methodology since it is focused on the individual. A preliminary report that used personal samplers to study ambient air concluded that data from fixed air stations was not reliable.[15] The value of personal monitors in environmental studies has been recognized since the mid-1970's.[16, 17] The National Academy of Sciences recommended the development of a national research and development program focusing on personal monitoring of exposure to airborne pollutants.[18]

The challenge faced by engineers and chemists was to design a personal exposure monitor that was both small, rugged, and lightweight so as not to interfere with a participant's daily activities, yet sensitive, reliable, and accurate enough to take valid measurements. All the attention this field has received made possible the further enhancements in miniaturization, adsorption techniques, and pump design of personal monitors. Personal samplers for gases were originally designed as active pump-like mechanisms that took

measurements by extracting a known volume of air.[19, 20, 21] The equipment required to collect accurate measures proved to be heavy, large, and complicated to operate.

In 1976, Yanagisawa developed a sampler that operated on the principle of diffusion. It was lightweight, small, inexpensive, and easy to operate, although the adsorption rate was subject to changes in wind velocity.[22] Palmes produced a personal sampler that takes its measurement from a column of air trapped in an acrylic tube.[23] This approach overcame the problem of false readings caused by wind velocity but, at the same time, sacrificed sensitivity. Aoki developed a plastic plate with small holes over an absorbent pad saturated with a chemical solution that reacts with a target pollutant.[24] This new personal sampler was inconvenient because of its large size and due to the necessity of maintaining the sampler in a horizontal position for accurate measurements. Further developments led to the "filter badge" designed by Yanagisawa and Nishimura.[25] It was a small, lightweight, and inexpensive absorbent pad that produced satisfactory results over a wide range of wind velocities and relative humidities. Enhancements of these passive monitors coupled with new collection techniques have made possible the accurate detection of other criteria pollutants.

The development of active personal measurements of inhalable and respirable suspended particulate (RSP) matter has received similar success to that of passive monitors. Initial limitations included noise, battery lifetime, and detection limit (i.e., sensitivity). Thomas[26] added noise-dampening material to reduce noise level and Lioy[27] went a step further by packing the pump in an acoustic shell. The short battery lifetime was remedied by changing the batteries every 12 hours.[28] In a study comparing personal, indoor, and outdoor levels of RSP in Portage, Wisconsin and Topeka, Kansas, personal exposures were shown to be higher than indoor levels, which in turn were higher than outdoor levels.[29] In an analysis of indoor and outdoor RSP relationships, it was determined that outdoor respirable particulate mass does not correlate well with personal or indoor metal concentrations.[30] In addition, the amount of time spent in motor vehicles was found to be a relatively good indicator of lead exposures. The results of a number of PTEAM studies indicate daytime personal particulate matter of 10 micrometers or less (PM_{10}) exposure levels and the concentrations of nearly all particle-bound elements were elevated relative to indoor and outdoor concentrations.[31]

In addition to the use of personal monitors to measure personal exposure, the TEAM approach also included the use of time activity diaries, a diary of the location and potential sources of exposure kept by the participant throughout the measurement period. The information from time activity diaries can also identify the level of physical activity of individuals to help determine dose from exposure. They can provide the amount of time spent at microenvironments both indoors and outdoors and may identify exposure sources that may have been present. In conjunction with personal exposure monitors, the data collected using time activity diaries can serve as time-weighted estimates of exposure. Moreover, when used with personal exposure monitors, they can identify an individual's use of materials that may explain an unusual increase in exposure. In the Total Human Exposure Study, the maintenance of a personal log was tested to determine its ability to identify various routes of exposure to benzo(a)pyrene (BaP) and PM_{10}.[32] It was observed that although outdoor sources accounted for most of the personal exposure, a variety of household appliances and personal activities were also identified as minor contributors. Liu developed a model of O_3 exposure based on outdoor measurements and time-activity information that was used to predict the mean personal exposure for a large population, with the highest R^2 value of 0.41.[33]

3.2 Measurement of Health Effects

As mentioned above, the TEAM approach also includes measurement of biological measures of exposure and effect, a relatively recent development in the field of environmental toxicology.

Early methods in toxicology were not sensitive enough to characterize the events that took place in the body between exposure and health effect – considered an unknown black box linking exposure and disease.[34] Researchers in the late 1970's attempted to determine exposure by measuring changes in the blood using hemoglobin adducts.[35] In 1982, Perera and Weinstein proposed using biomarkers to identify potential environmental contributors to cancer in humans and other researchers began using biomarkers to measure occupational exposure.[36] Hattis proposed the use of biomarkers in quantitative risk assessments, and described their use to characterize the dose-response relationship, to estimate internal dose, and to assess inter-individual variation.[37] The following year, the National Research Council of the National Academy of Science[38] issued a report that described the potential of biomarkers for quantitative risk assessment, the appropriate methods of validation of biomarkers, and presented the conceptual model of the black box, describing the internal biological events that lead from exposure to disease.

The conceptual model proposed by the National Research Council (NRC) divided biological events into four discrete stages representing two classes: 1) internal dose and biologically effective dose, representing biomarkers of exposure, and 2) early biological effect and altered structure or function, representing biomarkers of effect. A third class, biomarkers of susceptibility, refers to the transition steps between the stages, and reflects the uncertainty in the progression from one stage to the next. The NRC model identified the internal dose as a measure of the amount of contaminant absorbed by the body. Many factors influence the amount of contaminant that is absorbed into the system, including level of exposure, elimination processes, and the physical characteristics of the individual. Although there is a certain degree of variability across individuals, measures of the internal dose can provide information about exposure, and the amount of contaminant that is absorbed by the body, but not about the potential health risk. Biomarkers of the biologically effective dose indicate the amount of the contaminant that has been metabolized and distributed through the body to the target organs. Biomarkers of the biologically effective dose measure the amount of contaminant that has interacted with the cells of the body, such as DNA or protein. Since Osterman-Golkar and Ehrenberg[39] first proposed the use of hemoglobin adducts to monitor the internal dose of ethylene oxides, this approach has been used by researchers for biomarkers of exposure to a variety of compounds, including aromatic amines and polycyclic aromatic hydrocarbons.[40]

According to the NRC model, biomarkers of early effect are defined as "any change that is qualitatively or quantitatively predictive of health impairment or potential impairment resulting from exposure".[41] Examples of early biological effect include inhibition of d-aminolevulinic acid dehydratase (indicating lead toxicity), oncogene activation (indicating carcinogen exposure), and impaired cell-mediated response (indicating exposure to TCDD).[42] Measures of altered structure or function include enzymatic changes, functional test abnormalities, and tissue hyperplasia. Although biomarkers of effect are more predictive of disease than biomarkers of exposure, they are not as clearly linked with exposure to a particular toxin.[43] Some biomarkers of outcome are associated with exposure to a wide range of contaminants and, as such, provide an estimate of early effects that may or may not develop into long-term disease. For example, repeated respiratory infections or chronic lung inflammation may develop into irreversible lung damage, and measures of lung function would, therefore, provide a valuable indicator of exposure. Unfortunately, there is no way of determining the source or specific contaminant that caused the inflammation.

By 1992, biomarkers were included in the USEPA guidelines[44] for exposure assessment, but debate over the relevance and priority of measures of exposure continues.[45] Ongoing discussion typically focuses on comparisons between measures of personal exposure using passive samplers described previously and biological measures of exposure or effect.

Rappaport suggested that biological measures are more accurate than measures of the contaminant in air.[46] In a study of a cohort of workers exposed to styrene in a boat manufacturing facility, the researchers found that the variability across individuals was less extreme in the biological measures compared to the

measures of personal exposure in air. Measures of internal dose account for differences in uptake, metabolism, and elimination of toxins across individuals, so it can be argued that they are a more accurate measure of the toxicity that is actually available to cause adverse health effects.

Biological measures also take all exposure sources into account: inhalation, ingestion, and dermal exposure, and can therefore be used as a measure of total exposure. This inclusive scope causes some difficulties when the purpose of the exposure assessment is to identify the source of the contaminants because the amount of corresponding information that must be collected increases dramatically. It is also more costly and problematic to obtain biological samples, particularly of biomarkers such as lung tissue. Other difficulties with adequately correlating biomarkers with exposure include variability of exposures across time, multiple sources of exposure, and individual differences in uptake.

Notwithstanding the difficulties of using biological markers of exposure, the value of including biological markers along with more conventional measures of exposure is widely recognized.[47] Biomarkers can identify whether or not detectable exposure occurred, define the relationship between ambient levels, personal exposure, and internal dose, and identify how persistent the contaminant is over time. Specific biomarkers can be used to identify which contaminant is being metabolized when an individual is exposed to a complex mixture of contaminants.

The choice of which markers are appropriate for a study depends on the goals of the assessment, the predictive value of the particular marker, the availability or the ease of obtaining specimens, the sensitivity of the marker, and the cost of conducting the assay.[48] For example, the lifetime of metabolites or adducts in blood is relatively short, and the lifetime of these measures in urine is even shorter. Hemoglobin adducts resulting from acute exposure to a contaminant would no longer be evident in the blood after approximately one month, and metabolites in urine disappear even more quickly. The concurrent use of biomarker measurement with Time Activity Diaries can be used to infer whether the presence of a particular contaminant is more likely to be due to a single, recent, high-level exposure, or to a lower level of long-term exposure building up and maintaining a presence in the system; time-series measurements of the biomarker in question can further support this inference.

4.0 Main Study Objectives

The Main Study of the Alberta Oil Sands Community Exposure and Health Effects Assessment Program had three main objectives:

1. Describe the population and personal distribution of exposure to airborne chemicals and particulates:
   - estimate the population distribution of selected airborne chemicals and particulates;
   - estimate the seasonal variation of exposure and;
   - characterize the personal variation of exposure as a function of individual activity patterns.
2. Quantify the relative contribution of various exposure sources and pathways to airborne chemicals:
   - quantify the relative contribution of outdoor and indoor air to the total exposure.
3. Describe associations between exposure to airborne chemicals and human health effects:
   - analyze occurrence relationships between selected exposures, biomarkers, and health outcomes.

5.0 Study Design

The Alberta Oil Sands Community Exposure and Health Effects Assessment Program was modeled after the USEPA TEAM approach.[49] As discussed previously, the TEAM approach is based on four fundamental characteristics: direct measurement of all routes of exposure (breathing, ingestion, and skin contact), direct measurement of biomarkers, daily logs of a participant's activities and a representative probability sample. The study was designed to assess exposure and associated health effects by direct measurement of personal exposure, direct measurement of biomarkers, and daily logs of a participant's activities. The study did not use a representative probability sample, for two major reasons:

1) the high level of commitment required from participants; and

2) the high cost of administering a complex sampling design.

The science team determined that the high level of commitment required from potential participants would result in a biased sample, regardless of the recruitment method. Furthermore, the high cost of administering a complex sampling design was not considered to be offset by an improvement in the selection bias. Consequently, participants were recruited on a volunteer basis. The *Methods Report* provides a more detailed description of the various components in the study, including recruitment methods, study protocols, and validation studies. Please refer to this document for further detail.

The contaminants identified for personal exposure measurement for the Alberta Oil Sands Community Exposure and Health Effects Assessment Program were sulfur dioxide, nitrogen dioxide, ozone, volatile organic compounds and particulates. The final list of contaminants were identified using three criteria:

1) the local priority contaminants of concern;

2) national initiatives; and

3) the availability of technology to measure the contaminants.

The local community identified a number of priority contaminants, and these were highlighted during the public hearings conducted by the Alberta Energy and Utilities Board in relation to Syncrude's Mildred Lake Development Project (1994).[50] Human health concerns related to air quality were raised by various participants including aboriginal groups, environmental associations, and Alberta Health.

National initiatives also identified these contaminants as a priority, as evidenced by the Canada-wide standards initiative on particulate matter and ozone, among other contaminants.

Finally, the availability of appropriate technology was a key defining factor in the final selection. Personal samplers for ozone and particulate matter were commercially available. Commercially available VOC samplers were deployed during the pilot study and analyzed for a wide range of contaminants; the final selection of VOCs analyzed for the main study included all VOCs for which measurable quantities were identified during the pilot study. Samplers for SO_2 and NO_2 were not commercially available, but these contaminants were identified as a priority for measurement. Samplers for these two contaminants were developed and tested during the pilot study. Please refer to the Pilot Report for more details.

The selection of biomarkers for the Alberta Oil Sands Community Exposure and Health Effects Assessment Program was based on a number of factors, including the ability of the laboratory to measure low levels of relevant biological markers, the most appropriate media for measuring the markers, and the burden placed on each volunteer. The final set of biological measures of exposure included: trace metals such as arsenic, cadmium, lead, and uranium; nicotine; and metabolites of the BTEX compounds (benzene, toluene, ethylbenzene, m-, p-, and o-xylene). Although there are several methods of measuring

benzene exposure in biological media, the most appropriate measure of low-level exposure to benzene from environmental sources is urinary muconic acid.[51] Studies have shown that urinary muconic acid is the most sensitive measure available to detect environmental exposures of less than 1mg/m^3. [52] Similarly, urinary mandelic acid, hippuric acid, 2-, and 3-, 4-methylhippuric acids are indicative of exposure to ethylbenzene, toluene, and o- and m-xylene, respectively. Measures of serum levels of nicotine were included to identify the contribution from tobacco smoke to serum levels of both trace metals and B-TEX compounds.

The biological measures of effect included in the study were autoantibody activity, Immunoglobulin gamma E (IgE), a respiratory health assessment including a respiratory health history survey and a spirometry assessment, and a neurocognitive assessment.

In addition, it is important to estimate the impact on human health from natural sources such as pollen and dust, to determine the relative impact from oil sands activity. Increases in antinuclear autoantibodies result from a reaction by the immune system to external stressors. Comparison of prevalence with reference populations can be used to demonstrate differences in exposure and response, including an indication of whether there is evidence of elevated immune system reaction in the sample population.

The study included several measures to account for health effects such as allergies unassociated with exposure to airborne chemicals. One of the best markers of genetically inherited allergies (atopy) is the excessive production of Immunoglobulin gamma E (IgE). High levels of IgE are associated with an increased incidence of diseases including bronchial asthma, allergic rhinitis, and eczema. A comparison of the total serum IgE level in the two sample populations with reference populations from previous studies can indicate whether there is evidence of increased allergic response in the sample population.

The respiratory system is naturally a major site of exposure to airborne contaminants. The effects of exposure to airborne contaminants on the respiratory system may range from mild, acute, and reversible, to severe, chronic, and permanent. Epidemiological studies have shown increased respiratory symptoms (sneezing, cough, chest pain, wheezing) and asthma medication use;[53] hospital admissions for respiratory illness;[54] cardiovascular mortality;[55] and all-cause mortality[56] associated with increased concentrations of some airborne contaminants. Acute effects of exposure to such contaminants as ozone, nitrogen dioxide, sulfur dioxide, inhalable suspended particles, and volatile organic compounds, may include irritation of the respiratory tract, resulting in coughing, sneezing, chest pain, wheezing, and the exacerbation of asthma symptoms; higher concentrations may cause lung edema. In high concentrations, sulfur dioxide can even cause death due to spasm of the larynx and respiratory arrest.[57] Chronic exposure to these contaminants may cause structural alterations in the respiratory epithelium that compromise oxygen absorption and lung elasticity, reduce the ability of ciliated cells to clear mucus from the lungs, leading to increased susceptibility to infection, and may contribute to tumor formation.[58] Humerfelt argued that occupational exposure to sulfur dioxide and metal fumes results in an accelerated decline in forced expiratory volume in 1 second (FEV_1).[59]

Measuring the extent of damage due to exposure to airborne contaminants can be problematic. Spirometric measurements such as forced vital capacity (FVC) or FEV_1 produce consistent results, but may not be sensitive enough to detect damage to the smaller airways, which are the primary sites of attack by airborne contaminants. On the other hand, tests of small airway function, such as the forced expiratory flow between 25% and 75% of the FEV ($FEF_{25\%-75\%}$), are more sensitive, but show large within-individual variation, decreasing the reliability of results.[60] The measure of choice in this case was $FEF_{25\%-75\%}$ because it is sensitive enough to detect obstruction in the small airways, and its higher variability makes it more useful in the comparison of data from large populations.[61]

Neurocognitive impairments have been associated with exposure to a variety of contaminants, both through high volume occupational exposure and low-level environmental exposure. Neurobehavioral tests have been demonstrated to be sensitive to minute changes in neurocognitive functioning resulting from exposure to contaminants such as lead, mercury, aluminum, and volatile organic compounds. Organic solvents also pose a threat to the central nervous system because of their lipophilic characteristics. Short-term low-level exposure has been linked with a pre-narcotic reversible effect of psychomotor slowing or vigilance decrement.[62] Other studies have shown a pre-narcotic state of central nervous system depression, characterized by behavioral dysfunction.[63] Further evidence of the detrimental health effects of organic solvents have demonstrated that heavy and long-term exposure situations can induce a chronic, partially irreversible encephalopathy, with an excess of neuropsychiatric complaints.[64, 65] Volatile organic compounds (VOC) can have a similar impact on the central nervous system. Symptom questionnaires and rating scales have produced consistent evidence of sensory irritation or discomfort resulting from exposure to low-level VOC mixtures.[66] Among the wide range of VOCs, toluene is the best known neurotoxicant. Accidental occupational exposure[67] and controlled exposure experiments[68, 69] have demonstrated its adverse effects on balance, cognitive function, and color vision. Moreover, toluene toxicity can be further increased with the simultaneous exposure of methyl ethyl ketone.

In addition to the direct measures of exposure and the measurement of biological markers of exposure and effect, the study instruments also included a time-activity diary that required participants to record daily activities that might have an effect on exposure.

Figure 4 provides a pictorial description of some of these sources of data. Table 2 provides a more extensive list of data sources for the project, grouping them into various components and providing a purpose for collecting each source of data. The *Methods Report* provides a detailed description of the various components in the study, including the methods, protocols, and validation studies. Please refer to this document for further detail.

Figure 4: Components of the Study

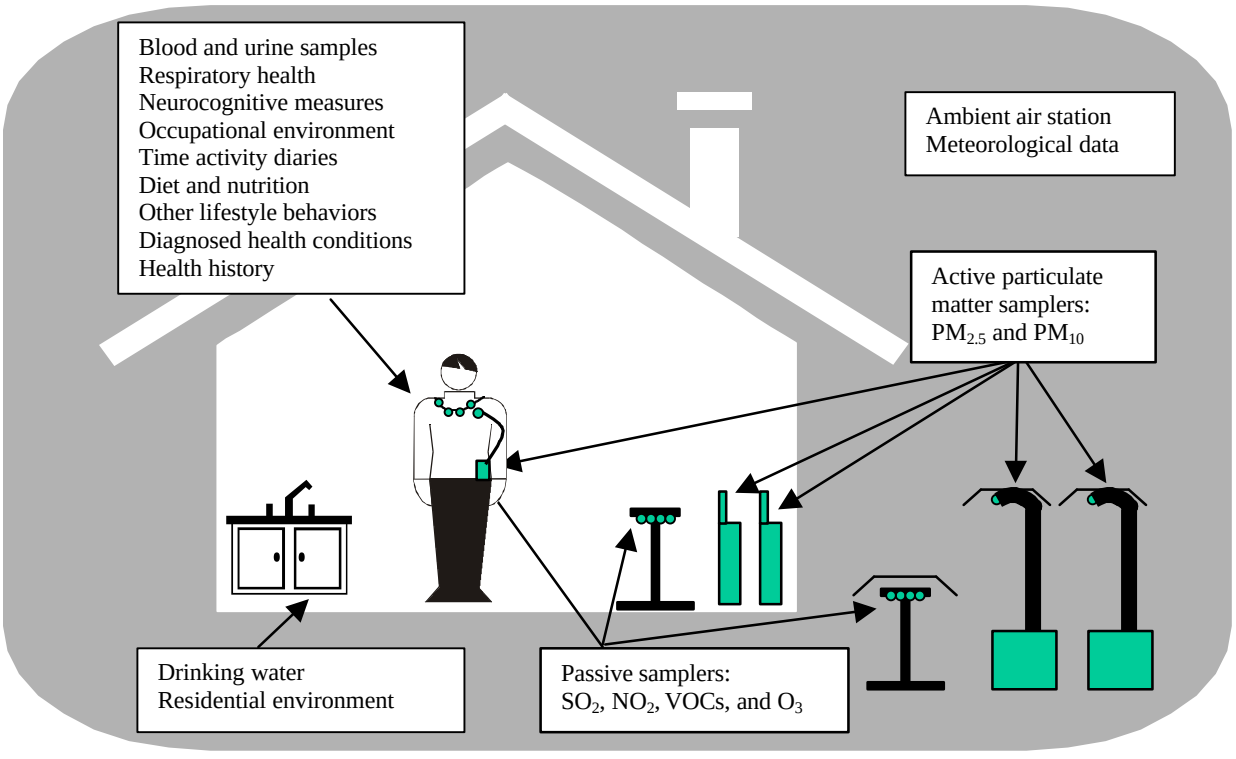


Table 2: Components of the Main Study

Component	Media or Source of Data	Purpose
Characteristics of the Sample	Vital Statistics Other Demographics	General information was collected to help characterize the samples and populations.
	Lifestyle behaviors	Questionnaires identified individual smoking habits, body mass index, nutritional intake, and physical activity levels.
	Drinking water	Routine chemistry and trace metals were measured in a sample of the drinking water used by the household.
	Time Activity Diary	The time activity diary identified potential routes of exposure in daily activities.
Exposure Measurement	Personal Exposure Monitors Passive samplers Particulate samplers	Exposure measurement identified the actual exposure levels of each participant during a regular day, using personal, indoor, and outdoor air monitors. A sub-sample of participants was asked to provide exposure measures for particulates.
	Electron microscopy	Particulate matter samplers were analyzed for the presence and type of organic, mineral, and metal particles.
	Household sources Work sources Dietary exposure	A questionnaire was used to identify potential sources in the home and work environments, and identification of potential dietary sources of exposure.
Biomarkers of Exposure	Blood	Analysis included cotinine (a metabolite of nicotine) and a variety of heavy metal compounds including arsenic, selenium, lead, vanadium, and cadmium.
	Urine	Analysis included metabolites of the BTEX compounds (benzene, toluene, ethylbenzene, m-, p-xylene, and o-xylene) and a variety of heavy metal compounds such as arsenic, selenium, lead, vanadium, and cadmium.
Biomarkers of Effect	Autoantibodies	Analysis included immunofluorescence microscopy to detect autoantibodies, which indicate elevated immune system reaction.
	Immunoglobulin gamma E (IgE)	Levels of IgE in blood were examined. High levels of IgE are associated with an increased incidence of diseases including bronchial asthma, allergic rhinitis, and eczema.
	Lung Function	Spirometry was used to measure the individual's lung capacity and volume during the exposure-monitoring period. A respiratory health survey was also administered.
	Neurocognitive measurement	Computerized neurocognitive tests and the completion of other activities were used to determine the possible impact of chronic exposure on neurocognitive functioning.
Measures of Health	Questionnaires	Questionnaires identified general, occupational, emotional, and psychological health.
		A questionnaire identified previously diagnosed health problems.
Exposure Sources	WBEA ambient station data Exposure measurements	Quantify relative contribution of local emission sources to exposure for various contaminants.

6.0 Characteristics of the Sample Populations

The Alberta Oil Sands Community Exposure and Health Effects Assessment Program's participants included 300 Fort McMurray residents as well as a control group of 34 Lethbridge residents. All participants were at least 18 years of age and all resided within the city limits of each townsite. The city maps of Figures 5 and 6 show the sampling distribution for Fort McMurray and Lethbridge, respectively. As is shown, sampling data was obtained from all areas of each city.

Figure 5: Distribution of Participants in Fort McMurray

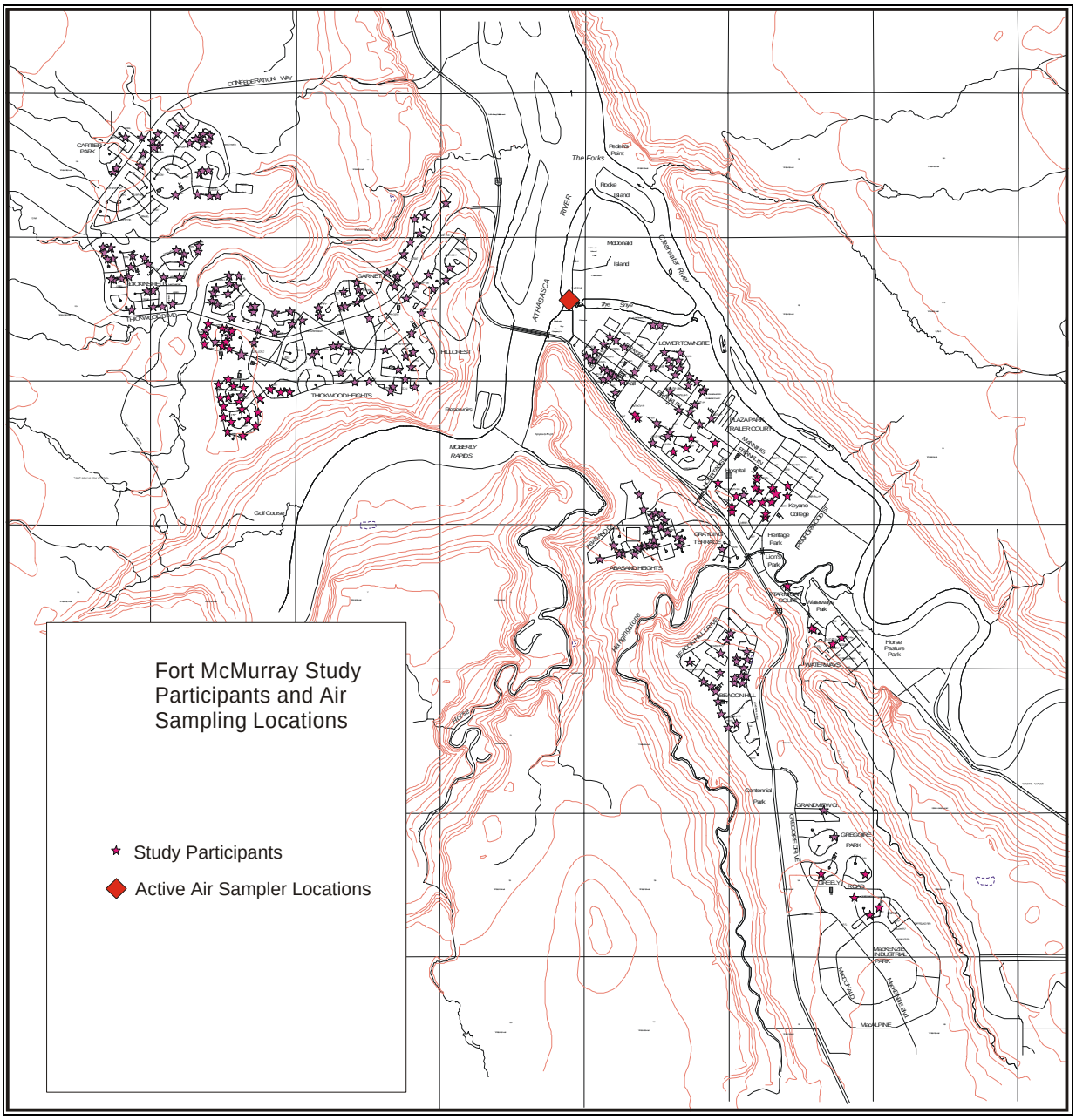
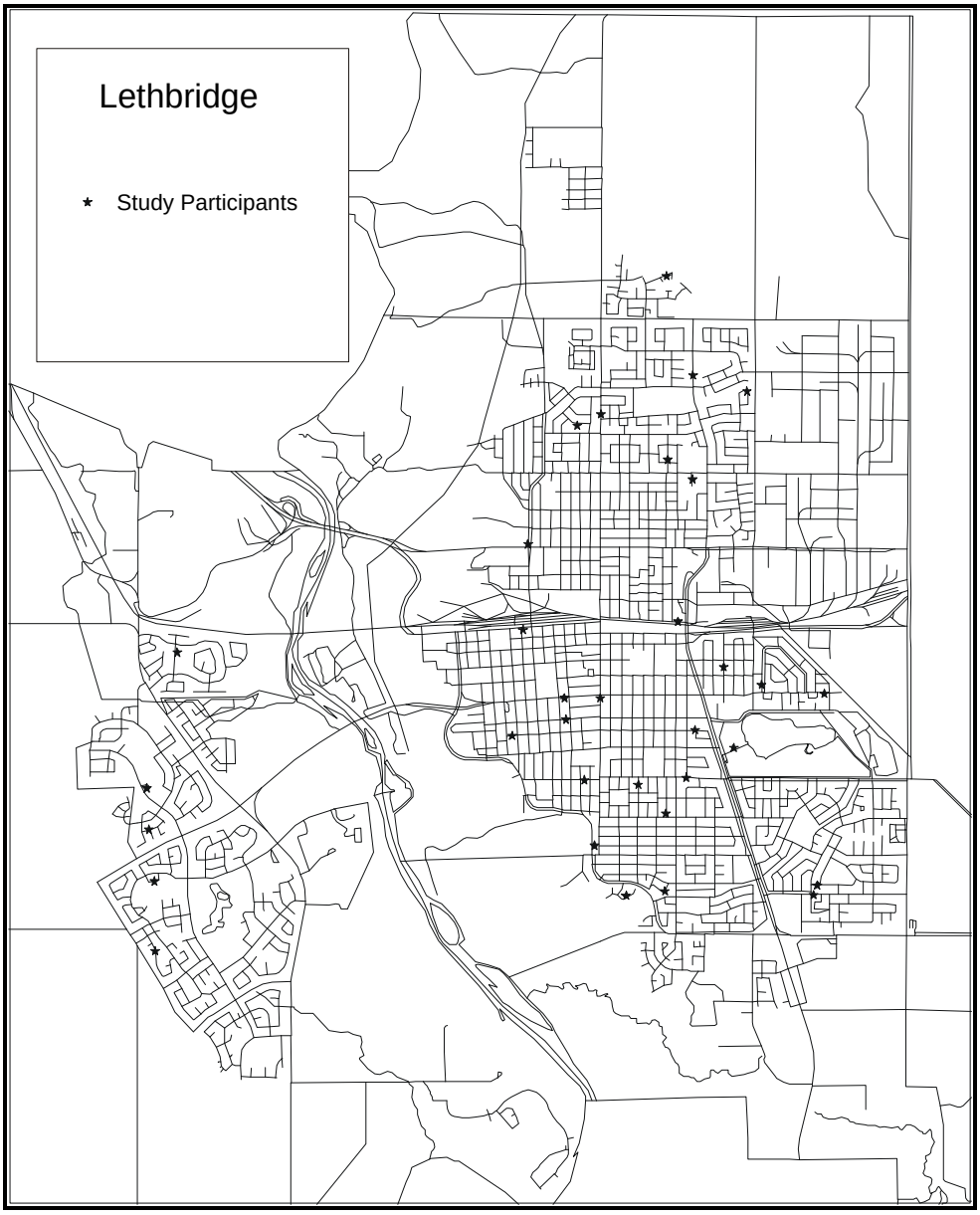


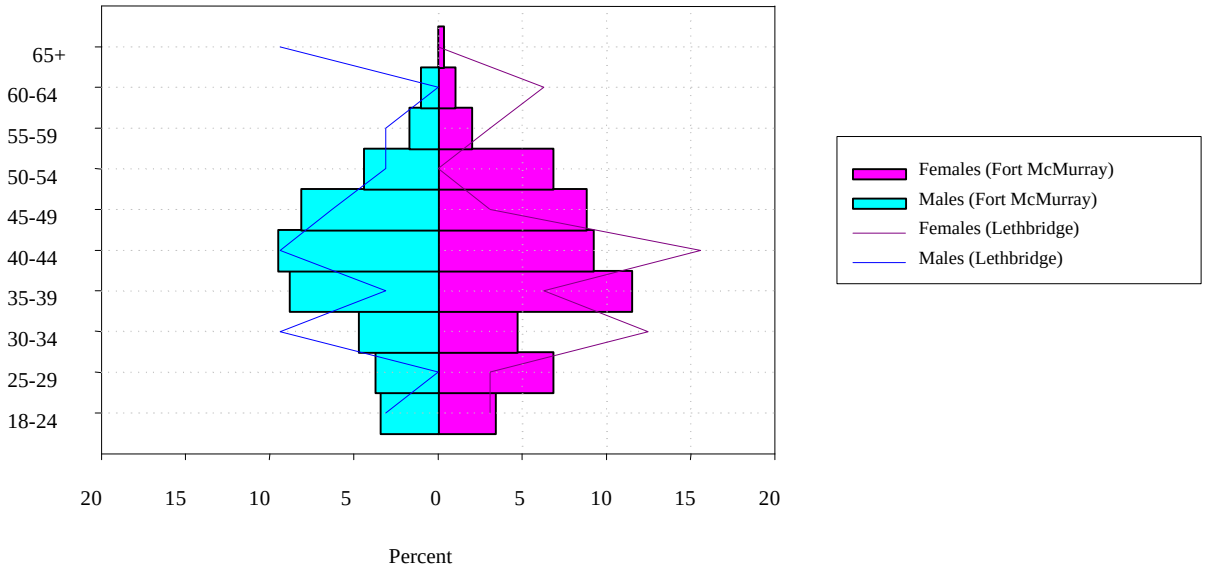
Figure 6: Distribution of Participants in Lethbridge



6.1 Age and Gender

The average age of the Fort McMurray sample population was 40 years (N = 300; SD = 10.05). The Lethbridge sample had a slightly higher average age of 44 years (N = 33; SD = 14.14). Figure 7 shows the age and gender distribution for the Fort McMurray and Lethbridge sample populations.

Figure 7: Age and Gender Distribution of Participants



Most of the Fort McMurray sample fell between the ages of 35 to 49 years of age. Very few participants were older than 55 years of age. The Lethbridge participants, although based on a small sample, had a higher percentage from the older age groups (55 years and over) and a lower percentage from the younger age groups (18 to 29 years). Female participants accounted for 55% of the Fort McMurray sample, which was very comparable to the 54.5% females in the Lethbridge sample.

Figures 8 and 9 show the age and gender distribution of adults living in the two cities. The mean age of the Fort McMurray adult population was 37.80 years (N = 25,740; SD = 12.37) and for Lethbridge it was 45.33 years (N = 62,190; SD = 18.51). As shown by the two figures, the population of Fort McMurray is very young in comparison to the Lethbridge population. The youngest age group (18 to 24 years) accounts for the largest proportion of the population in Fort McMurray while the older age groups account for the smallest percentage of the population. Conversely, the percentage of Lethbridge's population is highest in the oldest category (65 and over). A Health Needs Assessment[70] conducted in December 1997 by the NLRHA stated that the population distribution and age structure of the Northern Lights Health Region (NLHR) is considerably different from the provincial average. They found approximately 94% of the region's population is under the age of 55 years, compared to only 83% for the province. Similarly, the Fort McMurray sample chosen for this study reflected the general Fort McMurray population, consisting of 94.3% of participants younger than age 55.

Figure 8: Fort McMurray Population by Age Groups (% of Total)

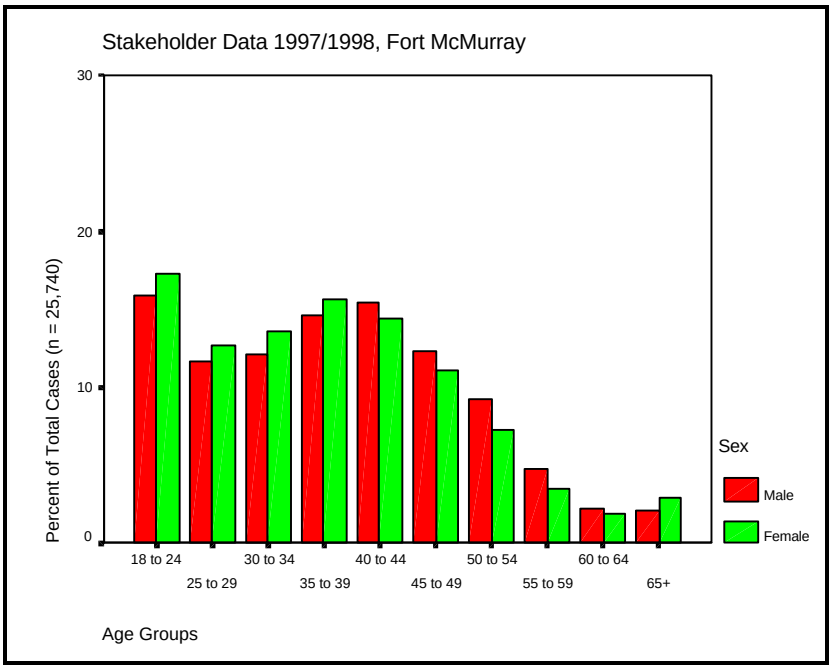
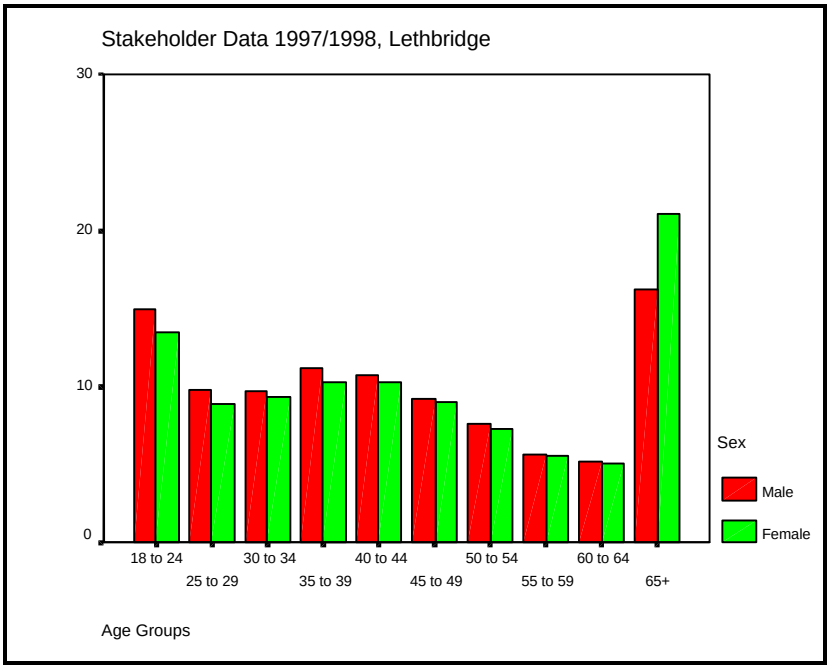


Figure 9: Lethbridge Population by Age Groups (% of Total)



6.2 Education

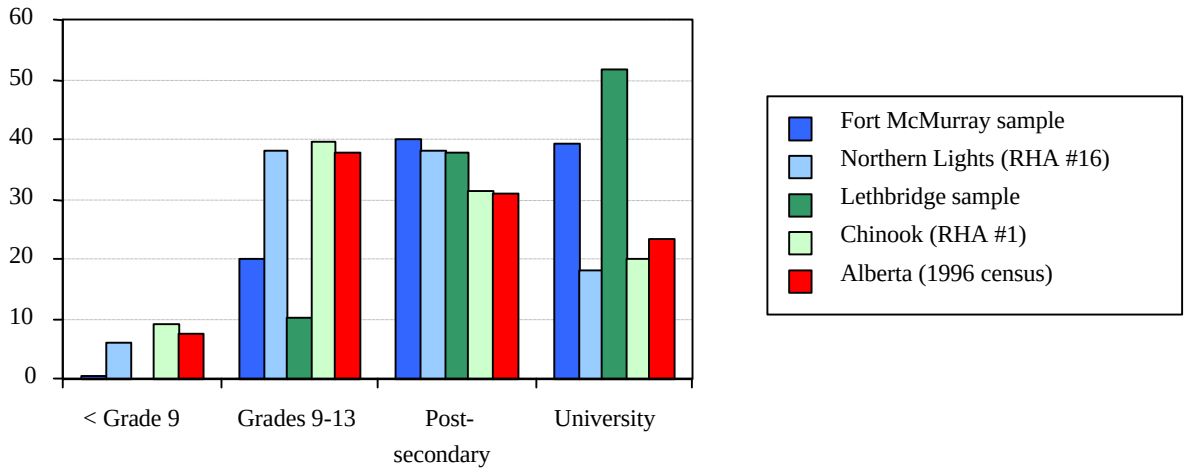
Years of education were examined for both sample populations. The average number of years of education was slightly lower for Fort McMurray participants compared to those from Lethbridge. For the Fort McMurray sample, the average years of education was 14.53 years (N = 274; SD = 2.19) compared to 14.90 years (N = 29; SD = 2.18) for the Lethbridge sample, a non-significant difference. Table 3 and Figure 10 show the level of the last year of education completed as percentages of each sample as well as for their respective health regions and the province of Alberta. As is shown, over half of the Lethbridge sample had completed at least one year of education at the university level compared to about 40% of the Fort McMurray sample. In comparison to the census data for their respective health regions and Alberta, both samples had higher levels of education.

Table 3: Level of Education

			Census Data*		
	Fort McMurray (N = 274)	**Lethbridge (N = 29)**	**RHA #16**	**RHA #1**	**Alberta**
Less than grade 9	0.4%	0.0%	5.9%	9.2%	7.5%
Grades 9 to 13	20.1%	10.3%	38.1%	39.6%	37.8%
Trades certificate or diploma and other non-university education	40.1%	37.9%	38.0%	31.2%	31.1%
University	39.4%	51.7%	18.1%	20.0%	23.5%

*Total population 15 years and over by highest level of schooling (20% sample data),
Source: Statistics Canada, 1996 Census Data.

Figure 10: Education of Participants



6.3 Language

English was indicated as the native language of 89.6% of the Fort McMurray sample population. In the 1996 census, 87.7% indicated their mother tongue as English, quite comparable to the Fort McMurray sample. The Lethbridge rate of 93.9% English was higher than the census rate of 83.1% for the Chinook Health Region.

6.4 Occupation

Almost half of the participants (42.2%) indicated that they were currently employed at one of the major oil sands industries in the Fort McMurray region (i.e., Syncrude Canada Ltd. or Suncor Energy). Table 4 displays the participants' primary employment status and whether this employment was full- or part-time.

Table 4: Primary Work or Employment Status

	Fort McMurray (N = 277)		Lethbridge (N = 30)	
Have a paid job outside of home	85.6%	84.4% FT 14.3% PT	63.3%	73.7% FT 26.3% PT
Self-employed in home	1.4%	25.0% FT 50.0% PT	3.3%	100% FT 0.0% PT
Student	1.4%	100% FT 0.0% PT	10.0%	100% FT 0.0% PT
Full-time homemaker	7.6%		0.0%	
Currently unemployed	1.1%		0.0%	
Retired or disabled	2.2%		23.3%	
Other	0.7%		0.0%	

Note: FT = Full-time, PT = Part-time

Table 5 shows the percentage of participants' who had a second job. A larger percentage of the Lethbridge sample had two jobs.

Table 5: Second Job

	Fort McMurray (N = 268)		Lethbridge (N = 27)	
Second Job	17.9%	6.3% FT 91.7% PT	37.0%	10% FT 80% PT
No Second Job	82.1%		63.0%	

Note: FT = Full-time, PT = Part-time

6.5 Income

Average household income was examined for the two sample populations. Fort McMurray's average annual household income of $60,000 to $69,999 was significantly higher than Lethbridge's $40,000 to 44,999 income. Over half (56.0%) of the Fort McMurray participants indicated their annual household income to be $80,000 or greater compared to only 14.3% of the Lethbridge participants. Table 6 and Figure 11 displays the income ranges for the two samples as well as the census data for the two health regions and the province. As is confirmed by the Northern Lights Health Region (RHA #16) data, the percentage of households making at least $80,000 annual income is about three times higher than both the Chinook Health Region (RHA #1) and Alberta as a whole. The lower income categories are under-represented while the higher income categories are over-represented in the Fort McMurray sample. The RHA averages fall within the range of that found in both sample groups. With similar figures from the

1991 census, the Northern Lights Regional Health Needs Assessment stated that the annual household income in the NLHRA is the highest in Alberta and among the highest in Western Canada.[71]

The cost of living is higher in Fort McMurray than Lethbridge. For instance, housing cost comparisons are estimated at $104,472 for Fort McMurray compared to $96,000 for Lethbridge.[72]

The socioeconomic status (SES) of each population was examined. Nine percent (9%) of the Fort McMurray adult population (between the ages of 18 and 65 years) and 23% of the Lethbridge adult population were defined as low SES and received a full subsidy from Alberta Health Care Insurance Plan and/or were receiving financial support from family and social services.

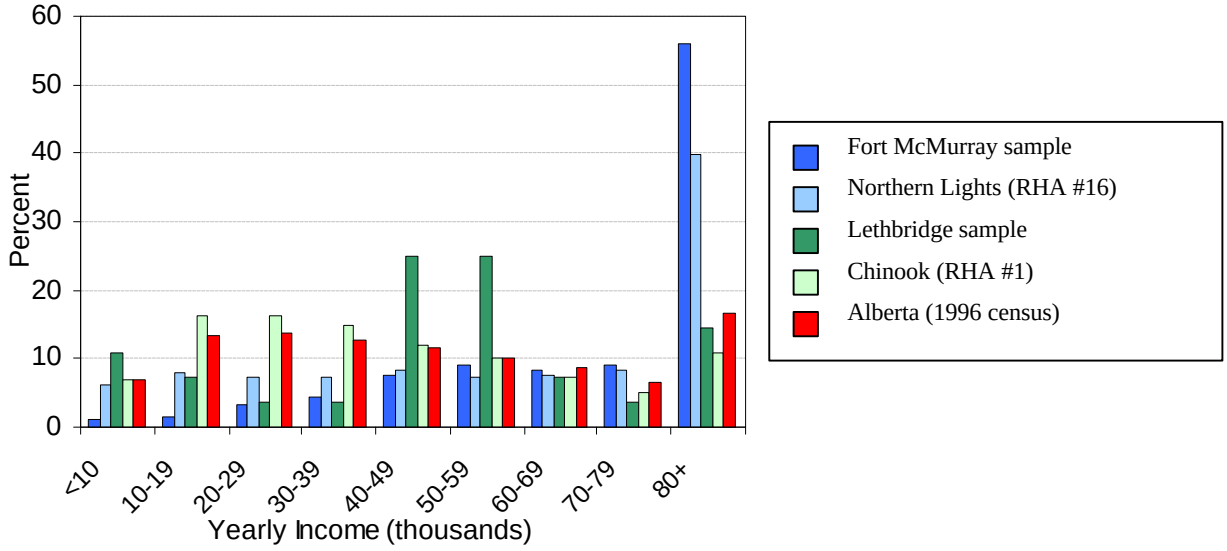
The average number of people per household was 3.26 in Fort McMurray with 4 people being the most common and 2.57 in Lethbridge with 2 people being the most common.

Table 6: Annual Household Income

			Census Data*		
	Fort McMurray (N = 268)	**Lethbridge (N = 28)**	**RHA #16**	**RHA #1**	**Alberta**
Less than $10,000	1.1%	10.7%	6.3%	6.8%	6.8%
$10,000 - 19,999	1.5%	7.1%	8.1%	16.3%	13.5%
$20,000 - 29,999	3.4%	3.6%	7.3%	16.3%	13.6%
$30,000 - 39,999	4.4%	3.6%	7.2%	14.8%	12.6%
$40,000 - 49,999	7.5%	25.0%	8.2%	12.1%	11.7%
$50,000 - 59,999	9.0%	25.0%	7.4%	10.3%	10.3%
$60,000 - 69,999	8.2%	7.1%	7.7%	7.3%	8.5%
$70,000 - 79,999	9.0%	3.6%	8.2%	5.2%	6.4%
$80,000 or greater	56.0%	14.3%	39.7%	11.0%	16.6%
Average	$60,000 to $69,999	$40,000 to 44,999	$69,899	$44,217	$51,118
Median			$66,866	$37,165	$42,701

* Household income of all private households (20% sample data), Source: Statistics Canada, 1996 Census Data.

Figure 11: Distribution of Household Income



6.6 Smoking

Of the Fort McMurray sample 44.8% and 46.7% of the Lethbridge sample indicated they had smoked as much as one cigarette a day for as long as one year. Whether the participant's currently smoked or not, both samples reported that when they did smoke, they smoked 11 to 20 cigarettes per day. Lethbridge participants had smoked for approximately 4 years longer than Fort McMurray participants had. Of the 83 Fort McMurray respondents who smoked and then quit, the mean time period since quitting was 13.36 years, while for Lethbridge it was longer (19.22 years).

The majority of Fort McMurray (79.6%) and Lethbridge (82.6%) respondents indicated that they worked in a non-smoking environment; however the average daily exposure to cigarette smoke (second-hand smoke) varied greatly across participants, from no exposure to as much as 900 minutes per day. Fort McMurray respondents reported being exposed for an average of 86.12 minutes per day while Lethbridge participants averaged 78.27 minutes per day. When the 124 individuals from Fort McMurray and 15 from Lethbridge that had indicated no second-hand smoke exposure were dropped from analysis, the times increased dramatically to 156.84 minutes and 156.53 minutes per day, respectively.

The Northern Lights Region Health Needs Assessment found that smoking prevalence in the NLHRA is higher than the Canadian average.[73] The percentage of regional residents who smoked daily was 32.7% compared to the Canadian average of 25%. These figures are high in comparison to both sample populations where it was found that 15.8% of Fort McMurray participants and 18.2% of Lethbridge participants currently smoked.

6.7 Body Mass Index (BMI)

A body mass index (BMI) was calculated for each participant based on reported height and weight. The BMI is considered a valid measure of obesity because it "is a simple convenient measure that correlates well with skinfold and body density measures and has been adopted in the *Canadian Guidelines for Health Weights.*[74] A BMI of less than 20 indicates that the individual is underweight for their height, and there may be some associated health problems. A BMI between 20 and 25 is considered a healthy range. A BMI of between 25 and 27 indicates that the individual is slightly overweight, which may lead to health problems for some people, while a BMI over 27 indicates an increased risk of health problems associated with weight.

Table 7 compares the proportion of study participants in each BMI category while Figure 12 shows the distribution of BMI for the two sample populations. The average BMI for the Fort McMurray participants was 27.06 and the average BMI for the Lethbridge participants was 27.47, not a large enough difference to be statistically significant. Only 4% of the Fort McMurray participants and 7% of the Lethbridge participants had a BMI of less than 20 (slightly underweight). Approximately 17% of Fort McMurray and 13% of Lethbridge participants had a slightly high BMI (slightly overweight). A large proportion of the Fort McMurray (44%) and Lethbridge (47%) participants had a BMI over 27 (overweight), 22.5% and 33%, respectively, of whom had a BMI greater than 30. Only approximately one-third of each sample population fell within the healthy weight category.

Table 7: Distribution of Body Mass Index (BMI) by Age and Sex

		Percentage of Participants by Age Group					
		< 20	**20 - 25**	**25 - 27**	**27 - 30**	**30 - 34**	**≥ 35**
Fort McMurray (N=271)		4.1	34.3	17.3	21.8	15.9	6.6
Males	< 25	20.0	50.0	20.0	10.0	0.0	0.0
	25 - 34	0.0	68.4	15.8	0.0	15.8	0.0
	35 - 44	0.0	24.5	16.3	34.7	20.4	4.1
	45 - 54	0.0	21.6	21.6	37.8	13.5	5.4
	55 - 64	0.0	14.3	14.3	42.9	14.3	14.3
	65 +	N/A	N/A	N/A	N/A	N/A	N/A
Females	< 25	11.1	44.4	11.1	22.2	11.1	0.0
	25 - 34	10.0	33.3	13.3	16.7	16.7	10.0
	35 - 44	6.6	44.3	14.8	11.5	11.5	11.5
	45 - 54	2.6	25.6	23.1	23.1	17.9	7.7
	55 - 64	0.0	33.3	22.2	11.1	33.3	0.0
	65 +	0.0	0.0	0.0	0.0	100.0	0.0
Lethbridge (N=30)		6.7	33.3	13.3	13.3	16.7	16.7
Males	< 25	0.0	0.0	100.0	0.0	0.0	0.0
	25 - 34	0.0	66.7	0.0	33.3	0.0	0.0
	35 - 44	0.0	33.3	0.0	0.0	33.3	33.3
	45 - 54	0.0	33.3	33.3	0.0	33.3	0.0
	55 - 64	0.0	0.0	0.0	100.0	0.0	0.0
	65 +	0.0	66.7	0.0	0.0	33.3	0.0
Females	< 25	0.0	100.0	0.0	0.0	0.0	0.0
	25 - 34	0.0	50.0	25.0	25.0	0.0	0.0
	35 - 44	28.6	0.0	14.3	14.3	14.3	28.6
	45 - 54	0.0	100.0	0.0	0.0	0.0	0.0
	55 - 64	0.0	0.0	0.0	0.0	33.3	66.7
	65 +	N/A	N/A	N/A	N/A	N/A	N/A

Figure 12: Distribution of Body Mass Index

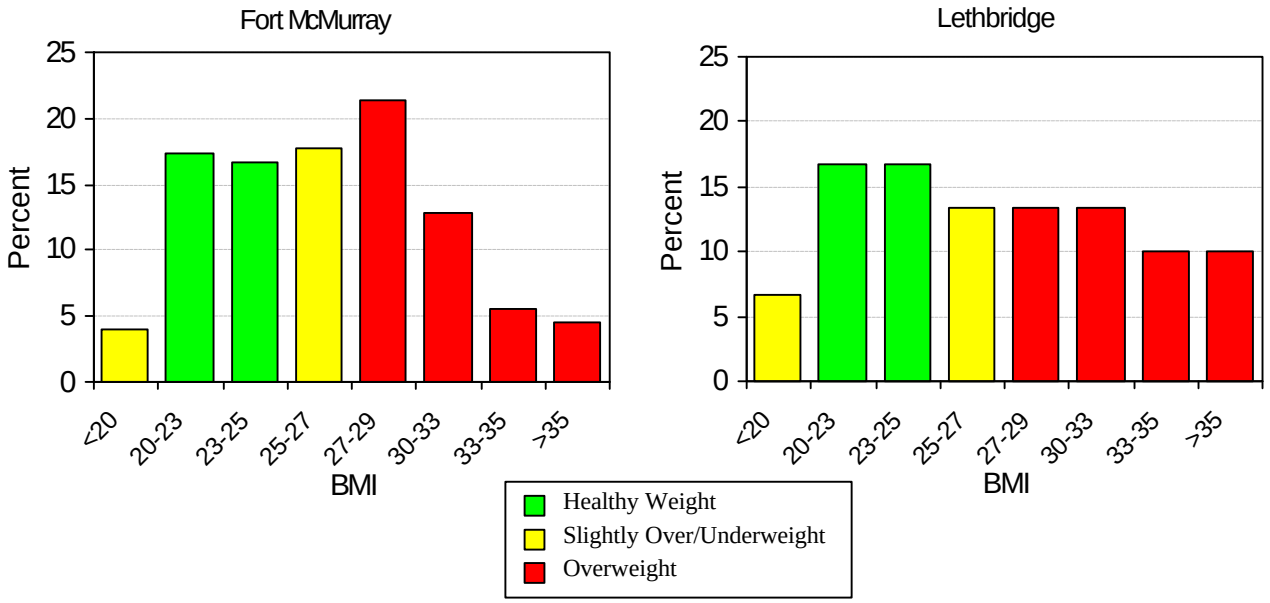


Table 8 shows the estimated BMI distribution for the Canadian population.[75] The study estimated the average BMI for the Canadian population to be 25.4, lower than either study population. Fewer study participants had a BMI in the lower or healthy range compared to the Canadian estimates. A larger percentage of study participants from Fort McMurray had a BMI in the range between 27 and 30 compared to the Canadian estimates, but fewer study participants from Lethbridge had a BMI in that range. A larger percentage of study participants from both study communities had a BMI greater than 30 compared to the Canadian estimates.

Table 8: Distribution of Body Mass Index (BMI) by Age and Sex, Canada

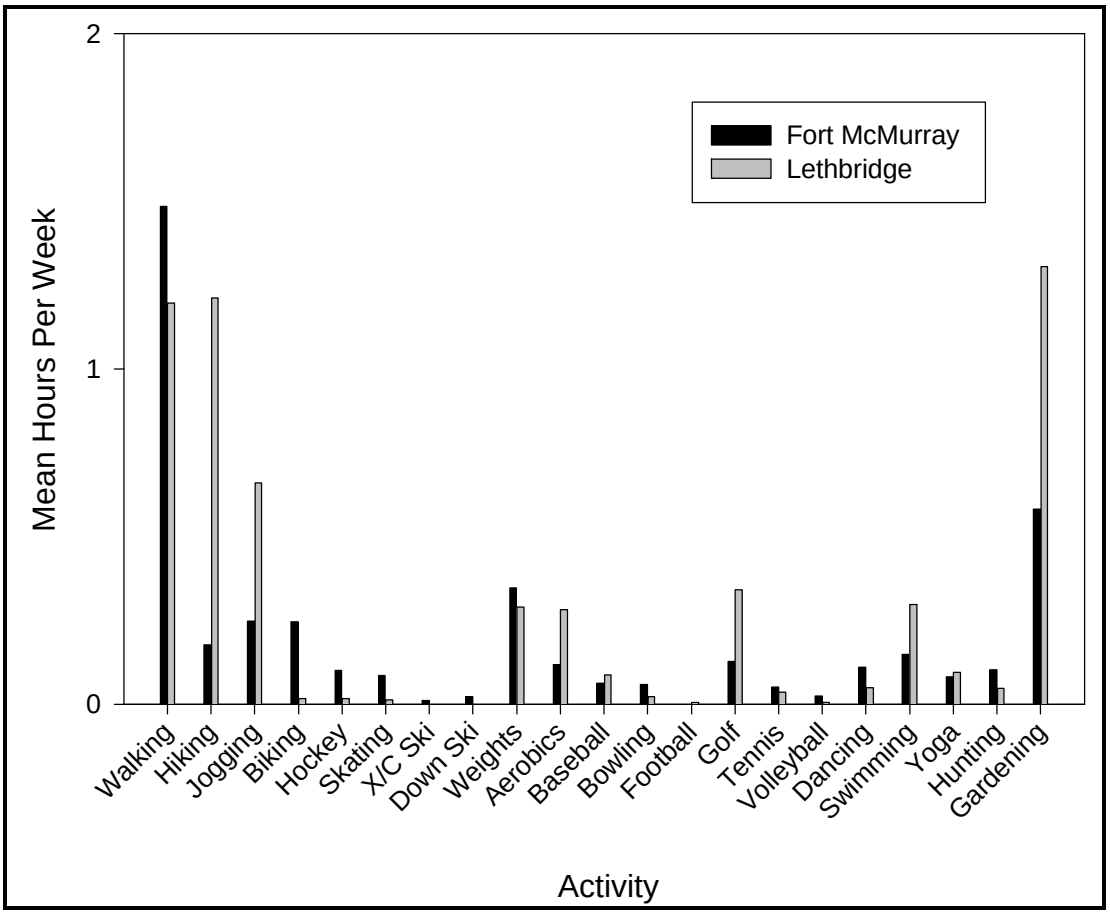
		Distribution of BMI % of Participants					
		< 20	**20 - 25**	**25 - 27**	**27 - 30**	**30 - 34**	**≥ 35**
Canada		9	43	17	17	11	3
Males	< 25	12	60	12	10	4	2
	25 - 34	6	48	19	18	7	1
	35 - 44	2	33	28	19	13	4
	45 - 54	1	30	23	32	12	1
	55 - 64	2	26	22	32	16	3
	65 +	4	34	23	25	13	2
Females	< 25	20	56	9	8	6	2
	25 - 34	18	52	12	9	6	3
	35 - 44	17	46	12	12	7	7
	45 - 54	6	48	13	13	16	3
	55 - 64	4	33	14	21	20	7
	65 +	6	37	17	22	13	5

6.8 Physical Activity Level

The physical activity section of the Health Habits and Diet Survey assessed participants' involvement in a variety of physical activities. For each activity, participants were asked how many times they had participated during the last three months, and how long they usually spent when they participated in that activity. The number of times each individual participated in that activity was multiplied by the duration to achieve an estimate of the total time spent in the activity, and that amount divided by 13 (the number of weeks in three months) to provide an estimate of personal average activity per week.

Figure 13 shows the average time per week Fort McMurray and Lethbridge study sample populations participated in various activities. Fort McMurray residents engaged in significantly more skating ($p=0.09$), cross-country skiing ($p=0.01$), downhill skiing ($p<0.005$), and dancing ($p=0.02$), than Lethbridge residents, but Lethbridge residents spent more time gardening ($p=0.03$) and spent more time in physical activities overall ($p=0.02$). Despite the difference in climate, the amount of time spent in outdoor compared to indoor activities did not differ significantly between the communities. An analysis was also performed concerning participation in team sports, but this difference was also non-significant.

Figure 13: Type of Activity

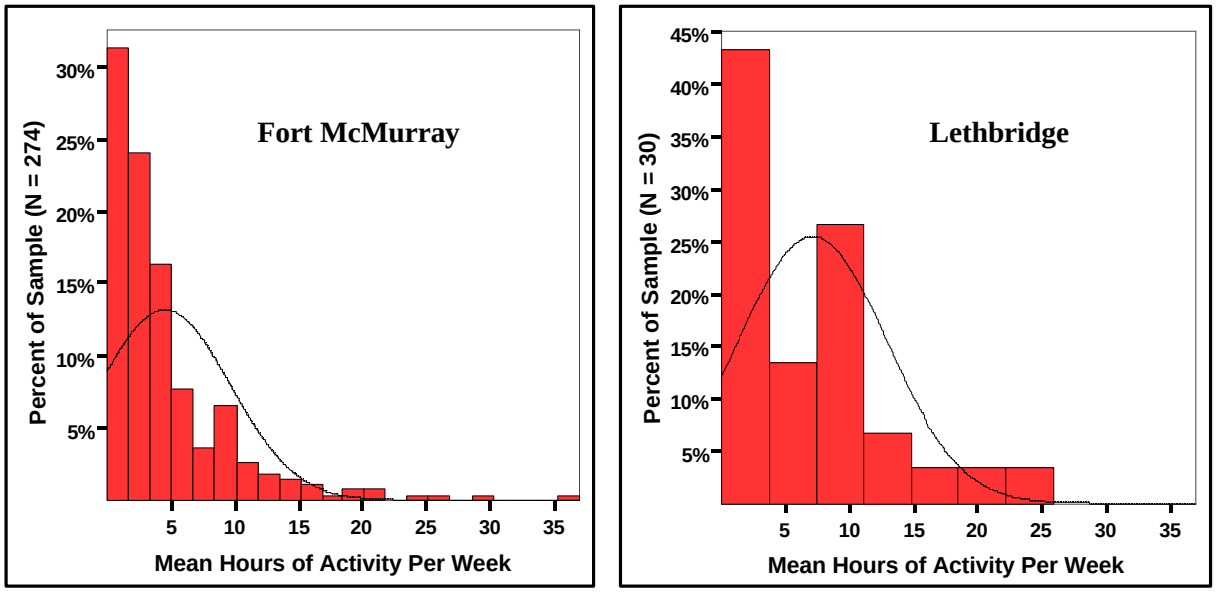


Health Canada recommends at least 20-30 minutes of vigorous activity, or 60 minutes of light effort, every day, to maintain good health.[76] In order to fulfill this recommendation, participants would have had

to engage in an average of 3.5 hours of vigorous activity or seven hours of light activity per week. As shown by Figure 14, the mean physical activity in Fort McMurray was 4.5 hours per week, and 7.1 hours per week in Lethbridge, a significant difference at $\alpha = 0.02$.

In comparison to 13.0% of Fort McMurray residents, none of the Lethbridge residents reported having engaged in no physical activities at all. In a Health Needs Assessment Survey conducted by the Northern Lights Regional Health Services, 22% of residents of the Fort McMurray area reported that they exercise either never or less than once a week;[77] and national statistics from Statistics Canada report the figure as 22.6% for all of Alberta. Even though a large proportion of the Lethbridge and Fort McMurray samples do not get enough exercise, they still surpass the provincial average.

Figure 14: Mean Hours of Activity Per Week



6.9 Nutritional Intake

Participants were asked about their usual dietary habits. Table 9 shows the average number of servings per day for each of the four main food groups, as well as the amount of fat intake and the number of servings of sweets and other foods. There was no difference in nutritional intake between the participants in Fort McMurray and the participants in Lethbridge. Both groups indicated that they ate less than the recommended 5 to 12 servings of grain products each day, and ate the minimum number (5 to 10) of servings of fruits and vegetables each day. The average number of servings of milk products corresponded to the recommended number (2 to 3), and the number of servings of meat and alternatives also corresponded to the minimum number of servings recommended by the Canada Food Guide (2 to 3). Respondents indicated that they consumed an average of between 2 and 3 servings of sweets or other non-nutritious foods each day.

Table 9: Daily Dietary Intake

Location	Grain Products	Fruit and Vegetables	Milk Products	Meat and Alternatives	Fat and Oil	Sweets
Fort McMurray	3.2	5.2	2.5	1.8	1.3	2.1
Lethbridge	3.4	5.6	2.1	2.2	1.4	2.9
Recommended # of servings per day	5 – 12	5 - 10	2 - 4	2 - 3	N/A	N/A

Table 10 shows that the average number of cups of coffee, drinks of cola, and drinks of alcohol were the same in the two communities: people drank an average of two cups of coffee per day, and less than one drink per day of cola or alcohol.

Participants were asked to approximate the amount of liquid they drank per day. Fort McMurray and Lethbridge respondents consumed an average of 7 cups (1.75 L) per day.

Table 10: Daily Coffee, Pop and Alcohol Intake

Location	Coffee	Cola	Beer	Wine	Liquor
Fort McMurray	2.1	0.5	0.3	0.1	0.1
Lethbridge	2.1	0.3	0.2	0.2	0.2

Table 11 summarizes the nutritional intake of the participants in the study, according to their responses to the Health Habits and Diet Survey combined with nutrition information for those foods.[78] Because thiamine content information was missing for many of the foods, thiamine has been eliminated from the analysis. The only statistically significant difference between the nutrient intakes of the towns was that females in Lethbridge consumed more potassium than females in Fort McMurray ($p=0.03$). Most mean nutrient intakes did not differ significantly from the Recommended Nutrient Intakes (RNIs); however, both samples consumed more vitamin C ($p<=0.01$) than the RNI. Fort McMurray males had a significantly higher proportion of calories from protein in their diet than the recommended minimum ($p=0.017$). Fort McMurray males and females ($p<0.0001$), and Lethbridge females ($p=0.0024$) consumed significantly more than the RNI of niacin, and Lethbridge males consumed marginally more ($p=0.062$). Fort McMurray females had higher average intake of folacin than the RNI ($p=0.004$).

Table 11: Average Nutrient Intake

Average Daily Intake	Recommended Nutrient Intake[79]		Fort McMurray		Lethbridge	
	Males	Females	Males (N=123)	Females (N=148)	Males (N=14)	Females (N=16)
Energy (kcal)	2700	2000	2046.21	1596.51	2099.54	1985.57
Fiber (g)			12.23	10.51	15.15	12.40
Protein (g)	61	44	57.87	44.03	61.86	53.49
% of Calories from Protein	Minimum 10% (both genders)		14% [b]	13%	14%	13%
Carbohydrates (g)			261.70	223.00	255.92	273.43
% of Calories from Carbohydrate	Minimum 55% (both genders)		66% [b]	71% [b]	67% [b]	70% [b]
Total Fat (g)			48.63	34.92	61.21	45.60
% of Calories from Fat	Maximum 30% (both genders)		19%	18%	22%	21%
Saturated Fat (g)			21.45	15.22	20.37	19.46
% of Calories from Saturated Fat	Maximum 10% (both genders)		9%	8%	8%	9%
Polyunsaturated Fat (g)	10.5	8.1	7.91	5.36	11.62	7.87
Cholesterol (mg)	American target is <300mg		121.03	88.13	104.05	107.45
Calcium (mg)	800	700	819.20	742.20	787.02	832.85
Iron (mg)	9	13	6.16	5.14	7.87	6.10
Sodium (mg)			1743.33	1454.61	1627.31	1675.55
Potassium (mg)			2950.58	2427.21 [a]	2915.23	3235.42 [a]
Vitamin A (Retinol Equivalents)	1000	800	449.43	453.55	395.28	407.57
Vitamin C (mg)	40	30	86.23 [b]	88.03 [b]	88.58 [b]	93.63 [b]
Riboflavin (mg)	1.4	1	0.01	0.01	0.01	0.00
Niacin (Niacin Equivalents)	19	14	32.85 [b]	21.99 [b]	30.44 [b]	26.52 [b]
Folacin (g)	220	175	228.61	212.44 [b]	281.11 [b]	217.38

[a] Difference between the townsites is significant at α=0.05.
[b] Difference from recommended is significant at α=0.05.

6.10 Local Wild Food Sources

The frequency of consumption of local wild food sources was recorded because this can indicate whether there are other sources of contaminants or pathways of exposure that are unique to the local population. Eighty percent (80%) of the population in Fort McMurray and all Lethbridge participants indicated that they eat locally grown fruits and vegetables when available.

Table 12 shows the percentage of each study sample that consumed local wild food by type. Sixty-three percent (63%) of the Fort McMurray participants indicated that they ate local wild berries. Half of all participants (51.5%) in Fort McMurray indicated that they ate wild local blueberries, and almost as many (46.4%) indicated that they ate wild raspberries. Wild strawberries and saskatoons were also frequently stated as a local fruit consumed by the Fort McMurray sample population. Fifty-seven (57%) of the Lethbridge participants indicated that they ate local wild berries. Strawberries, saskatoons, and raspberries were the most frequently cited foods consumed by Lethbridge study participants.

Consumption of local wild game was not as common as consumption of wild fruits, although 32.5% of the sample in Fort McMurray stated that they ate local moose, and 24.5% stated they ate local deer. Grouse was the only other game animal consumed by a large portion of the Fort McMurray study population (12%). By comparison, only 17% of the Lethbridge participants indicated that they ate locally caught wild meat of any kind.

A number of participants in both cities indicated that they ate locally caught fish, although the most common fish consumed differed according to the city. Walleye was the most frequently mentioned fish in Fort McMurray (25%), whereas Lethbridge participants (23%) mentioned trout more frequently.

Table 12: Percentage of Sample Consuming Local Wild Foods by Type

Food (Berries)	Fort McMurray	Lethbridge	Food (Meat)	Fort McMurray	Lethbridge	Food (Fish)	Fort McMurray	Lethbridge
Blueberries	51.5	16.7	Bear	2.2	3.3	Arctic grayling	2.9	0.0
Chokecherries	9.1	23.3	Beaver	1.5	0.0	Burbot	0.4	0.0
Crabapples	11.7	13.3	Caribou	1.8	0.0	Fish eggs	0.7	0.0
Cranberries	14.6	3.3	Deer	24.5	10.0	Goldeye	1.8	0.0
Currants	1.8	3.3	Duck	5.1	0.0	Perch	18.2	6.7
Gooseberries	3.6	6.7	Goose	5.5	0.0	Pike	21.5	10.0
Raspberries	46.4	30.0	Grouse	12.4	0.0	Sturgeon	0.4	3.3
Rose hips	3.3	3.3	Moose	32.5	6.7	Trout	19.0	23.3
Saskatoons	24.1	30.0	Pheasant	1.8	0.0	Walleye	24.8	3.3
Soapberries	1.1	0.0	Ptarmigan	3.6	0.0	Whitefish	9.1	16.7
Strawberries	34.3	33.3	Rabbit/hare	6.2	0.0			

6.11 Sources of Drinking Water

Data was collected on characteristics of household drinking water and personal drinking water habits. All Fort McMurray respondents (N = 277) indicated their source of tap water as the city water treatment facility. Of those participants who indicated whether their tap water was hard or soft, 83.3% (N = 210) indicated that it was hard while the remaining 16.7% responded that their water was soft. Tap water was used for drinking and drink mixes by 84.4% (N = 275) of participants. When drinking water from the tap, 63.3% (N = 256) indicated that they run the water for a period of time before filling their glass and 27.7% indicated that they “sometimes” do. About one-third (32.1%; N = 274) of respondents indicated that they have a filter of some type that “purifies the water”, most of which were the activated carbon type (e.g.,

Brita, Amway). Bottled water was used by 27.4% (N = 277) of respondents, and another 31.8% indicated "sometimes". Of those that used bottled water, 35% (N = 160) indicated they use it for all drinking, while others limited their use of bottled water to travelling (55%), at work or school (46.9%), cooking (2.5%), and other uses (8.8%).

6.11.1 Drinking Water Quality

The field monitoring teams collected a sample of water from participants' kitchen taps that were analyzed for routine and trace metal analysis. There were a total of 237 routine analyses completed, 233 from Fort McMurray and four from Lethbridge. In addition, 238 trace metal analyses were completed, 234 from Fort McMurray and four from Lethbridge. Only four water samples were collected in Lethbridge to verify that the water quality was consistent with the city's water treatment plant; after this was established, it was determined that there was no longer a need to continue collecting water samples from Lethbridge participants. Detailed information regarding the methodologies of the analyses can be found in the *Methods Report*.

Routine Analysis

Routine analysis of water consists of measuring the following properties: conductivity, sodium, potassium, calcium, magnesium, hardness, iron, alkalinity, carbonate, bicarbonate, chloride, fluoride, nitrate and nitrite, sulfate, and total dissolved solids. The detection limits for the following analyses are shown in Table 13.

Table 13: Detection Limits for Routine Analysis Measures in Water Samples

Routine Analysis Measure	Detection Limit
Conductivity	10 µS/cm
Sodium	1 mg/L
Potassium	0.2 mg/L
Calcium	1 mg/L
Magnesium	1 mg/L
Hardness, Total	1 mg/L $CaCO_3$
Iron	0.02 mg/L
Alkalinity, Total	1 mg/L $CaCO_3$
Carbonate	N/A
Bicarbonate	1 mg/L HCO_3
Chloride	0.5 mg/L
Fluoride	0.05 mg/L
Nitrate + Nitrite (N)	0.05 mg/L NO_3 (N)
Sulfate	2 mg/L
Total dissolved solids (TDS)	1 mg/L

Table 14 shows the results of the routine analysis for all samples including: the number of samples, minimum and maximum concentration values, the maximum allowable concentration (MAC)/aesthetic objective (AO) for each measure, mean values of all samples for each measure, and the standard deviations. As is shown by the table, none of the measures examined in the routine analysis of water exceeded the Canadian drinking water quality guideline MAC/AO limits.

Table 14: Routine Analysis in Water Samples for Fort McMurray

Measure	# of samples	Minimum	Maximum	MAC/AO	Mean	S.D.
pH	233	6.97	8.33	6.5-8.5	7.93	0.14
Conductivity	233	263	450	N/A	354.6	57.6
Sodium	233	5	88	200 mg/L*	15.6	12.5
Potassium	233	<0.2	6.4	N/A	1.62	0.65
Calcium	233	<1	50		35.9	8.7
Magnesium	233	<1	14		9.8	2.6
Hardness, total ($CaCO_3$)	233	<1	183		130.0	32.1
Iron	233	<0.02	0.27	0.3 mg/L*	0.034	0.040
Total alkalinity ($CaCO_3$)	233	82	166	N/A	121.7	22.4
Carbonate	233	0	1	N/A	0.004	0.1
Bicarbonate	233	100	202	N/A	148.3	27.3
Chloride	233	7.1	16.6	250 mg/L*	11.39	2.38
Fluoride	233	0.52	1.04	1.5 mg/L	0.709	0.070
Nitrate + Nitrite (N)	233	<0.05	1.96	10 mg/L	0.219	0.180
Sulfate	233	19	47	500 mg/L*	30.8	6.6
Total dissolved solids (calculated)	233	132	237	500 mg/L*	179.8	32.0

*aesthetic objective (AO)

Trace Metals Analysis

The detection limits for all trace metal analysis was 1.0 µg/L except for iron that had a detection limit of 20 µg/L. The following trace metals were not detected in any of the 234 Fort McMurray samples collected: silver, beryllium, thallium, and vanadium. Table 15 shows the number of samples, the minimum and maximum values, the maximum allowable concentration (MAC)/interim maximum allowable concentration (IMAC)/aesthetic objective (AO) for each measure, means, and standard deviations for all other trace metals examined.

Table 15: Trace Metal Analysis in Water Samples for Fort McMurray

Metal	# of samples	Minimum	Maximum	MAC/IMAC/AO	Mean	S.D.
Aluminum	234	31	475	200 µg/L*	174.6	65.8
Arsenic	234	<1	2	25 µg/L**	0.2	0.4
Boron	234	15	94	5000 µg/L**	33.5	9.7
Barium	234	<1	132	1000 µg/L	58.0	16.4
Cadmium	234	<1	3	5 µg/L	0.01	0.2
Cobalt	234	<1	10	N/A	0.1	0.9
Chromium	234	<1	9	50 µg/L	2.4	1.6
Copper	234	<1	832	1000 µg/L***	22.6	60.7
Iron	234	<20	614	300 µg/L***	38.6	57.0
Manganese	234	<1	59	50 µg/L***	19.6	13.4
Molybdenum	234	<1	15	N/A	0.9	1.5
Nickel	234	<1	6	N/A	2.6	0.8
Lead	234	<1	6	10 µg/L	0.3	1.0
Antimony	234	<1	112	N/A	3.0	10.9
Selenium	234	<1	2	10 µg/L	0.02	0.2
Strontium	234	<1	619	N/A	256.3	71.7
Titanium	234	<1	2	N/A	0.01	0.1
Uranium	234	<1	1	100 µg/L	0.01	0.1
Zinc	234	<1	46	5000 µg/L***	5.4	7.3

* currently under review for municipal water treatment plants
** interim MAC (IMAC)
*** aesthetic objective (AO)

The tables below show the number of samples for a particular concentration for some of the trace metals examined.

Table 16: Aluminum in Water Samples

Concentration	# of Samples
1 – 100 µg/L	15
101 – 200 µg/L	146
201 – 300 µg/L	67
301 – 400 µg/L	4
400 – 500 µg/L	2

There currently exists no established health-based guideline for aluminum in drinking water although this is currently under review. Health Canada guidelines (1999) indicate that, “water treatment plants using aluminum-based coagulants should optimize their operations to reduce aluminum levels in treated water to the lowest extent possible as a precautionary measure. *Operational guideline values* of less than 100

µg/L total aluminum for conventional treatment plants and less than 200 µg/L total aluminum for other types of treatment systems are recommended".[80]

Table 17: Iron in Water Samples

Concentration	# of Samples
< 20 µg/L	95
21 – 40 µg/L	37
41 – 80 µg/L	80
81 – 120 µg/L	10
121 – 160 µg/L	7
161 – 200 µg/L	3
> 200 µg/L	2

The aesthetic objective (AO) for iron is 300 µg/L. Two of the samples collected were above the AO limit at 321 and 614 µg/L. The AO level was established at a point above which iron levels cause staining of laundry and plumbing fixtures and cause undesirable tastes in beverages. There is no evidence to indicate that concentrations of iron commonly present in food or drinking water constitute any hazard to human health.

Table 18: Manganese in Water Samples

Concentration	# of Samples
< 1 µg/L	3
1 – 10 µg/L	73
11 – 20 µg/L	72
21 – 30 µg/L	30
31 – 40 µg/L	37
41 – 50 µg/L	12
51 – 60 µg/L	7

The aesthetic objective (AO) for manganese is 50 µg/L. Nine of the samples from Fort McMurray were at or above this limit. Manganese at this level is not considered to represent a threat to health, and drinking water with much higher concentrations has been safely consumed. The AO was established at a point above which deposition and staining problems may occur. Manganese is regarded as one of the least toxic elements to humans and animals. Currently, there is no MAC for manganese in drinking water.

6.12 Time Activity Diaries

Participants were asked to keep a time activity diary in which they recorded activities, the amount of time each of these activities encompassed, and specific exposures to certain chemicals for the four days in which their exposure to chemical concentrations was being monitored. The time activity diaries were coded into a set of times spent in general activities for each day, and into the presence or absence of a set of specific activities which might have led to unusual levels of exposure. Figure 15 shows the average levels of activities for the group as a whole, while Table 19 presents the associated numerical information.

Figure 15: Average Proportion of Time in a Day

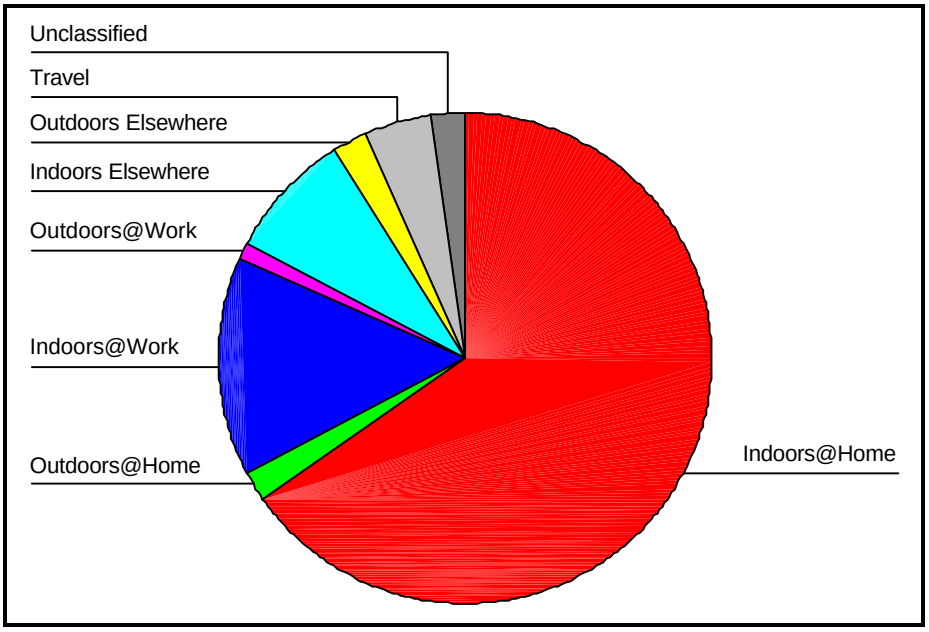


Table 19: Means and Standard Deviations of Proportion of a Day Spent in Activity Groupings

	Mean	Standard Deviation
Indoors @ Home	.65	.19
Outdoors @ Home	.02	.05
Indoors @ Work	.14	.17
Outdoors @ Work	.01	.06
Indoors Elsewhere	.08	.11
Outdoors Elsewhere	.02	.05
Travel	.05	.04

There are trade-off relationships among the relative mixes of general activities across different individuals. Table 20 presents the Pearson Product Moment correlation coefficients across the seven major categories of activities.

Table 20: Correlations between Proportion of Time Spent in General Activity Types

	IH	OH	IW	OW	IA	OA	T
IH	1.00						
OH	.00	1.00					
IW	-.59	-.22	1.00				
OW	-.19	-.04	.00	1.00			
IA	-.16	-.05	-.36	-.14	1.00		
OA	-.09	.02	-.16	-.04	-.01	1.00	
T	-.42	-.13	.26	.05	.16	.01	1.00

Examination of this table shows a clear relationship between time spent indoors at home (IH), indoors at work (IW), and travel (T) such that as time spent indoors at work increases, travel time increases, and time spent indoors at home decreases. Similarly, with an increase in indoor activities elsewhere, travel time increases while time spent indoors at home and indoors at work decreases.

Gender and job status are also a major determinant of the relative activity mix. Table 21 shows that there is an interaction between job status and gender.

Table 21: Gender and Job Status

Full-time jobs	59.8% of females	(15.4% at Oil Sands Plants)
	96.1% of males	(74.4% at Oil Sands Plants)
Part-time jobs	22.7% of females	
	2.4% of males	

Table 22 summarizes regression analyses (Generalized Linear Models using Generalized Estimating Equations) using job status, day of the week, and part of the year in which the individual was assessed to predict the relative mix of daily activities.

Table 22: Regression Coefficients (Via GEE) (*=>p<0.05)

	IH	OH	IW	OW	IA	OA	T
Constant	.785	.039	-.001	.000	.088	.030	.033
Job:							
Full-time	-.175	-.024	.207	.008	-.007	-.010	.013
@ plants	-.041	.003	.039	.012	-.034	.005	.010
Part-time	-.092	-.019	.090	.001	-.022	-.006	-.000
Weekend:	.004	-.004	-.001	-.000	.021	-.015	-.006
If full-time	.158	.019	-.186	-.005	.008	.025	-.012
If part-time	.071	.013	-.046	-.001	-.014	.018	-.001
Gender	-.010	.004	-.011	.008	-.013	.002	-.003
Quarter*:							
Q1: January, February, March	-.030	-.022	.013	.003	.045	-.015	.013
Q2:April, May, June	-.009	.002	.005	-.005	.013	.005	.005
Q4:October, November, December	-.002	-.020	.037	-.003	.015	-.017	-.000

***** Q1, Q2, and Q4 in comparison to Q3 (Summer):July, August, September

The tables show that job status is a major determinant of the amount of time spent indoors at home, indoors at work, and in travel. These relationships include differential patterns on the weekends for individuals who are employed full-time. As previously noted, these three types of activities are closely related to each other.

Table 23 presents the proportion of days in which particular exposures (or activities increasing the likelihood of specific exposures) were noted in the analysis of the time activity diaries.

Table 23: Proportion of Days When Specific Exposures Indicated

	Passive or active smoke	Painting	Gasoline	Housecleaning	Burning	Misc. Chemicals
Female:						
Full-time job:						
No	.236	.046	.068	.211	.118	.312
Yes	.314	.045	.045	.119	.127	.343
Male:						
Full-time job						
No	.250	.042	.042	.042	.000	.250
Yes	.167	.043	.078	.054	.093	.148
Total	.233	.045	.064	.110	.108	.250

Analyses of the relationships between time activity and personal exposures are reported in detail in a later section of this report.

7.0 Air-Borne Contaminants

7.1 Passive Samplers

Passive air quality measurements were taken with four separate samplers, each deployed for a 24-hour period. Each participant was requested to wear one of each of these samplers for four consecutive sampling periods, resulting in four 24-hour samples for each participant taken on four consecutive days in each sampling location. Each participant carried samplers around their neck, hanging in their breathing zone (Personal sample), had a sampler deployed inside their home (Indoor sample), and had a sampler deployed in the environment immediately outside their home (Outdoor sample). Finally, a sampler of each type was deployed in a single ambient site for each day of the study period. Table 24 shows the sampler types and the chemicals monitored by each sampler.

Table 24: Samplers and Chemical Concentrations Measured

Sampler	Chemical Concentrations Measured
NO_2	Nitrogen Dioxide
SO_2	Sulfur Dioxide
O_3	Ozone
Volatile Organic Compounds	Hexane
	2-butanone
	3-methylhexane
	Benzene
	Heptane
	Toluene
	Octane
	Ethylbenzene
	m-, p-xylene
	o-xylene
	Nonane
	Decane
	Limonene

The Field Teams successfully deployed 22,430 personal exposure monitors (PEMs) throughout the course of the study. Of these, only 30 PEMs had missing data, 16 could not be linked to log sheet data (i.e., location, date, and time of deployment/retrieval), and 14 had no laboratory analysis data (i.e., level of contaminant). Table 25 shows how the remaining 22,400 PEMs were distributed throughout Fort

McMurray and Lethbridge, including the PEMs deployed at the ambient air monitoring station in Fort McMurray.

Table 25: Distribution of Personal Exposure Monitors (PEMs)

# by Location	# by Type	Fort McMurray	Lethbridge
5,141 Personal	1,286 NO_2	1,163	123
	1,284 SO_2	1,161	123
	1,284 O_3	1,161	123
	1,287 VOCs	1,163	124
5,158 Indoor	1,291 NO_2	1,167	124
	1,288 SO_2	1,165	123
	1,289 O_3	1,166	123
	1,290 VOCs	1,166	124
5,151 Outdoor	1,286 NO_2	1,163	123
	1,288 SO_2	1,165	123
	1,290 O_3	1,166	124
	1,287 VOCs	1,164	123
5,131 Blank	1,283 NO_2	1,158	125
	1,283 SO_2	1,158	125
	1,283 O_3	1,158	125
	1,282 VOCs	1,158	124
1,819 Ambient station	1,771 Ambient	443 NO_2	N/A
		443 SO_2	N/A
		443 O_3	N/A
		442 VOCs	N/A
	48 Ambient blank	12 NO_2	N/A
		12 SO_2	N/A
		12 O_3	N/A
		12 VOCs	N/A
	22,400	**20,421**	**1,979**

Note: Ambient station PEMs deployed in Fort McMurray only.

The goal of the study was to collect four consecutive 24-hour samples from each participant, although due to a variety of factors, some participants were unable to complete all four sampling periods. Of the 300 Fort McMurray participants, 280 (93.3%) were able to complete all four 24-hour sampling periods. Thirty (88.3%) of 34 Lethbridge volunteers completed all four sampling periods. Those that were unable to complete the PEM component had anywhere from no PEM sampling completed to three sampling periods completed.

Calculation of the concentrations of each chemical from the amount of material detected on each sampler filter involved formulae relating sampling rates to concentration levels. In addition, a time correction was applied to correct for the precise amount of time (in minutes) that the samplers were exposed to air. A correction for blank levels (levels measured on unexposed sampler filters) was also applied. This correction itself involved an examination of the variability of the blank values over the course of the study, and for many chemicals resulted in a complex time dependent correction.

In the sections that follow, three graphs and one table are presented to describe the study results for each chemical.

The first graph shows the distribution of all measures taken through the study from the Fort McMurray location for each of the sample types: personal, indoor, outdoor, and ambient exposure. The graph plots the calculated 24-hour average concentration in the air to which the sampler was exposed plotted against the percentile of this exposure level in the particular sample type across all samples collected. The median exposure level is located at the point where a vertical line drawn from the 50^{th} percentile mark on the horizontal axis intersects with the curve. The concentration level at that point is read from the vertical axis by drawing a horizontal line from that point on the curve to the vertical axis. The vertical axis is presented as a logarithmic scale that reflects the general finding of positive skew in distributions of chemicals in air. If the line deviates from a straight line and especially if the curvature is marked at either end (usually the end indicating higher exposure levels), this indicates a skewed distribution of exposure to that chemical more marked than the log normal distribution. The degree of slope in the linear section of the curve is related to the overall variability of the sample such that steeper slopes indicate more variable distributions. Curves that do not appear to start at percentile 0 indicate that a proportion of cases fell below the sampling detection limit for the sampler for that chemical. The proportion of samples for which this is true is determined by noting the percentile level at which the curve begins.

The second graph represents a line of best fit derived by locally weighted regression methods to show the seasonal trend in the sampled concentrations for each sample type. The lines appear smooth, but they typically represent a very weak relationship between season and concentration. To illustrate that this relationship is weak, the individual concentrations are plotted on this graph as points.

The table presents the reliability of the samplers at each location. They are calculated under the assumption that they are measuring an exposure value that remains constant over the four days of exposure collection. The reliability coefficients can range from 1.0, that would indicate perfect reliability, to 0 (or conceivably slightly negative), that would indicate that the sampling was not at all reliable from day to day. Reliability coefficients that reach levels of 0.4 or greater provide good evidence that the exposure level remains relatively constant over the 4-day period for samples of that chemical at that site type across the set of participants. Reliability coefficients below this level generally indicate that exposure levels fluctuate greatly for that chemical at that site type from day to day.

The third graph was designed to give an indication of the degree of relationship between levels of personal exposure and levels of indoor and outdoor concentrations respectively. It is created as follows: first, the personal exposure levels are averaged across the four days of sampling for each participant; second, these averaged personal exposure values are ranked from highest to lowest; third, a graph is

created which orders the data from highest to lowest (where the concentration is given on the vertical axis, and the order values for each participant are presented along the horizontal axis); fourth, the 4-day average values for outdoor and indoor concentrations are plotted at the horizontal point in the graph at which the point indicating the personal concentration for that participant had previously been plotted; fifth, a locally weighted regression line is produced to help visualize the association between personal exposure and indoor and outdoor exposure. For strong relationships, the interpolated lines for the associated sampler sites will mimic the general downward trend of the line for personal exposure (and at the same time the points will cluster closely around this line). The stronger the relationship, the closer the curves will be to being parallel to each other. Weak or non-existent relationships will be characterized by interpolated lines that are parallel or close to parallel to the horizontal axis. In general, even strong apparent relationships had only moderate correlations (0.4-0.5) between personal exposure and either indoor or outdoor exposure.

7.1.1 Nitrogen Dioxide (NO_2)

Figure 16 shows the cumulative distribution of NO_2 concentrations for the four types of samplers (personal, indoor, outdoor and ambient). Very few samplers were below the detection limit; concentrations measured on the personal samplers were greater than the other sampler locations, but the differences were not large.

Figure 16: Distribution of Nitrogen Dioxide

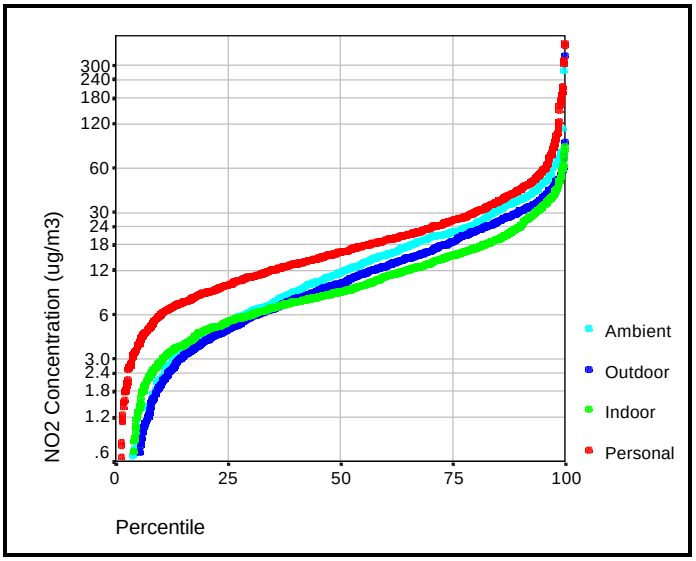


Figure 17 shows smoothed curves (produced by locally weighted regression) to represent the seasonal trend in NO_2 concentrations. Concentrations measured at all sources vary across the seasons, reaching peak concentrations in the winter months. Personal concentration measures were greater than any other source of NO_2.

Figure 17: Seasonal trend in Nitrogen Dioxide Concentration

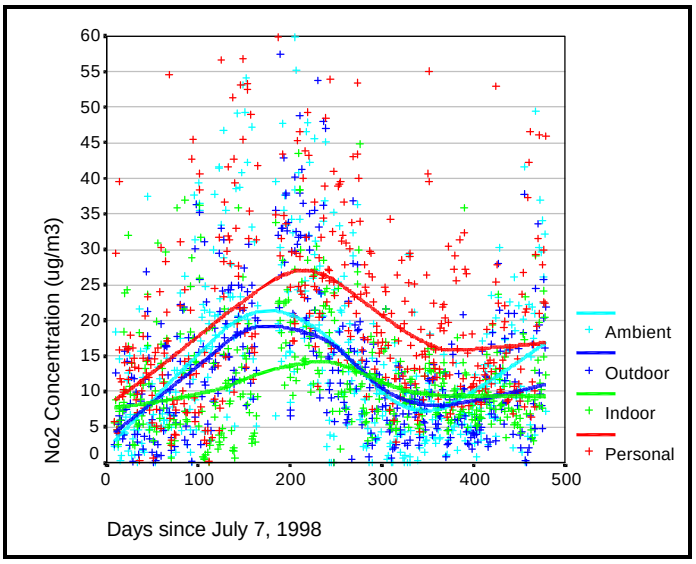


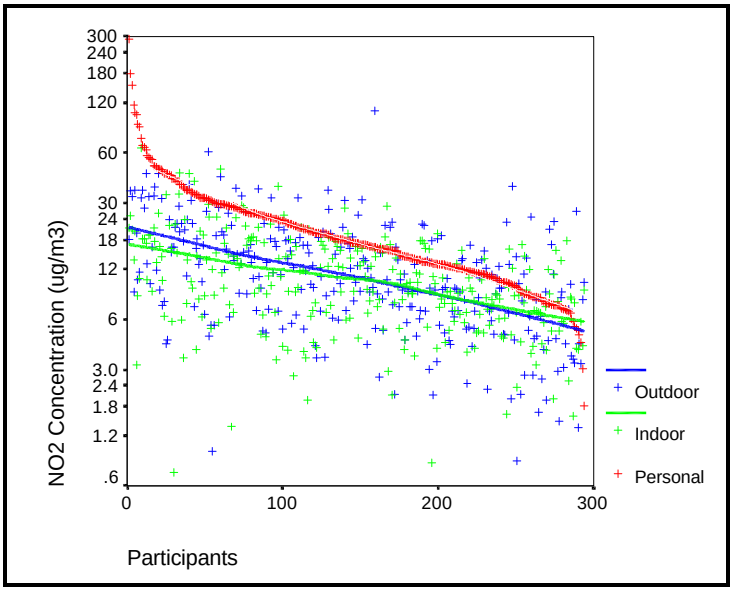
Table 26 shows that the measurement of NO_2 concentrations are relatively stable across the 4-day testing period for the personal and indoor locations, but less stable for samples taken at the outdoor location.

Table 26: Reliability of Nitrogen Dioxide Levels Over 4-day Periods

Single Measure Intraclass Correlation	r	se
Personal	.49	.03
Indoor	.49	.03
Outdoor	.34	.03

Figure 18 shows the relationship between the 4-day averages monitored personally, indoors and outdoors. The graph shows the ordered personal exposure levels for each subject in the study, and their corresponding levels of indoor and outdoor concentration levels. A locally weighted regression curve has been added for indoor and outdoor concentration levels to give an indication of the strength of the association between personal levels and indoor and outdoor levels respectively. A horizontal line would show no relationship while positive associations would be shown by sloped lines (and particularly by the relative degree of scatter of the individual points around those lines). This graph shows moderate relationships between measures of indoor and outdoor concentrations and measures of personal concentrations.

Figure 18: Relationship between 4-day Average Exposures to Nitrogen Dioxide by Sampler Site



7.1.2 Sulfur Dioxide (SO_2)

Figure 19 shows the cumulative distribution of SO_2 concentrations for the four types of samplers (personal, indoor, outdoor and ambient). Concentration levels were below the detection limit for more than one quarter of the indoor and personal samplers and approximately 15% of outdoor and ambient samplers. At the median (50^{th} percentile) the ambient and outdoor concentrations were approximately double the personal concentrations.

Figure 19: Distribution of Sulfur Dioxide

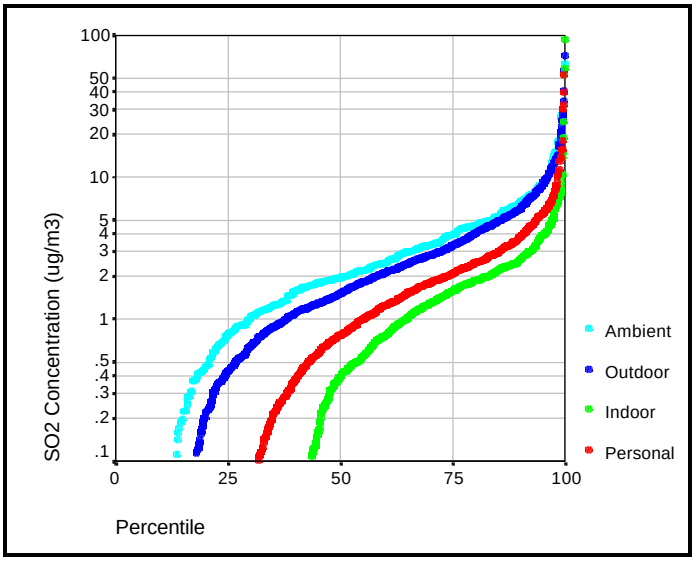


Figure 20 shows smoothed curves (produced by locally weighted regression) to represent the seasonal trend in SO_2 concentrations. Seasonal fluctuations in concentrations measured at all sources did not vary as dramatically as the measures for NO_2 discussed previously.

Figure 20: Seasonal Trend in Sulfur Dioxide Concentration

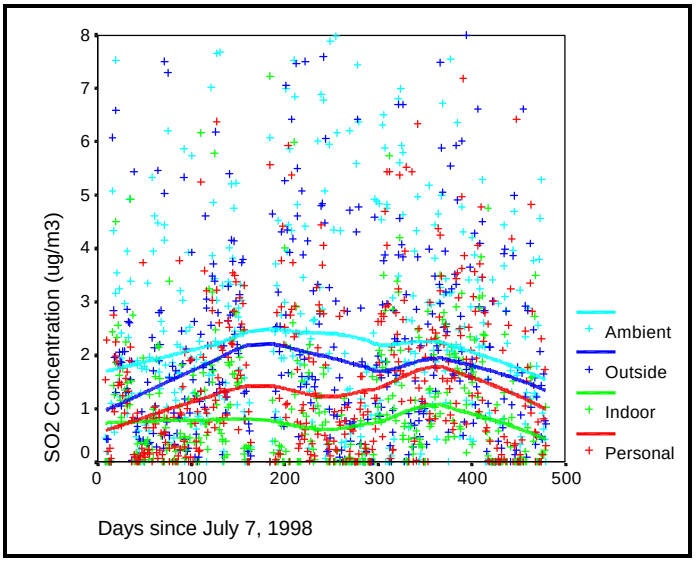


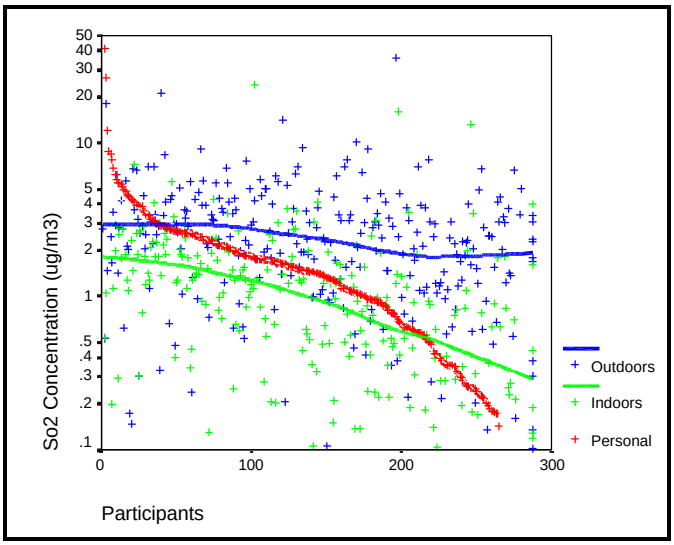
Table 27 shows that the measurement of SO_2 concentrations are not very stable across the 4-day testing period. This means that the amount of SO_2 to which each individual sampler was exposed varied significantly across the 4-day testing period. This may be due in part to the relatively large number of measurements that showed undetectable levels of SO_2.

Table 27: Reliability of Sulfur Dioxide Levels Over 4-day Periods

Single Measure Intraclass Correlation	r	se
Personal	.00	.05
Indoor	.02	.04
Outdoor	.04	.04

Figure 21 shows the relationship between the 4-day averages monitored personally, indoors and outdoors. This graph shows a relationship between personal and indoor concentrations and no significant relationship between these two measures and outdoor concentrations.

Figure 21: Relationship between 4-day Average Exposures to Sulfur Dioxide by Sampler Site



7.1.3 Ozone

Figure 22 shows the cumulative distribution of ozone concentrations for the four types of samplers (personal, indoor, outdoor, and ambient). While the concentrations never fell below measurable levels for ambient and outdoor samplers, approximately one quarter of the personal and indoor samplers registered concentrations lower than the detection limit for the samplers. (This is indicated by the fact that the curves for personal and indoor concentrations begin at about the 25th percentile on the graph). At the median (50th percentile) the ambient and outdoor concentrations were approximately one order of magnitude higher than the personal and indoor samplers were. Other researchers[81] have also reported that ambient and outdoor concentrations are considerably above personal exposure levels in other locales, though less dramatically than was seen here. This finding speaks to the inherent inaccuracy of using ambient concentration levels as a proxy for personal exposure.

While all distributions are positively skewed, less than 1% of the concentrations for personal exposures exceeded 50 ug/m^3 while over half of the concentration measures for the ambient station exceeded that level. Finally, this graph suggests that personal ozone exposure is more strongly related to indoor concentrations than to outdoor concentrations. A more detailed discussion of determinants of exposure level is presented below and again in a later section.

Figure 22: Distribution of Ozone

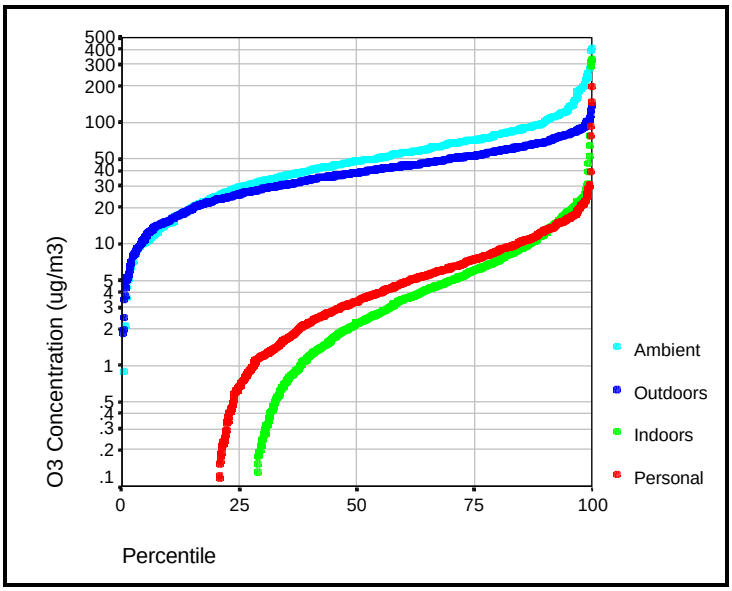


Figure 23 shows smoothed curves (produced by locally weighted regression) to represent the seasonal trend in ozone exposures. It is clear that ambient concentration levels vary across the seasons, peaking in the spring at levels approximately double the summer and fall lows. Outdoor levels in the sites within the town-site show a similar pattern. While a similar general trend is apparent in the indoor and personal exposure measures, the cycle is slightly delayed relative to indoor and outdoor levels, with the peak occurring later in spring/summer, and the minimum levels occurring in January. These trends are relatively weak as indicated by the large amount of scatter around the curves formed by the individual points.

Figure 23: Seasonal Trend in Ozone Concentration

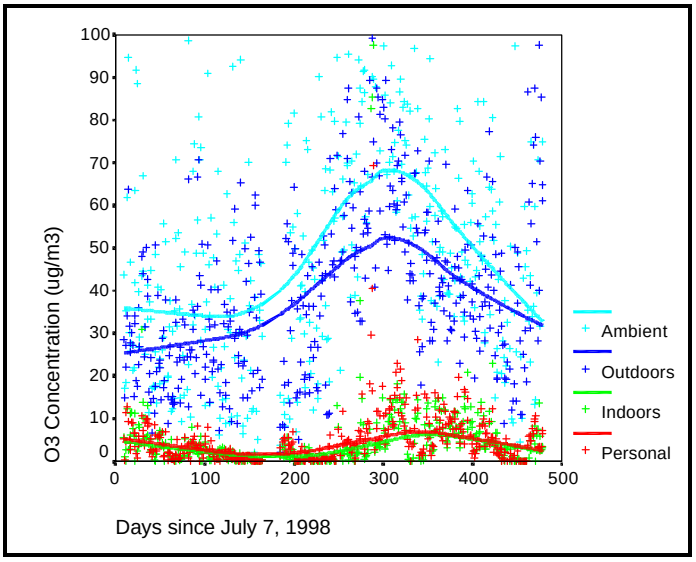


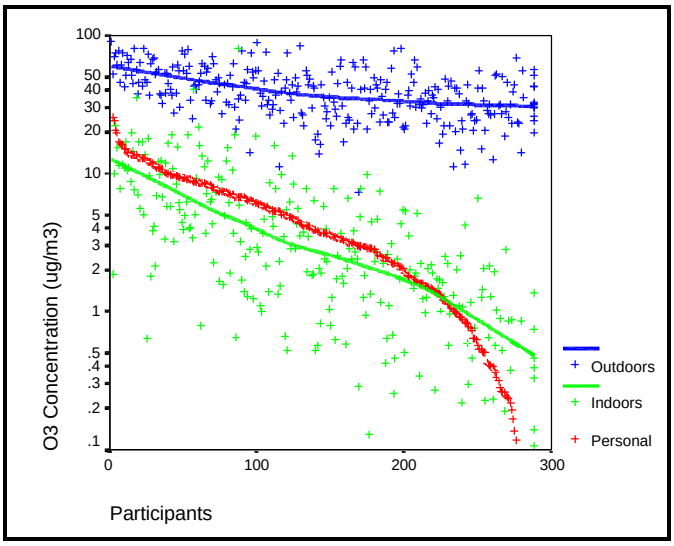
Table 28 shows that the measurements of ozone concentrations are quite stable across the 4-day testing periods. Specifically, indoor concentration levels are most stable, outdoor levels are least stable, and personal concentrations are intermediate between the two. This (and the differential in levels noted above) is consistent with a model that suggests that the ultimate source of ozone is the outdoor air (where concentration levels vary according to external determinants). Indoor concentrations are more stable from day to day, while individuals' personal exposures vary more than indoor concentrations do because they are also exposed to ozone when they venture outdoors.

Table 28: Reliability of Ozone Levels Over 4-day Periods

Single Measure Intraclass Correlation	r	se
Personal	.65	.04
Indoor	.77	.04
Outdoor	.53	.05

Finally, Figure 24 shows the relationships between 4-day averages monitored personally, indoors, and outdoors. The graph shows the ordered personal exposure levels for each subject in the study, and their corresponding levels of indoor and outdoor concentration levels. The current figure shows a strong relationship between personal and indoor exposure concentrations such that high levels of personal exposure are consistently associated with higher levels of indoor exposure concentrations. The relationship between outdoor exposures and personal exposures is weaker, but positive nevertheless, especially at the left side of the graph that shows the highest exposure levels. Again, the relative levels of the three exposures is strongly suggestive of a model of ozone diffusion which moves from outdoors to indoors and then to the person, who also moves outdoors often enough to raise personal exposure levels above the indoor concentration levels. A more detailed analysis that attempts to add features like the time activity pattern and job status, as well as housing characteristics to this model is presented in a later section.

Figure 24: Relationship between 4-day Average Exposures to Ozone by Sampler Site



7.1.4 Volatile Organic Compounds

The analyses of the volatile organic compounds (VOCs) detailed in the next several pages share several general features: 1) there were generally a large number of measurements which were below detectable limits; 2) personal exposure levels were generally higher than indoor and outdoor levels; and 3) the strongest relationships occurred between personal and indoor levels of concentration, suggesting indoor sources of exposure for most of these chemicals.

Hexane

Figure 25 shows the cumulative distribution of hexane concentrations for the four types of samplers (Personal, Indoor, Outdoor, and Ambient). More than half of the ambient samplers had concentrations of hexane below detectable limits, as did almost half of the outdoor samplers, 30% of indoor samplers and 20% of personal samplers. At the 50th percentile, personal and indoor concentrations were much higher than outdoor concentrations.

Figure 25: Distribution of Hexane

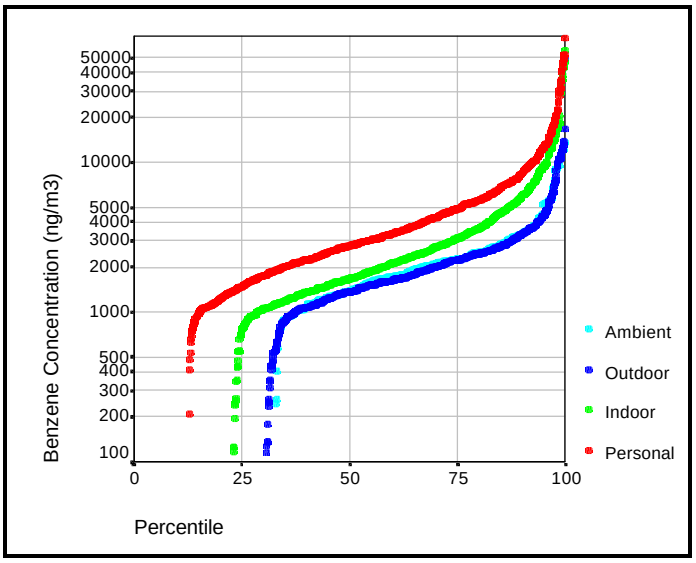


Figure 26 shows the seasonal trend in hexane concentrations. Personal exposure to hexane varies across the seasons, reaching peak levels in the fall. Average concentrations on personal samplers fluctuated across the seasons more than samplers of hexane in other locations.

Figure 26: Seasonal Trend in Hexane Concentration

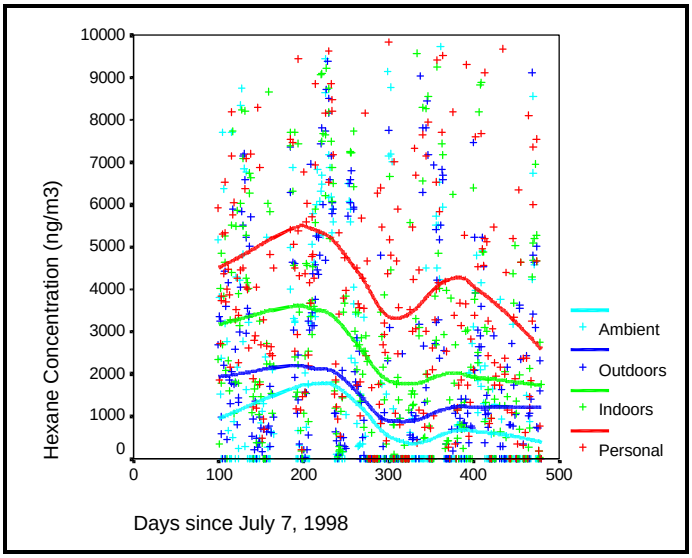


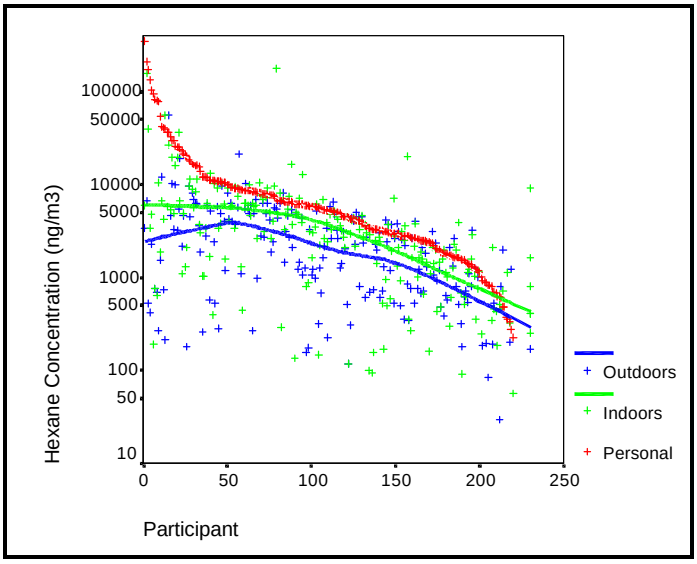
Table 29 shows that the measurement of hexane concentrations is not very stable across the 4-day testing period. This results from the large number of non-detectable samples.

Table 29: Reliability of Hexane Levels Over 4-day Periods

Single Measure Intraclass Correlation	r	se
Personal	.10	.06
Indoor	.15	.06
Outdoor	.12	.12

Figure 27 shows the relationship between the 4-day average concentration obtained from the personal, indoor and outdoor samplers. There is a moderate relationship between measures of indoor and of outdoor concentrations and measures of personal concentration.

Figure 27: Relationship between 4-day Average Exposures to Hexane by Sampler Site



2-butanone

Figure 28 shows the cumulative distribution of 2-butanone concentrations for the four types of samplers. This contaminant was not detectable on the majority of samplers at any location: more than 85% of the personal and indoor samplers did not have detectable concentrations, and more than 95% of ambient and outdoor samplers did not have detectable concentrations of 2-butanone. Of the few samplers that had detectable concentrations, indoor and personal samplers were significantly greater than outdoor and ambient measures.

Figure 28: Distribution of 2-butanone

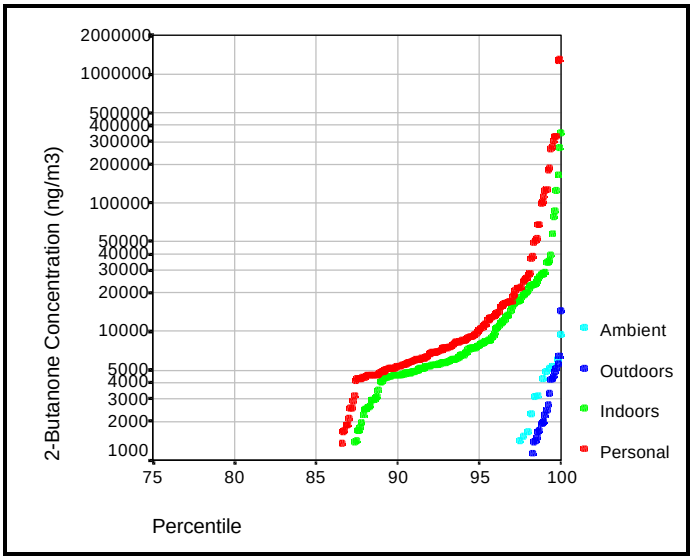


Figure 29 shows the seasonal trend in 2-butanone concentrations. There was a slight increase in personal concentrations during the winter, but no seasonal variation at the other locations.

Figure 29: Seasonal Trend in 2-butanone Concentration

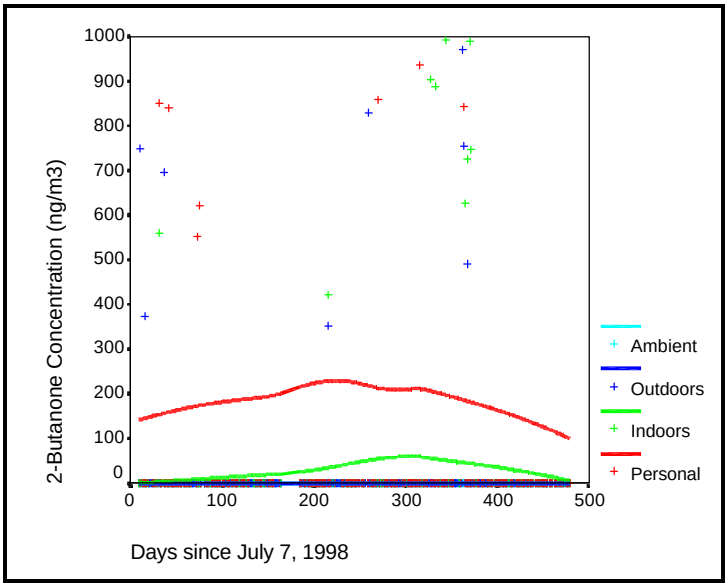


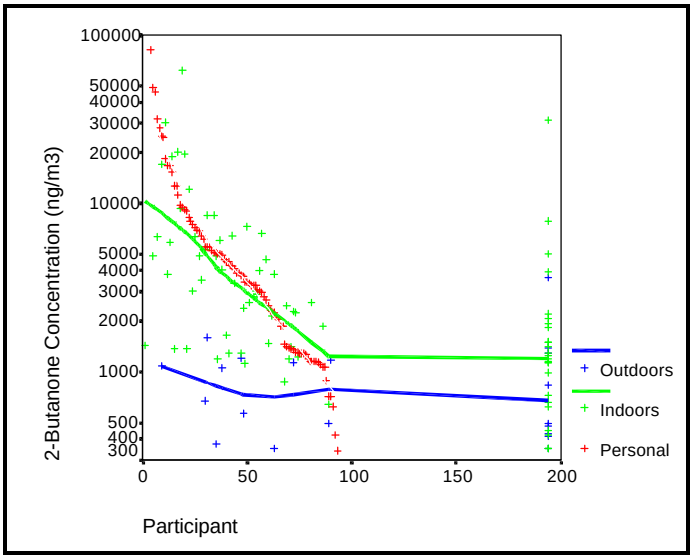
Table 30 shows that the measurement of 2-butanone concentrations is stable across the 4-day testing period at the indoor location only. This results from the large number of non-detectable samples.

Table 30: Reliability of 2-butanone Levels Over 4-day Periods

Single Measure Intraclass Correlation	r	se
Personal	.05	.05
Indoor	.65	.05
Outdoor	.00	.05

Figure 30 shows the relationships between 4-day averages monitored personally, indoors, and outdoors. The graph shows a strong relationship between personal and indoor exposure concentrations such that high levels of personal exposure are consistently associated with higher levels of indoor exposure concentrations. There is no relationship between outdoor exposures and personal exposures.

Figure 30: Relationship between 4-day Average Exposures to 2-butanone by Sampler Site



3-Methylhexane

Figure 31 shows the cumulative distribution of 3-methylhexane concentrations for the four types of samplers (Personal, Indoor, Outdoor, and Ambient). Almost half of the personal samplers, more than 60% of the indoor samplers and more than 75% of the outdoor and ambient samplers had concentrations of 3-methylhexane below detectable limits. Personal and indoor concentrations were much higher than outdoor concentrations.

Figure 31: Distribution of 3-methylhexane

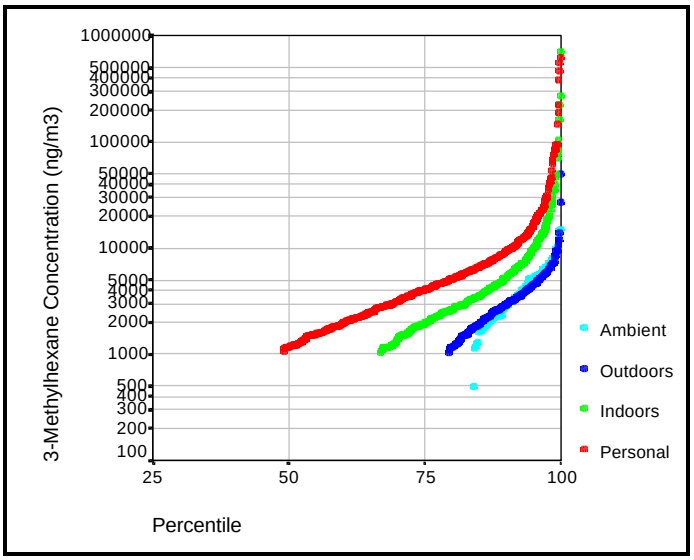


Figure 32 shows the seasonal trend in 3-methylhexane concentrations. Personal exposure to 3-methylhexane varies across the seasons, reaching peak levels in the spring and fall. Average concentrations on personal samplers fluctuated across the seasons more than samplers at indoor locations, and samplers located at the outdoor and ambient locations did not vary across seasons.

Figure 32: Seasonal Trend in 3-methylhexane Concentration

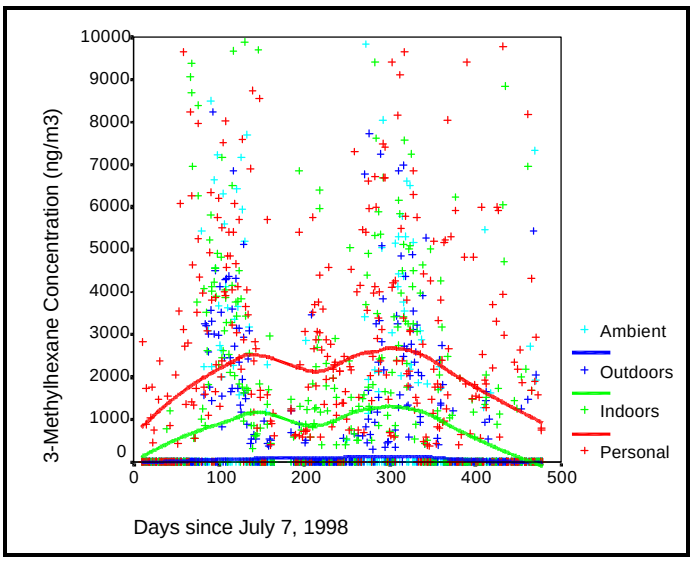


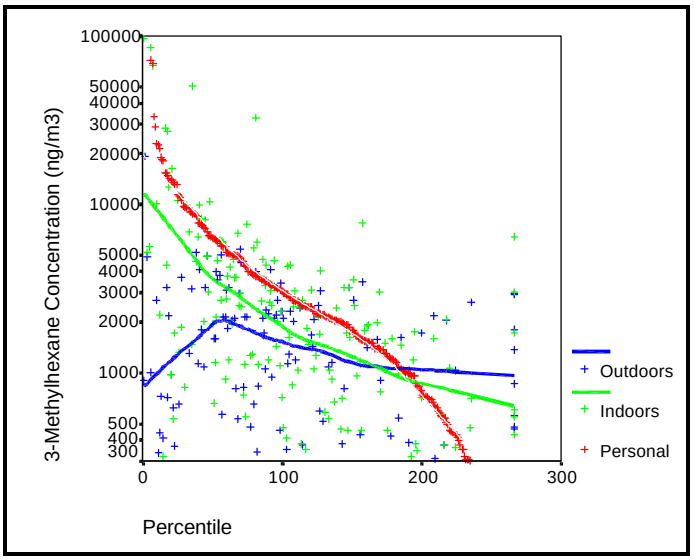
Table 31 shows that the measurement of 3-methylhexane concentrations is not very stable across the 4-day testing period for any of the three locations. This results from the large number of non-detectable samples.

Table 31: Reliability of 3-methylhexane Levels Over 4-day Periods

Single Measure Intraclass Correlation	r	se
Personal	.08	.05
Indoor	.20	.06
Outdoor	.28	.06

Figure 33 shows the relationships between 4-day averages monitored personally, indoors, and outdoors. The graph shows a strong relationship between personal and indoor exposure concentrations such that high levels of personal exposure are consistently associated with higher levels of indoor exposure concentrations. There is no relationship between outdoor exposures and personal exposures.

Figure 33: Relationship between 4-day Average Exposures to 3-methylhexane by Sampler Site



Benzene

Figure 34 shows the cumulative distribution of benzene concentrations for the four types of samplers (Personal, Indoor, Outdoor, and Ambient). More than 25% of the ambient and outdoor samplers had concentrations of benzene below detectable limits, as did almost 25% of the indoor samplers, and more than 10% of the personal samplers. At the 50th percentile, personal concentrations were almost double outdoor and ambient concentrations.

Figure 34: Distribution of Benzene

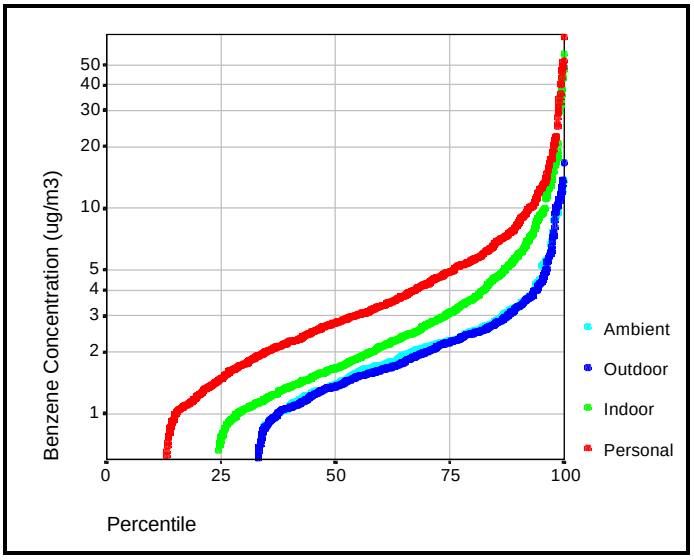


Figure 35 shows the seasonal trend in benzene concentrations. Personal exposure to benzene varies across the seasons, reaching peak levels in the winter. Average concentrations on indoor samplers reflected a similar seasonal trend but at lower concentrations. Outdoor and ambient concentrations also fluctuated slightly across the seasons, but to a much smaller degree.

Figure 35: Seasonal Trend in Benzene Concentration

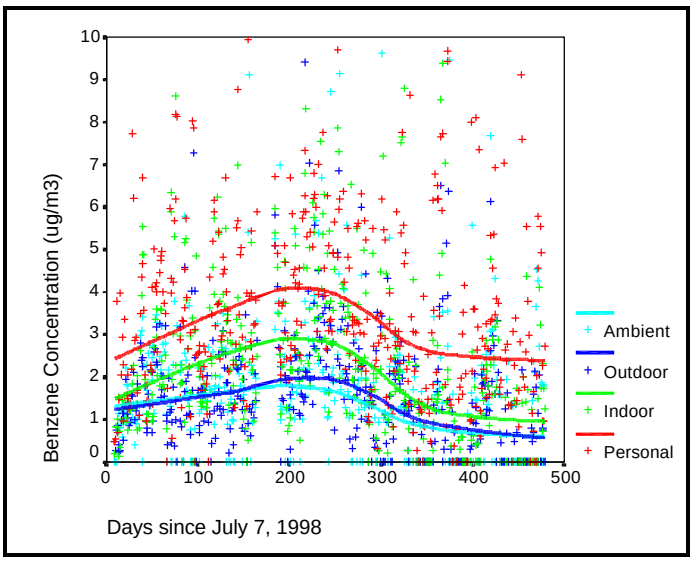


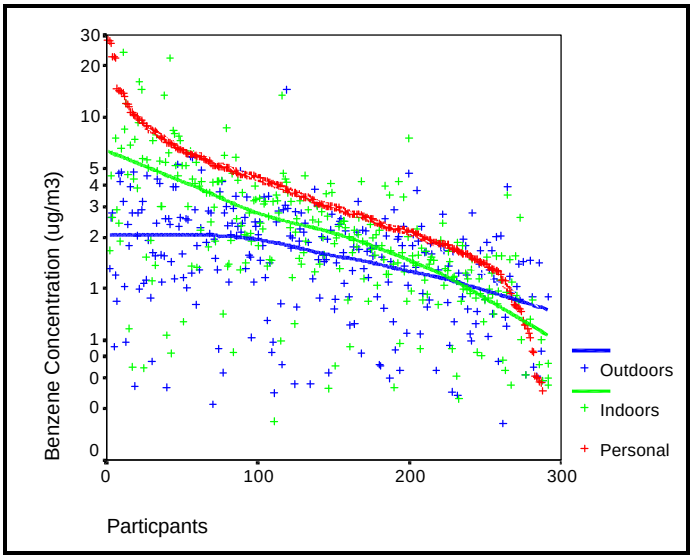
Table 32 shows that the measurement of benzene concentrations is not very stable across the 4-day testing period on the outdoor or personal samplers, but is quite consistent on the indoor samplers.

Table 32: Reliability of Benzene Levels Over 4-day Periods

Single Measure Intraclass Correlation	r	se
Personal	.32	.06
Indoor	.71	.04
Outdoor	.15	.06

Figure 36 shows the relationships between 4-day averages monitored personally, indoors, and outdoors. The graph shows a strong relationship between personal and indoor exposure concentrations such that high levels of personal exposure are consistently associated with higher levels of indoor exposure concentrations. The relationship between personal exposure and outdoor exposure is also positive, although not as strong.

Figure 36: Relationship between 4-day Average Exposures to Benzene by Sampler Site



Heptane

Figure 37 shows the cumulative distribution of heptane concentrations for the four types of samplers (Personal, Indoor, Outdoor, and Ambient). More than half of the indoor samplers had concentrations of heptane below detectable limits, as did more than 75% of the ambient and outdoor samplers and approximately 30% of personal samplers. Personal and indoor concentrations were much higher than outdoor or ambient concentrations.

Figure 37: Distribution of Heptane

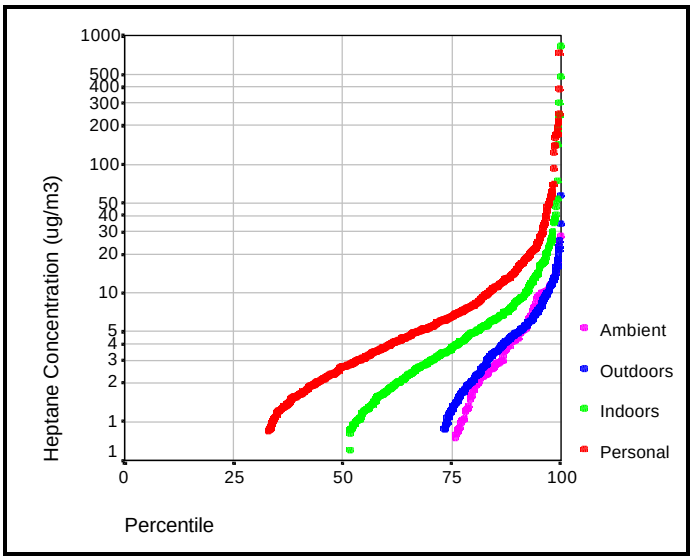


Figure 38 shows the seasonal trend in heptane concentrations. Personal exposure to heptane fluctuates across the seasons, reaching peak levels in the spring and fall. Average concentrations on personal samplers were much higher than concentrations measured on indoor samplers. Ambient and outdoor concentrations did not vary significantly across the seasons.

Figure 38: Seasonal Trend in Heptane Concentration

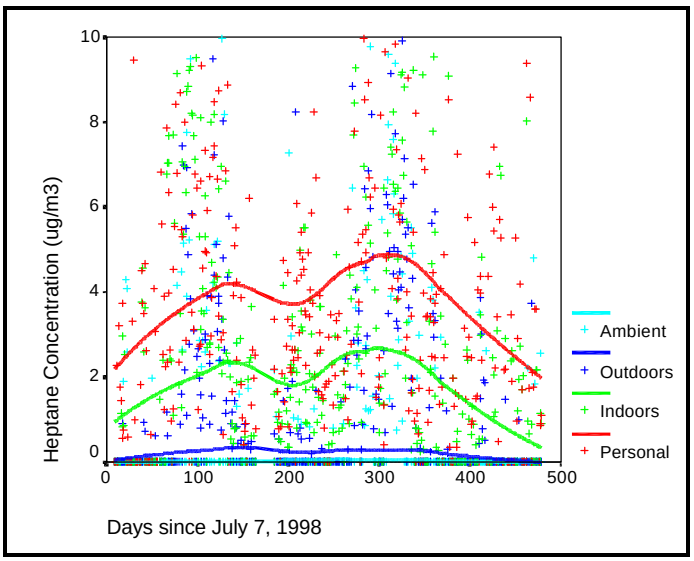


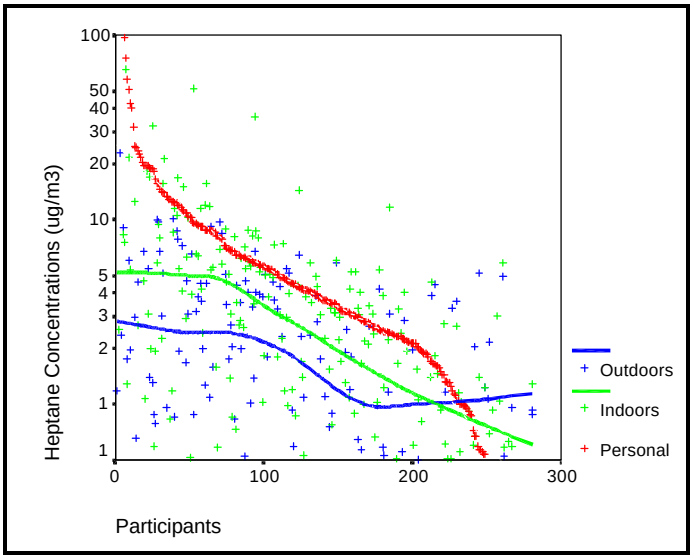
Table 33 shows that the measurement of heptane concentrations is not stable across the 4-day testing period at any of the sampling locations.

Table 33: Reliability of Heptane Levels Over 4-day Periods

Single Measure Intraclass Correlation	r	se
Personal	.09	.05
Indoor	.33	.06
Outdoor	.34	.07

Figure 39 shows the relationships between 4-day averages monitored personally, indoors, and outdoors. The graph shows a relatively strong relationship between personal and indoor exposure concentrations such that high levels of personal exposure are consistently associated with higher levels of indoor exposure concentrations. There is a weak positive relationship between outdoor exposures and personal exposures.

Figure 39: Relationship between 4-day Average Exposures to Heptane by Sampler Site



Toluene

Figure 40 shows the cumulative distribution of toluene concentrations for the four types of samplers (Personal, Indoor, Outdoor, and Ambient). More than 40% of the ambient and outdoor samplers had concentrations of toluene below detectable limits; less than 10% of the personal samplers and 15% of the indoor samplers had concentrations below detectable limits. At the 50th percentile, personal concentrations were an order of magnitude higher than outdoor concentrations.

Figure 40: Distribution of Toluene

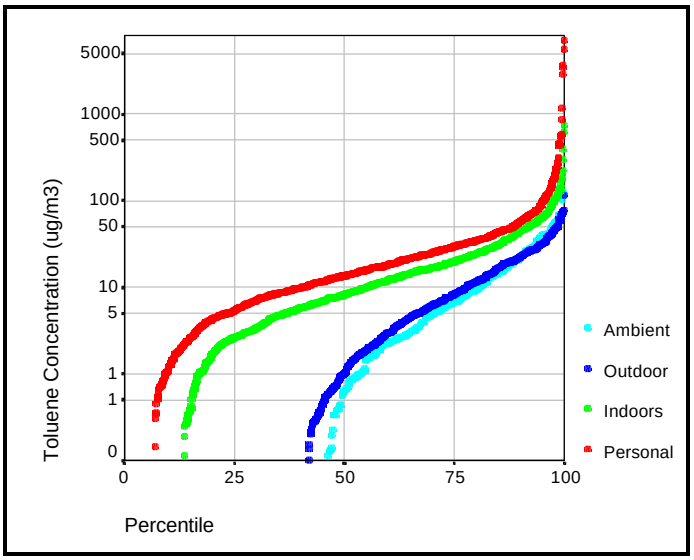


Figure 41 shows the seasonal trend in toluene concentrations. Personal exposure to toluene varies across the seasons, reaching peak levels in the fall and spring. Average concentrations on personal samplers were much higher than indoor concentrations, and both fluctuated across the seasons more than samplers located at outdoor and ambient locations did.

Figure 41: Seasonal Trend in Toluene Concentration

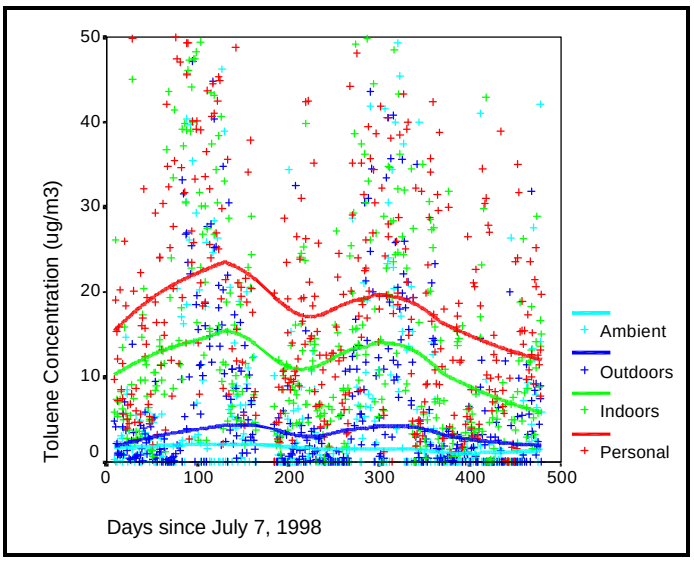


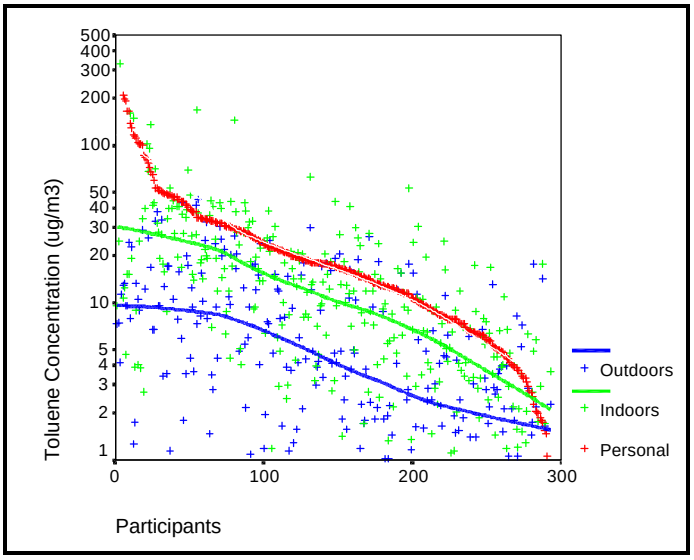
Table 34 shows that the measurement of toluene concentrations is relatively stable across the 4-day testing period for indoor and personal samplers, but not for outdoor samplers.

Table 34: Reliability of Toluene Levels Over 4-day Periods

Single Measure Intraclass Correlation	r	se
Personal	.49	.06
Indoor	.43	.06
Outdoor	.29	.06

Figure 42 shows the relationships between 4-day averages monitored personally, indoors, and outdoors. The graph shows a strong relationship between personal exposure concentrations and both indoor and outdoor exposure concentrations such that high levels of personal exposure are consistently associated with higher levels of indoor and outdoor exposure concentrations.

Figure 42: Relationship between 4-day Average Exposures to Toluene by Sampler Site



Octane

Figure 43 shows the cumulative distribution of octane concentrations for the four types of samplers (Personal, Indoor, Outdoor, and Ambient). Very few samplers had detectable concentrations of octane: 70% of the personal samplers had concentrations below detectable limits, more than 80% of the indoor samplers, and more than 95% of the outdoor and ambient samplers had concentrations below detectable limits.

Figure 43: Distribution of Octane

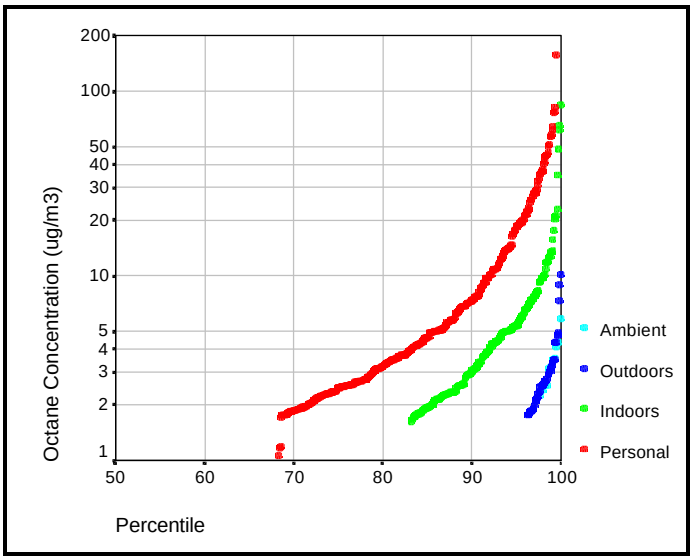


Figure 44 shows the seasonal trend in octane concentrations. Personal exposure to octane varies across the seasons, reaching peak levels in the winter. Average concentrations on outdoor samplers fluctuated very slightly, and outdoor and ambient concentrations did not vary over the study period.

Figure 44: Seasonal Trend in Octane Concentration

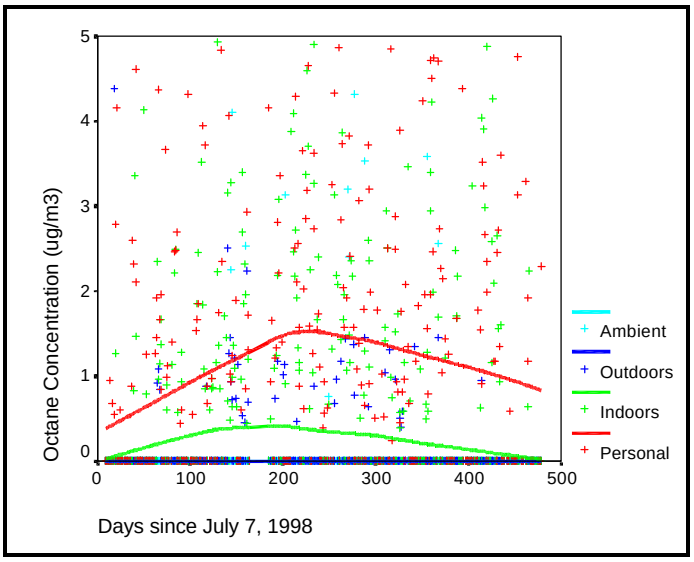


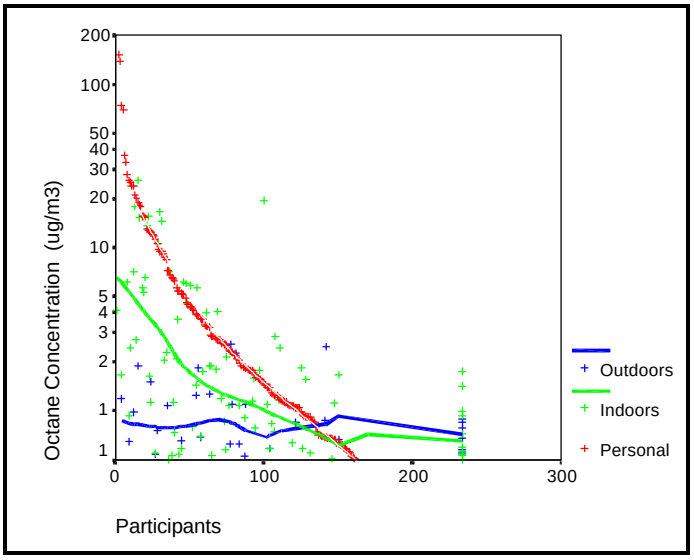
Table 35 shows that the measurement of octane concentrations is not very stable across the 4-day testing period. This results from the large number of non-detectable samples and the variation across the four days when concentrations were detectable.

Table 35: Reliability of Octane Levels Over 4-day Periods

Single Measure Intraclass Correlation	r	se
Personal	.26	.06
Indoor	.27	.06
Outdoor	.02	.05

Figure 45 shows the relationships between 4-day averages monitored personally, indoors, and outdoors. The graph shows a strong relationship between personal and indoor exposure concentrations, but no relationship with outdoor concentrations.

Figure 45: Relationship between 4-day Average Exposures to Octane by Sampler Site



Ethylbenzene

Figure 46 shows the cumulative distribution of ethylbenzene concentrations for the four types of samplers (Personal, Indoor, Outdoor, and Ambient). More than half of the samplers had concentrations of ethylbenzene below detectable limits: 62% personal samplers, 81% of indoor samplers and 97% of outdoor and ambient samplers had concentrations that were below detectable limits. Once again, personal and indoor concentrations were significantly greater than outdoor and ambient concentrations.

Figure 46: Distribution of Ethylbenzene

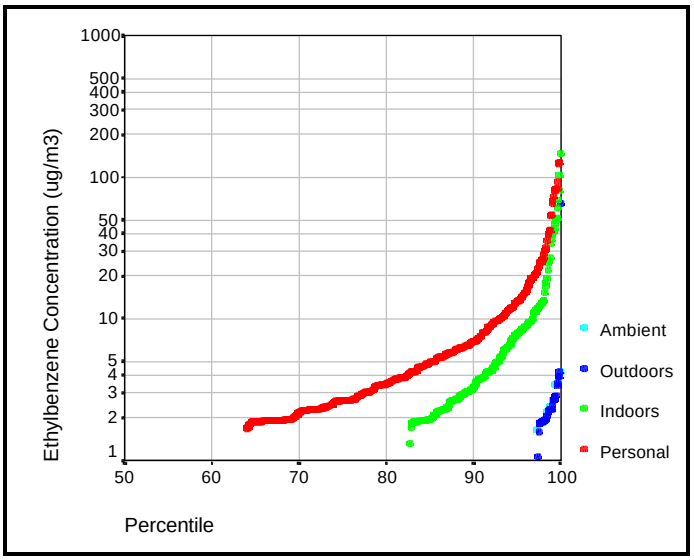


Figure 47 shows the seasonal trend in ethylbenzene concentrations. Ethylbenzene concentrations did not vary significantly during the course of the study. Concentrations of ethylbenzene measured on personal samplers were higher than outdoor samplers, and unrelated to measures on ambient and outdoor samplers.

Figure 47: Seasonal Trend in Ethylbenzene Concentration

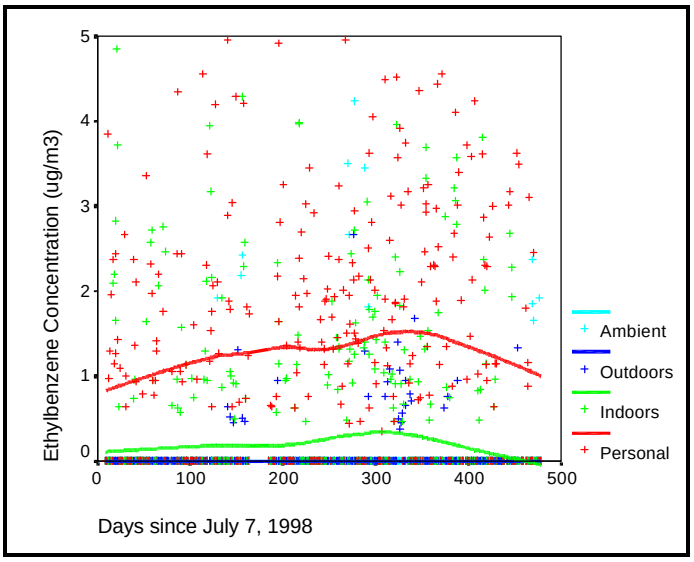


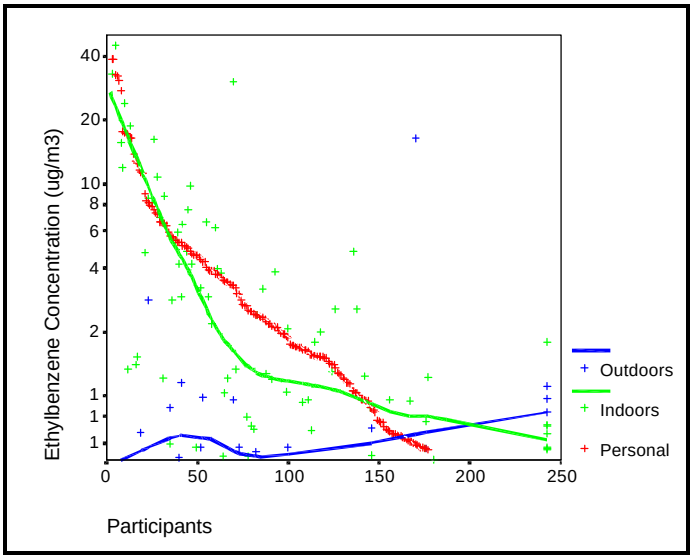
Table 36 shows that the measurement of ethylbenzene concentrations is quite stable across the 4-day testing period for the samplers located indoors, but not for the personal or the outdoor samplers.

Table 36: Reliability of Ethylbenzene Levels Over 4-day Periods

Single Measure Intraclass Correlation	r	se
Personal	.13	.06
Indoor	.62	.05
Outdoor	.01	.05

Figure 48 shows the relationships between 4-day averages monitored personally, indoors, and outdoors. The graph shows a strong relationship between personal and indoor exposure concentrations but no relationship between either of these concentrations and outdoor exposures concentrations.

Figure 48: Relationship between 4-day Average Exposures to Ethylbenzene by Sampler Site



M-, P-xylene

Figure 49 shows the cumulative distribution of m-, p-xylene concentrations for the four types of samplers (Personal, Indoor, Outdoor, and Ambient). More than 40% of the ambient and outdoor samplers had concentrations of m-, p-xylene below detectable limits, but less than 15% of the personal and indoor samplers were below the detection limit. At the 50th percentile, personal and indoor concentrations were double outdoor and ambient concentrations.

Figure 49: Distribution of m-, p-xylene

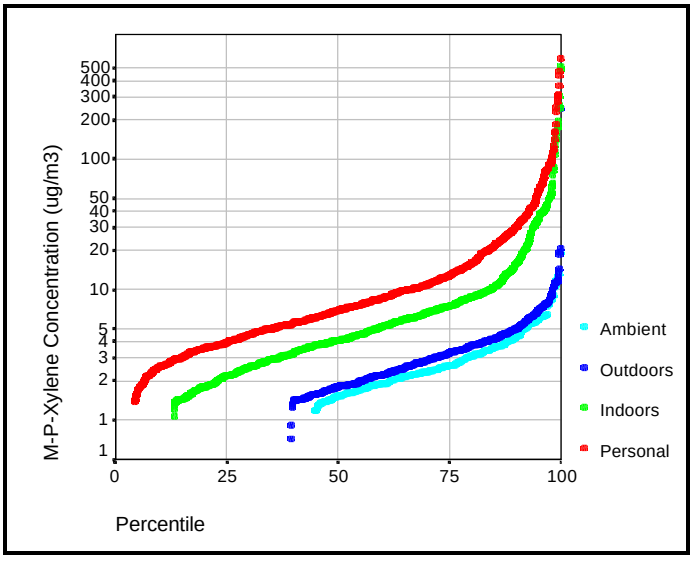


Figure 50 shows the seasonal trend in m-, p-xylene concentrations. There was no significant seasonal variation concentration of m-, p-xylene for any of the sampler types. Personal concentrations of m-, p-xylene were higher than indoor concentrations, and both were much higher than outdoor or ambient concentrations throughout the duration of the study.

Figure 50: Seasonal Trend in m-, p-xylene Concentration

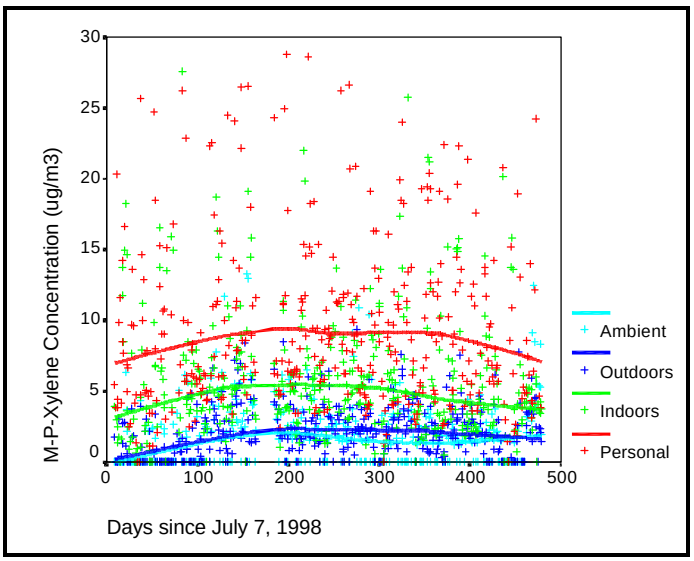


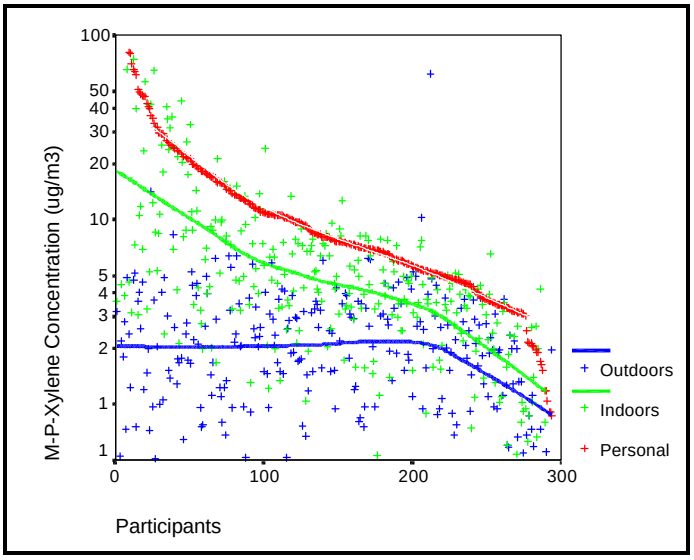
Table 37 shows that the measurement of m-, p-xylene concentrations is not very stable across the 4-day testing period for the personal or outdoor locations, but is quite stable for the indoor samplers.

Table 37: Reliability of m-, p-xylene Levels Over 4-day Periods

Single Measure Intraclass Correlation	r	se
Personal	.15	.05
Indoor	.61	.05
Outdoor	.02	.05

Figure 51 shows the relationships between 4-day averages monitored personally, indoors, and outdoors. The graph shows a strong relationship between personal and indoor exposure concentrations and no relationship with outdoor exposure concentrations.

Figure 51: Relationship between 4-day Average Exposures to m-, p-xylene by Sampler Site



O-Xylene

Figure 52 shows the cumulative distribution of o-xylene concentrations for the four types of samplers (Personal, Indoor, Outdoor, and Ambient). More than 65% of the personal samplers, 80% of the indoor samplers, and 98% of the outdoor and ambient samplers had concentrations of o-xylene below detectable limits. Personal and indoor concentrations were much higher than outdoor and ambient concentrations.

Figure 52: Distribution of o-xylene

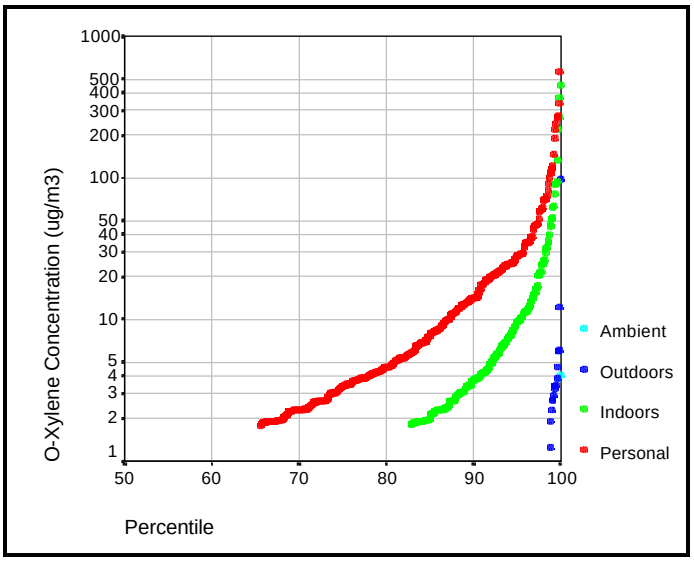


Figure 53 shows the seasonal trend in o-xylene concentrations. Personal exposure to o-xylene fluctuates somewhat across the duration of the study, but indoor, outdoor and ambient concentrations did not vary. Average concentrations on personal samplers were significantly higher than concentrations on any other type of sampler.

Figure 53: Seasonal Trend in o-xylene Concentration

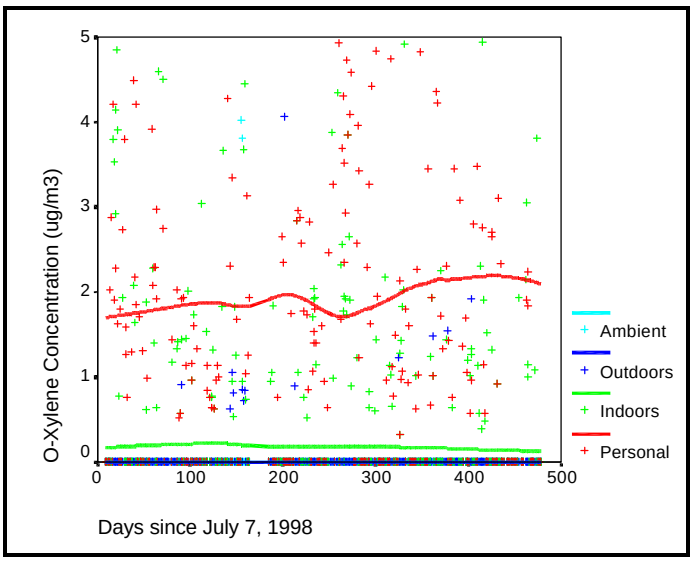


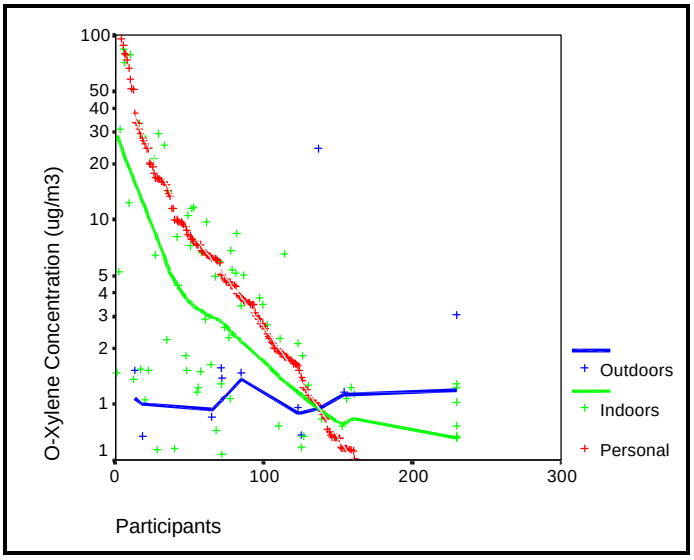
Table 38 shows that the measurement of o-xylene concentrations is not very stable across the 4-day testing period for any type of sampler.

Table 38: Reliability of o-xylene Levels Over 4-day Periods

Single Measure Intraclass Correlation	r	se
Personal	.05	.05
Indoor	.15	.05
Outdoor	.00	.05

Figure 54 shows the relationships between 4-day averages monitored personally, indoors, and outdoors. The graph shows a strong relationship between personal and indoor exposure concentrations but no relationship between personal exposures and outdoor exposures.

Figure 54: Relationship between 4-day Average Exposures to o-xylene by Sampler Site



Nonane

Figure 55 shows the cumulative distribution of nonane concentrations for the four types of samplers (Personal, Indoor, Outdoor, and Ambient). Almost 65% of the personal samplers, more than 80% of the indoor samplers, and 98% of the outdoor and ambient samplers had concentrations of nonane below detectable limits. Personal and indoor concentrations were much higher than outdoor and ambient concentrations.

Figure 55: Distribution of Nonane

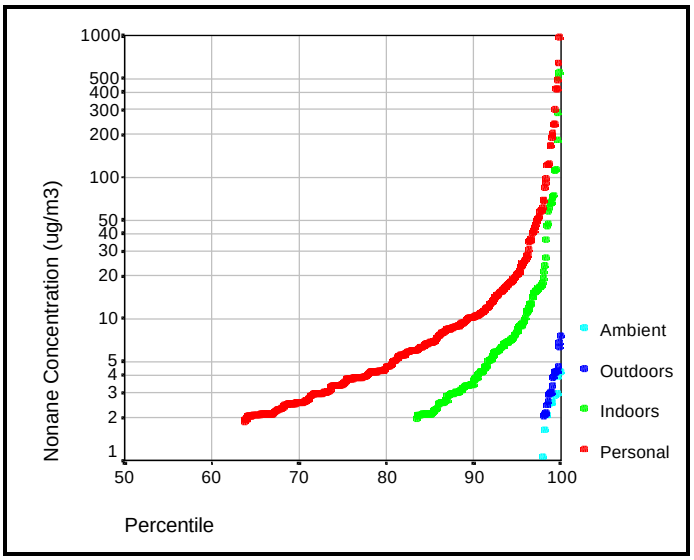


Figure 56 shows the seasonal trend in nonane concentrations. There was a very slight increase in personal exposure to nonane across the course of the study.

Figure 56: Seasonal Trend in Nonane Concentration

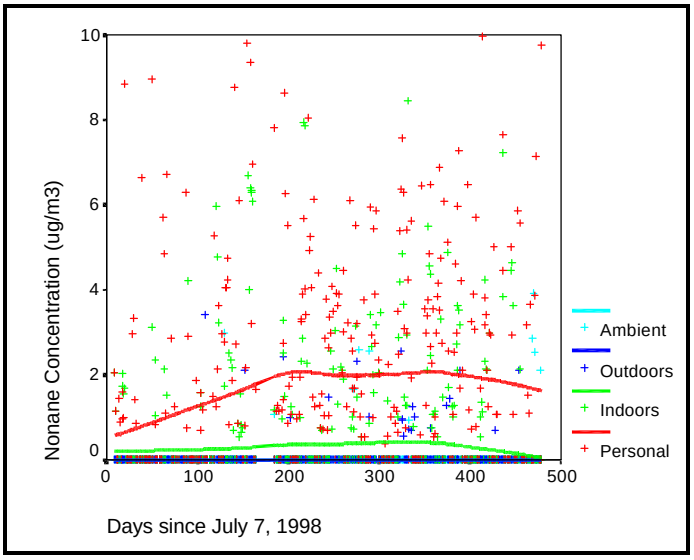


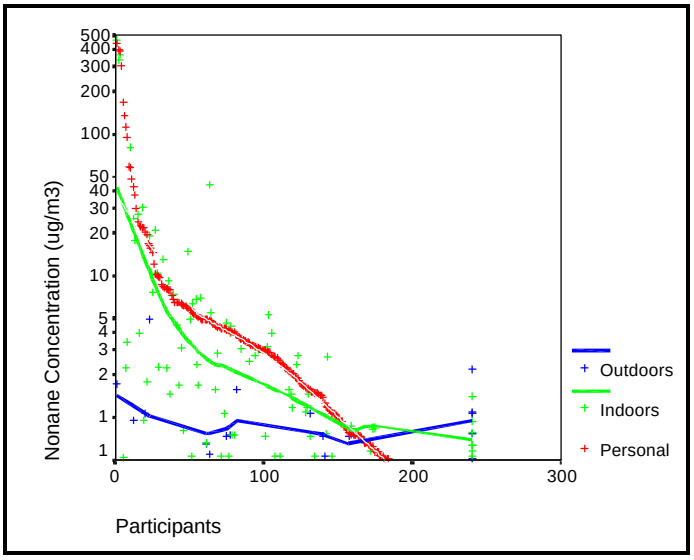
Table 39 shows that the measurement of nonane concentrations is not very stable across the 4-day testing period on any of the sampler types. This results from the large number of non-detectable samples.

Table 39: Reliability of Nonane Levels Over 4-day Periods

Single Measure Intraclass Correlation	r	se
Personal	.15	.05
Indoor	.14	.05
Outdoor	.28	.06

Figure 57 shows the relationships between 4-day averages monitored personally, indoors, and outdoors. The graph shows a strong relationship between personal and indoor exposure concentrations, but no relationship between personal exposures and outdoor or ambient exposures.

Figure 57: Relationship between 4-day Average Exposures to Nonane by Sampler Site



Decane

Figure 58 shows the cumulative distribution of decane concentrations for the four types of samplers (Personal, Indoor, Outdoor, and Ambient). As with many of the other volatile organic compounds, the majority of the sample population was not exposed to measurable levels of the contaminant. Almost 70% of the personal samplers had concentrations of decane below detectable limits, as did more than 80% of the indoor samplers, and 89% of the outdoor and ambient samplers. Personal and indoor concentrations were much higher than outdoor or ambient concentrations.

Figure 58: Distribution of Decane

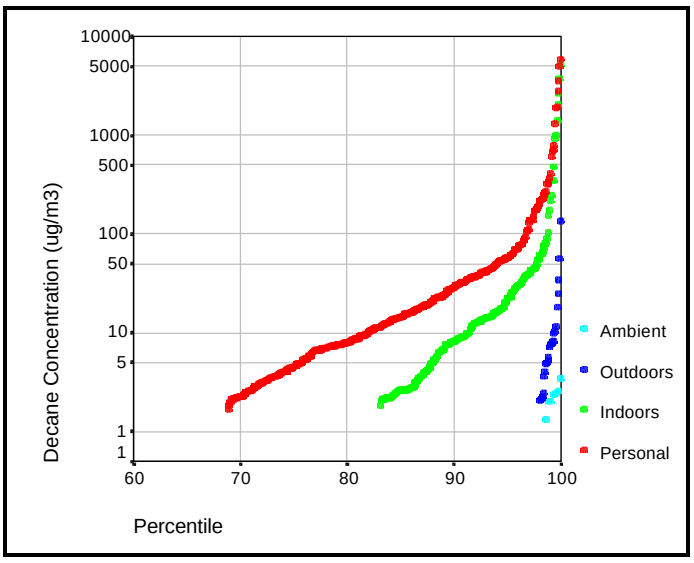


Figure 59 shows the seasonal trend in decane concentrations. Personal exposure to decane did not vary across the seasons, and was unrelated to concentrations measured on the indoor samplers.

Figure 59: Seasonal Trend in Decane Concentration

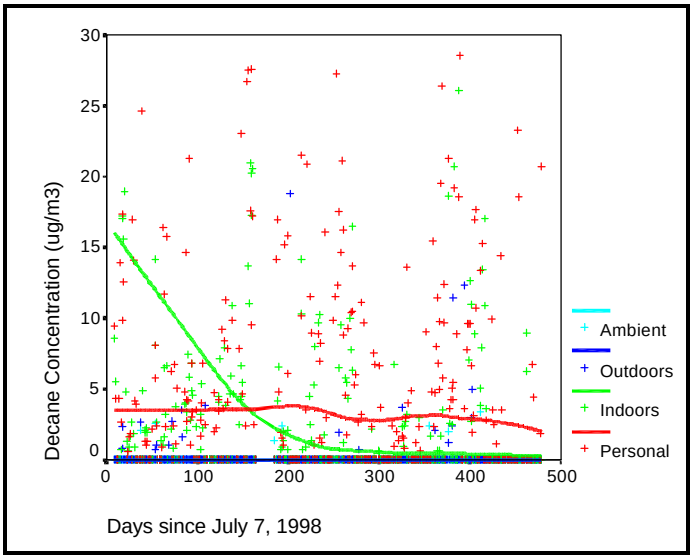


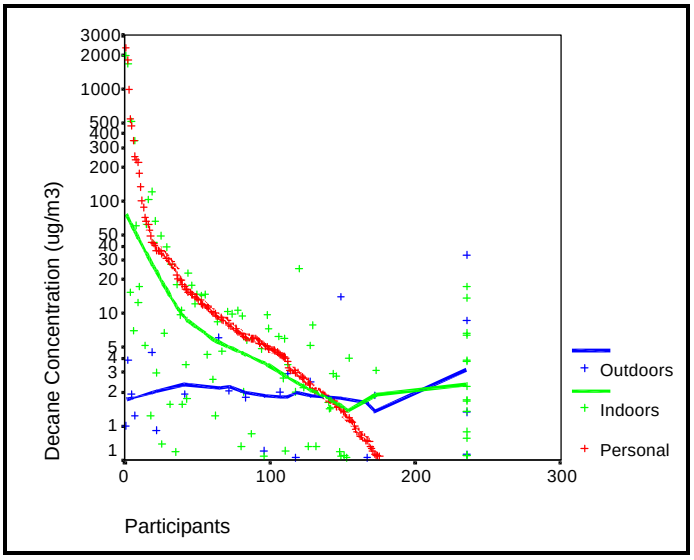
Table 40 shows that the measurement of decane concentrations is not very stable across the 4-day testing period for any of the sampler types. This results from the large number of non-detectable samples.

Table 40: Reliability of Decane Levels Over 4-day Periods

Single Measure Intraclass Correlation	r	se
Personal	.26	.06
Indoor	.33	.06
Outdoor	.00	.05

Figure 60 shows the relationships between 4-day averages monitored personally, indoors, and outdoors. The graph shows a moderate relationship between personal and indoor exposure concentrations such that high levels of personal exposure are consistently associated with higher levels of indoor exposure concentrations. There is no relationship between outdoor exposures and personal exposures.

Figure 60: Relationship between 4-day Average Exposures to Decane by Sampler Site



Limonene

Figure 61 shows the cumulative distribution of limonene concentrations for the four types of samplers (Personal, Indoor, Outdoor, and Ambient). Almost all of the personal and indoor samplers had measurable concentrations of limonene, while very few of the outdoor and ambient samplers had measurable concentrations of this contaminant. Personal exposure is higher than indoor exposure, and significantly higher than outdoor exposure.

Figure 61: Distribution of Limonene

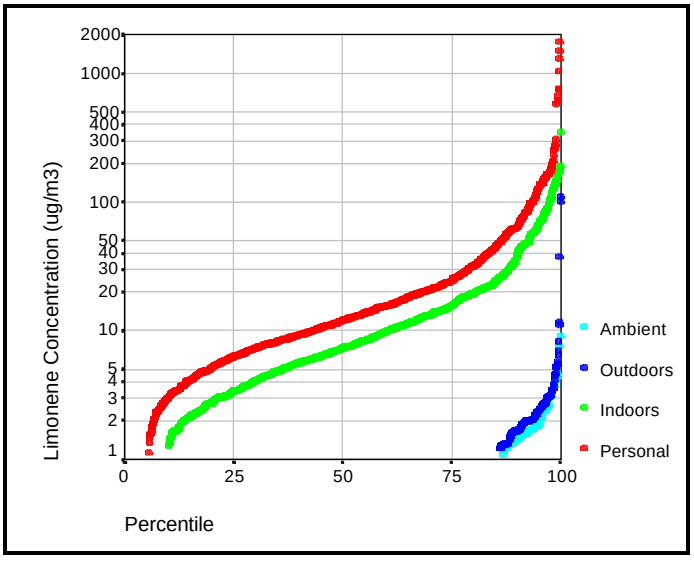


Figure 62 shows the seasonal trend in limonene concentrations. Personal exposure to hexane varies across the seasons, reaching peak levels in the winter, and varies directly with indoor concentrations. Measurable concentrations obtained from the outdoor locations and the ambient site were primarily obtained in the late summer, but these were unrelated to indoor or personal exposure concentrations.

Figure 62: Seasonal Trend in Limonene Concentration

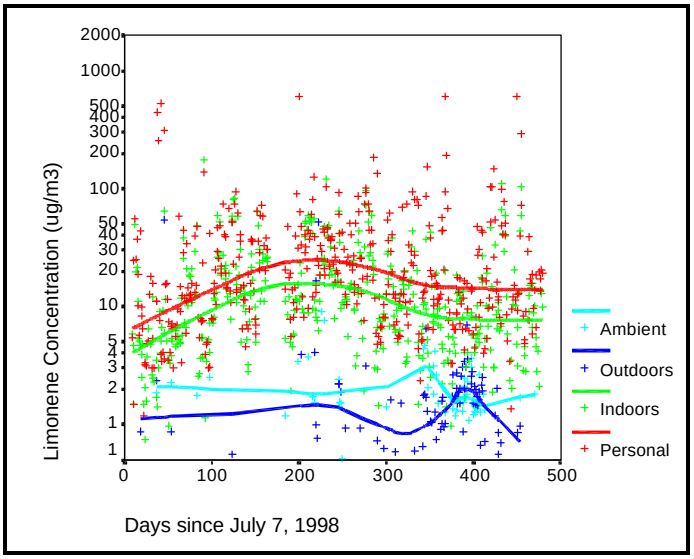


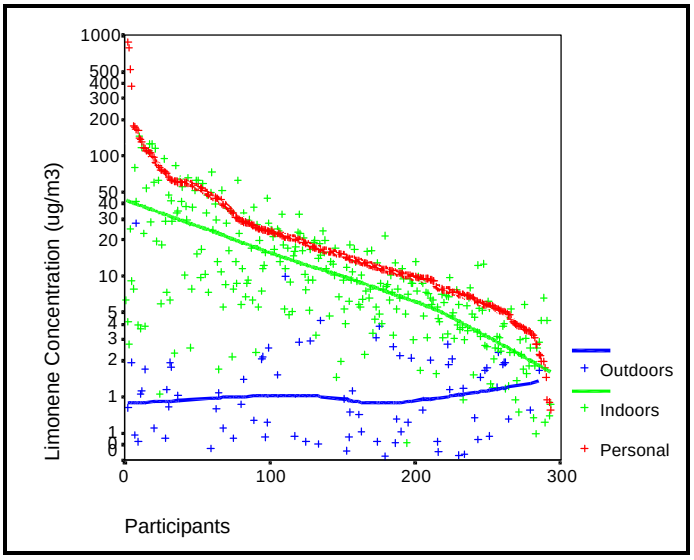
Table 41 shows that the measurement of limonene concentrations is quite stable across the 4-day testing period on the indoor samplers, but was not stable on the personal or outdoor samplers.

Table 41: Reliability of Limonene Levels Over 4-day Periods

Single Measure Intraclass Correlation	r	se
Personal	.04	.05
Indoor	.54	.06
Outdoor	.04	.05

Figure 63 shows the relationships between 4-day averages monitored personally, indoors, and outdoors. The graph shows a strong relationship between personal and indoor exposure concentrations such that high levels of personal exposure are consistently associated with higher levels of indoor exposure concentrations. There is no relationship between outdoor exposures and personal exposures.

Figure 63: Relationship between 4-day Average Exposures to Limonene by Sampler Site



7.1.5 Comparison of Fort McMurray and Lethbridge Samples

Each participant from Lethbridge was also assessed for four consecutive days for personal, indoor, and outdoor sampling. Table 42 tabulates the differences between the two communities. For each chemical and each sampler type, a nonparametric test was conducted to determine differences. Caution should be exercised in interpreting these results since a large number of specific comparisons were made, and the number of participants from Lethbridge was small.

Blank cells indicate no significant difference; > indicates Lethbridge levels higher than Fort McMurray levels ($p<0.05$); < indicates Lethbridge levels lower than Fort McMurray levels ($p<0.05$). Boxplots (Figures 64 to 68) for certain chemicals are also presented to illustrate the magnitude of the differences.

Table 42: Nonparametric Comparisons of Chemical Concentrations between Fort McMurray Participants and Lethbridge Participants

Chemical Concentrations Measured	Lethbridge Personal	Lethbridge Indoors	Lethbridge Outdoors
Nitrogen Dioxide			>
Sulfur Dioxide	<		<
Ozone	>		>
Hexane			
2-butanone			
3-methylhexane	<		<
Benzene	<	<	<
Heptane	<		<
Toluene		>	
Octane	<		
Ethylbenzene	<		
m-, p-xylene	<		
o-xylene	<		
Nonane			
Decane	<	<	
Limonene			<

Figure 64: Levels of NO_2 for Fort McMurray and Lethbridge Participants

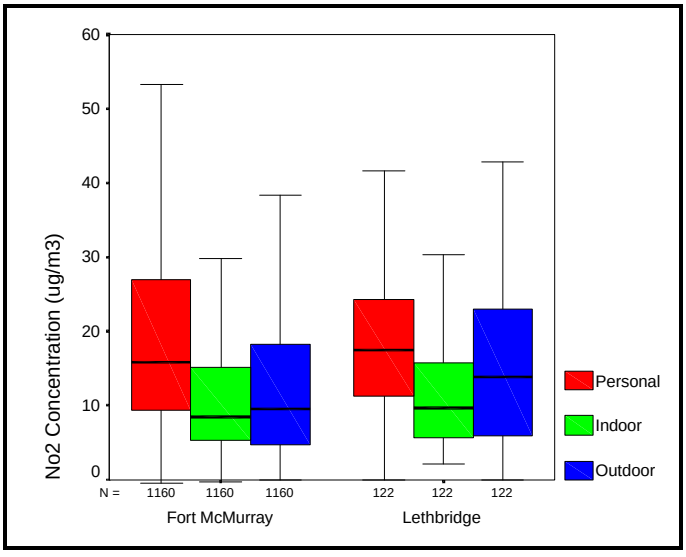


Figure 65: Levels of SO_2 for Fort McMurray and Lethbridge Participants

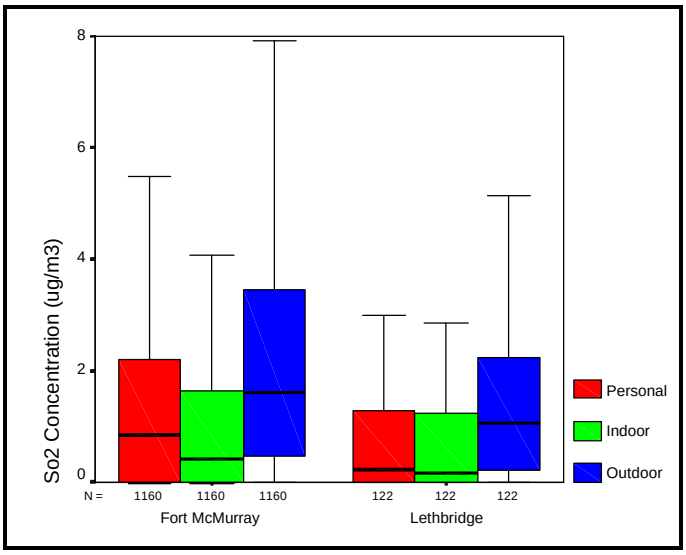


Figure 66: Levels of O_3 for Fort McMurray and Lethbridge Participants

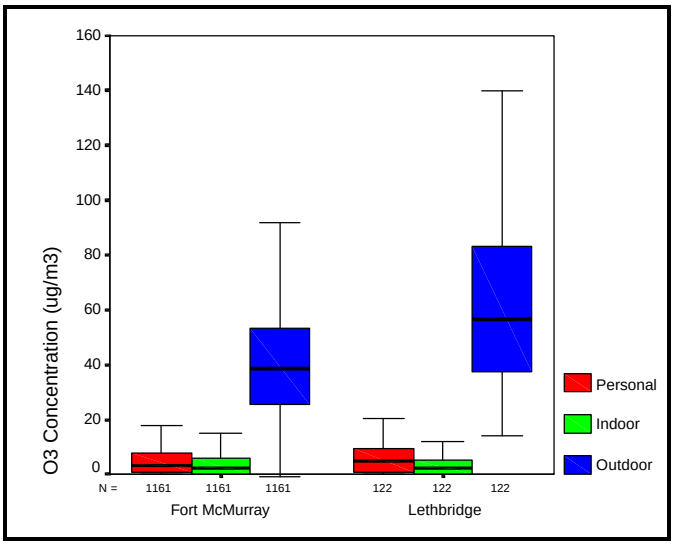


Figure 67: Levels of Methylhexane for Fort McMurray and Lethbridge Participants

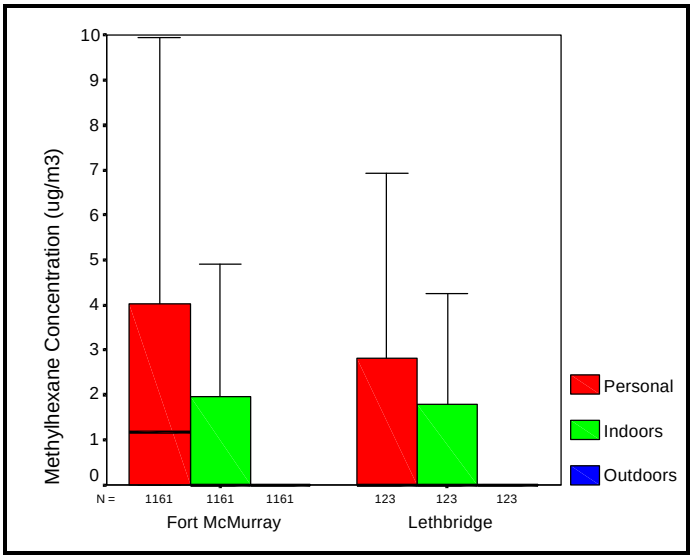
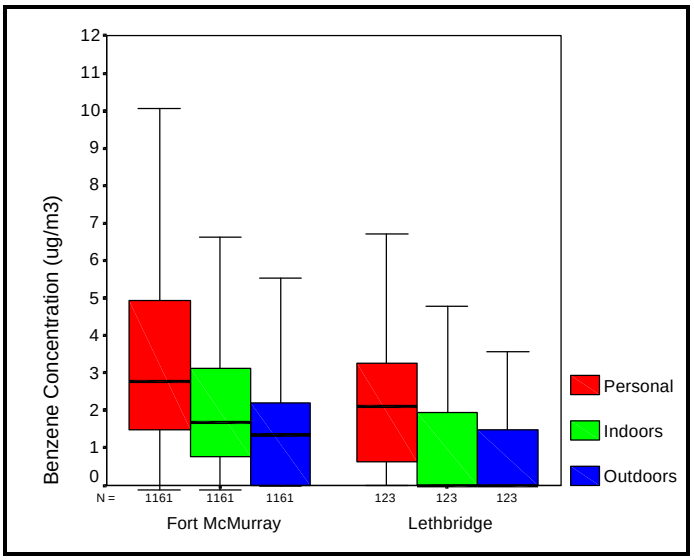


Figure 68: Levels of Benzene for Fort McMurray and Lethbridge Participants



7.2 Particulate Samplers

Particulate matter (PM) samples were also collected from selected participants as well as from the ambient air monitoring station in Fort McMurray. As with the PEMs, the particulate filters were deployed inside and outside the households, attached in the area of the individual's breathing zone, and blanks were also completed occasionally for quality assurance and control purposes. Particulate matter samples were collected in two sizes, $PM_{2.5}$ (smaller air-borne particles less than 2.5 µm in size) and PM_{10} (larger air-borne particles less than 10µm in size). For indoor and outdoor samples, both sizes were collected on each of four consecutive days. Samples of both sizes were also collected at the ambient site. For personal samples, individuals wore the $PM_{2.5}$ samplers on two days (typically the 1st and 3rd day) and the PM_{10} samplers on the other two days (typically the 2nd and 4th day).

From each sample it was possible to determine the concentration of particles in the air. Each sample was also analyzed for the quantity of each of a large number of metals it contained. Table 43 shows the metals that were analyzed.

Table 43: Metals Analyzed from Particulate Samples

Standard Chemical Abbreviation	Chemical Name	Standard Chemical Abbreviation	Chemical Name
AG	Silver	MN	Manganese
AL	Aluminum	MO	Molybdenum
AS	Arsenic	NA	Sodium
B	Boron	NI	Nickel
BA	Barium	P	Phosphorus
BE	Beryllium	PB	Lead
BI	Bismuth	S	Sulfur
CA	Calcium	SB	Antimony
CD	Cadmium	SE	Selenium
CL	Chlorine	SI	Silicon
CO	Cobalt	SN	Tin
CR	Chromium	SR	Strontium
CU	Copper	TH	Thorium
FE	Iron	TI	Titanium
HG	Mercury	TL	Thallium
K	Potassium	U	Uranium
LI	Lithium	V	Vanadium
MG	Magnesium	ZN	Zinc

As with the PEMs, the goal of the PM component was to collect four consecutive 24-hour samples from each participant. As with the passive samplers, some participants were unable to complete all four periods of sampling. Of the 48 Fort McMurray participants wearing the particulate samplers, 42 (87.5%) were able to complete all four 24-hour samples. All 6 (100%) of the Lethbridge volunteers completed the four sampling periods. The sole reason for the non-completion of the PM component by some of the Fort McMurray participants was equipment problems. For these problematic days as much data as possible was collected and may prove to be salvageable for analysis purposes. Table 44 shows the distribution of the 1,999 particulate matter filters that were used during the study.

Table 44: Distribution of Particulate Matter (PM) Filters

# by Location	PM Cut Size	Fort McMurray	Lethbridge	Totals
207 Personal	0 – 2.5	92	13	105
	0 – 10	90	12	102
416 Indoor	0 – 2.5	183	25	208
	0 – 10	183	25	208
423 Outdoor	0 – 2.5	187	25	212
	0 – 10	187	24	211
183 Blank	0 – 2.5	81	5	86
	0 – 10	90	7	97
739 Ambient station	0 – 2.5	369	0	369
	2.5 – 10	369	0	369
	0 – 10	1	0	1
31 Lab blanks	N/A	N/A	N/A	31
				1999

Notes: Ambient station PM filters deployed in Fort McMurray only. Lab blanks not loaded with PM filters. Figures include filters used for electron microscopy.

Analysis proceeded in two parts. The first part replicates the basic analysis procedures used for the passive samplers. For each of the two sizes of particle the same three graphs and one table are presented below, showing the overall concentration (by weight) of particulate matter.

Figure 69 shows the cumulative distribution of $PM_{2.5}$ concentrations for the four types of samplers. Indoor, outdoor and ambient concentrations were very similar to each other, and personal measurements were higher than all three types.

Figure 69: Distribution of $PM_{2.5}$

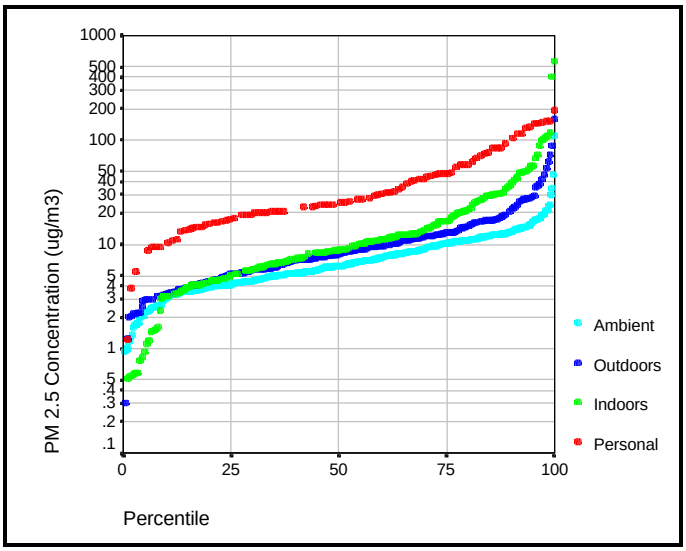


Figure 70 shows the smoothed curves representing the seasonal trend in $PM_{2.5}$ concentrations. Personal concentrations varied across the course of the study, with higher values in summer and fall, and lowest values in the late spring. Indoor, outdoor and ambient concentrations did not vary across the study period.

Figure 70: Seasonal Trend in $PM_{2.5}$ Concentration

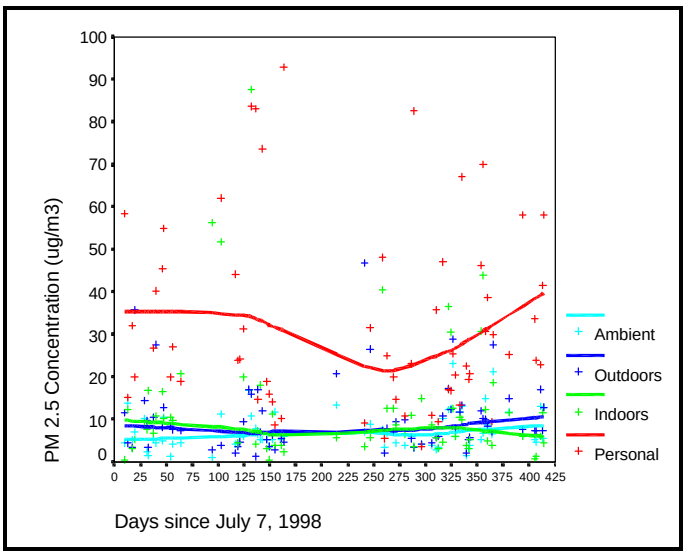


Table 45 shows that the measurement of $PM_{2.5}$ concentrations is relatively stable across the testing period for personal and indoor sampler types, but not for the outdoor samplers.

Table 45: Reliability of $PM_{2.5}$ Levels Over 4-day Periods

Single Measure Intraclass Correlation	r	se
Personal 2 day sample 1	.51	.20
Personal 2 day sample 2	.40	.40
Indoor	.50	.16
Outdoor	.29	.14

Figure 71 shows the 4-day average personal exposure concentrations compared to average indoor and outdoor concentrations. There is a moderate correlation between personal and indoor concentrations, and no relationship to outdoor concentrations.

Figure 71: Relationship between 4-day Average Exposures to $PM_{2.5}$ by Sampler Site

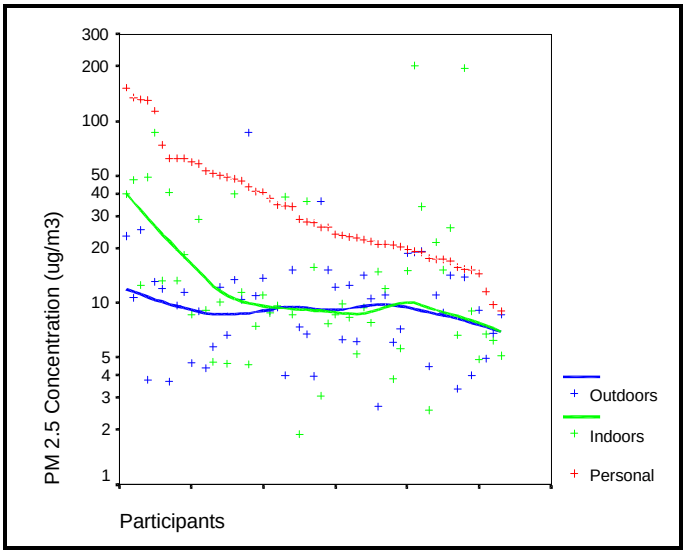


Figure 72 shows the cumulative distribution of PM_{10} concentrations for the four types of samplers. As we saw with the $PM_{2.5}$ concentrations, indoor, outdoor and ambient concentrations were very similar to each other, and personal measurements were higher than all three types.

Figure 72: Distribution of PM_{10}

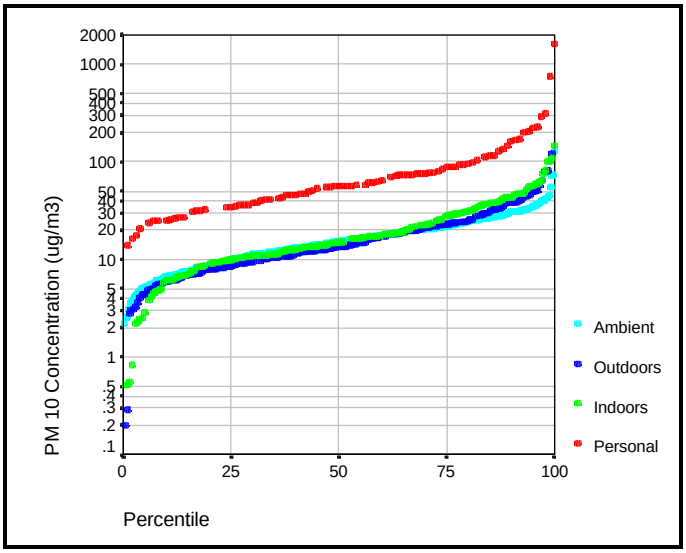


Figure 73 shows the smoothed curves representing the seasonal trend in PM_{10} concentrations. Personal and outdoor concentrations varied slightly across the course of the study, with higher values during the summer. Indoor and ambient concentrations did not vary across the study period.

Figure 73: Seasonal Trend in PM_{10} Concentration

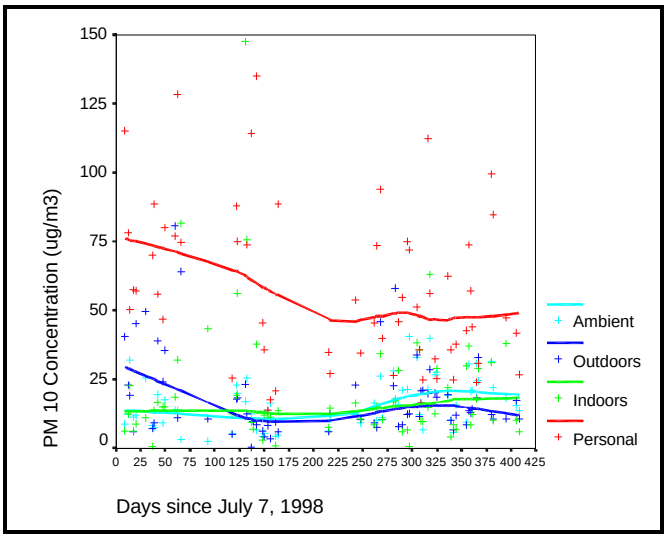


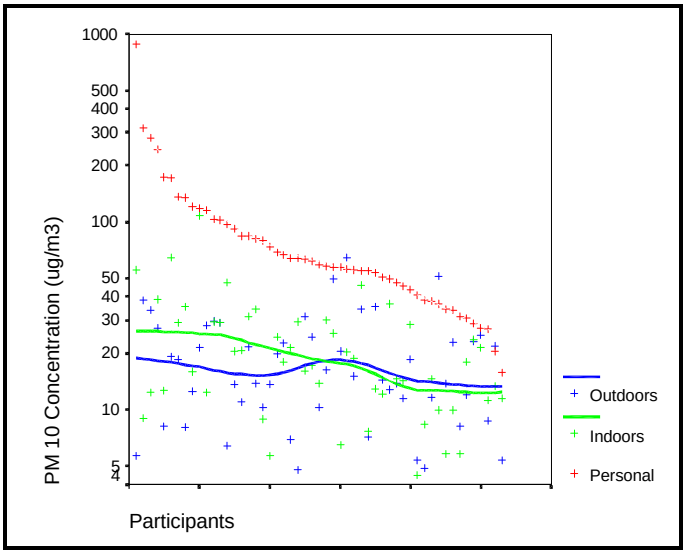
Table 46 shows that the measurement of PM_{10} concentrations is relatively stable across the testing period for indoor sampler types, but not for the outdoor samplers. Personal samplers are moderately stable.

Table 46: Reliability of PM_{10} Levels Over 4-day Periods

Single Measure Intraclass Correlation	r	se
Personal 2 day sample 1	.35	.40
Personal 2 day sample 2	.40	.38
Indoor	.70	.10
Outdoor	.25	.14

Figure 74 shows the 4-day average personal exposure concentrations compared to average indoor and outdoor concentrations. There is no correlation between personal concentrations and either indoor or outdoor concentrations.

Figure 74: Relationship between 4-day Average Exposures to PM_{10} by Sampler Site



Concentration levels were compared between Fort McMurray and Lethbridge participants for both $PM_{2.5}$ and PM_{10} samples. For $PM_{2.5}$, Lethbridge had lower levels of indoor particulate ($p<0.05$) though levels for personal and outdoor exposures were comparable. This is shown in Figure 75. For PM_{10}, Lethbridge had lower levels of personal particulate ($p<0.05$) though levels for indoor and outdoor exposures were comparable. This is shown in Figure 76.

Figure 75: Levels of $PM_{2.5}$ for Fort McMurray and Lethbridge Participants

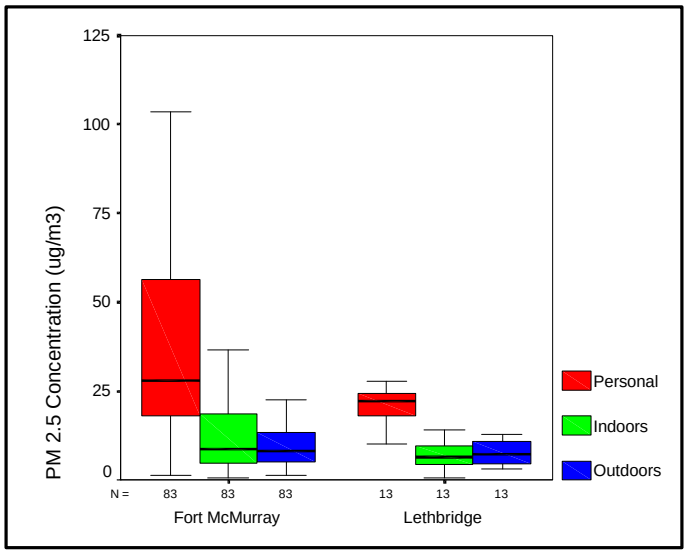
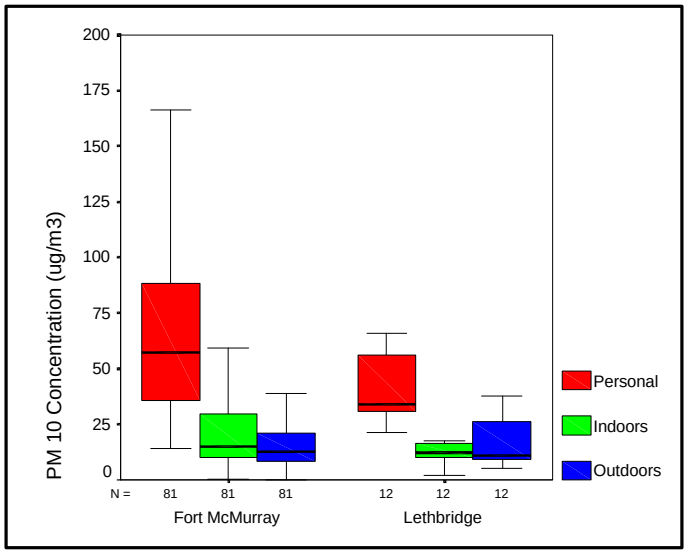


Figure 76: Levels of PM_{10} for Fort McMurray and Lethbridge Participants



The second part of particulate analysis concerned the composition of the particulate and involved a consideration of the relative amounts of the analyzed metals found in the samples. The following three figures (Figures 77 to 79) show the relative amounts of the various metals in the particulate. The first (Figure 77) shows the average amounts of metal (in ng/m^3) across both types of particulate and all sampler types. A major purpose of this figure is to provide a labeling scheme for the two figures that follow. In other words, Figure 77 shows the average concentration for copper on the vertical bar labeled 23 on the horizontal axis. The next graph (Figure 78) shows personal, indoor, outdoor, and ambient relative concentrations of metals in $PM_{2.5}$ in the same order as shown in the previous graph (where copper is again placed on the vertical line labeled 23). The next graph (Figure 79) shows personal, indoor,

outdoor, and ambient relative concentrations of metals in PM_{10}, again in the same order as shown in Figure 77.

Figure 77: Overall Concentrations of Metals in Particulate

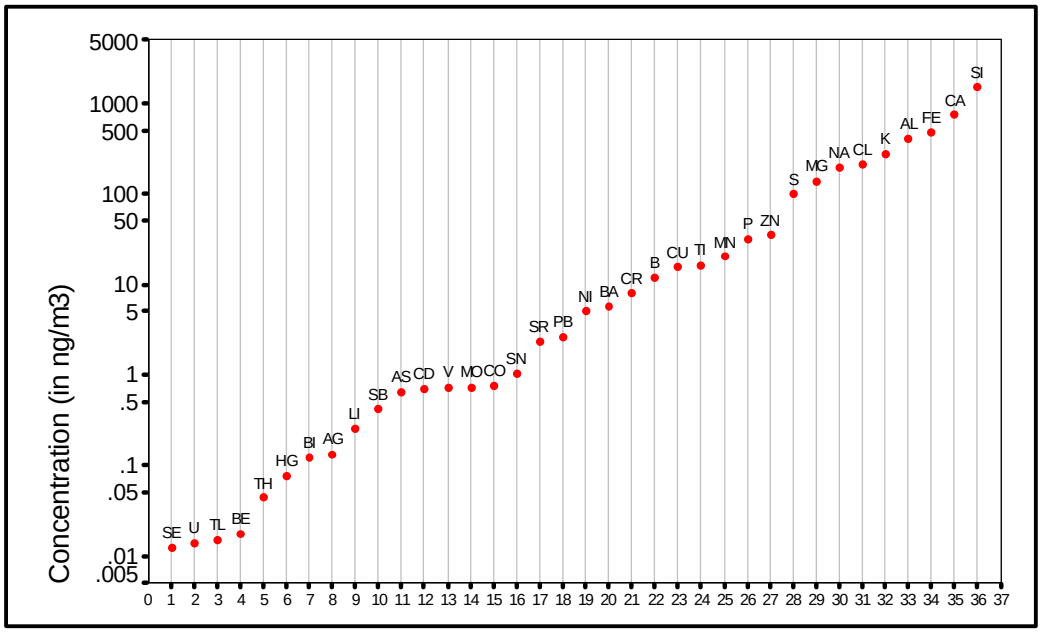


Figure 78: Concentrations of Metals in $PM_{2.5}$

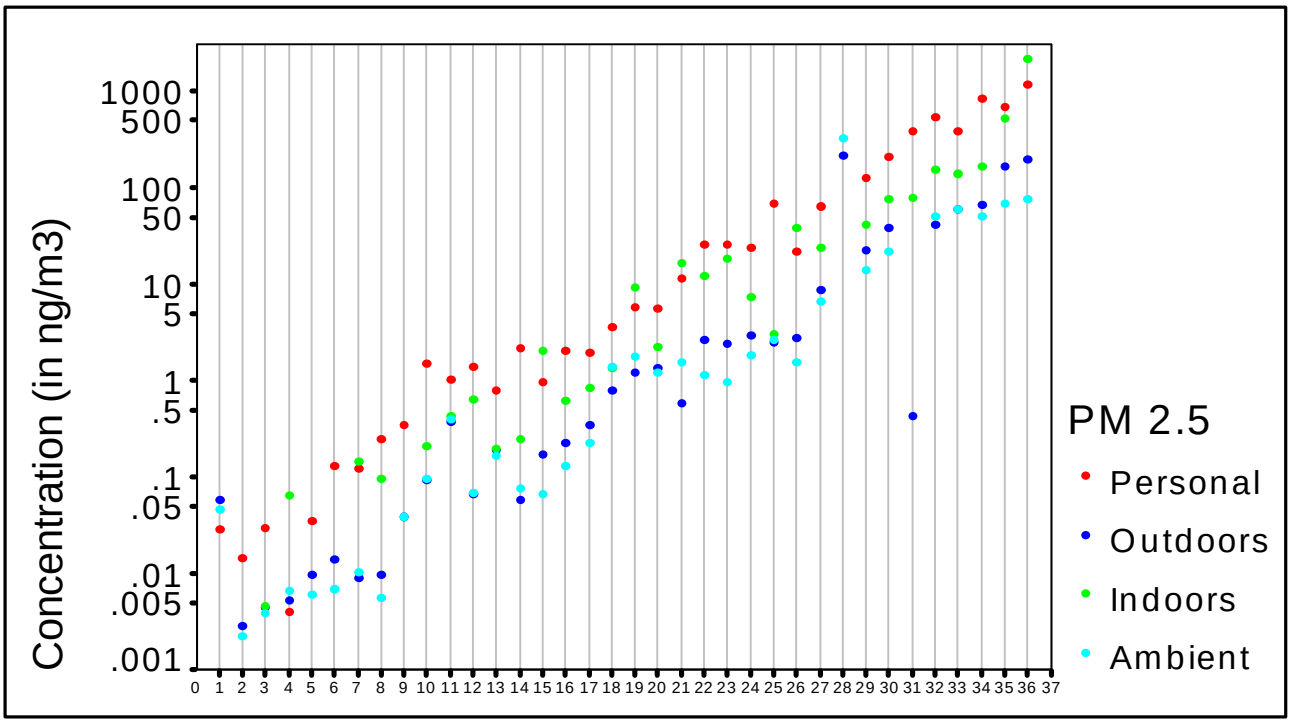
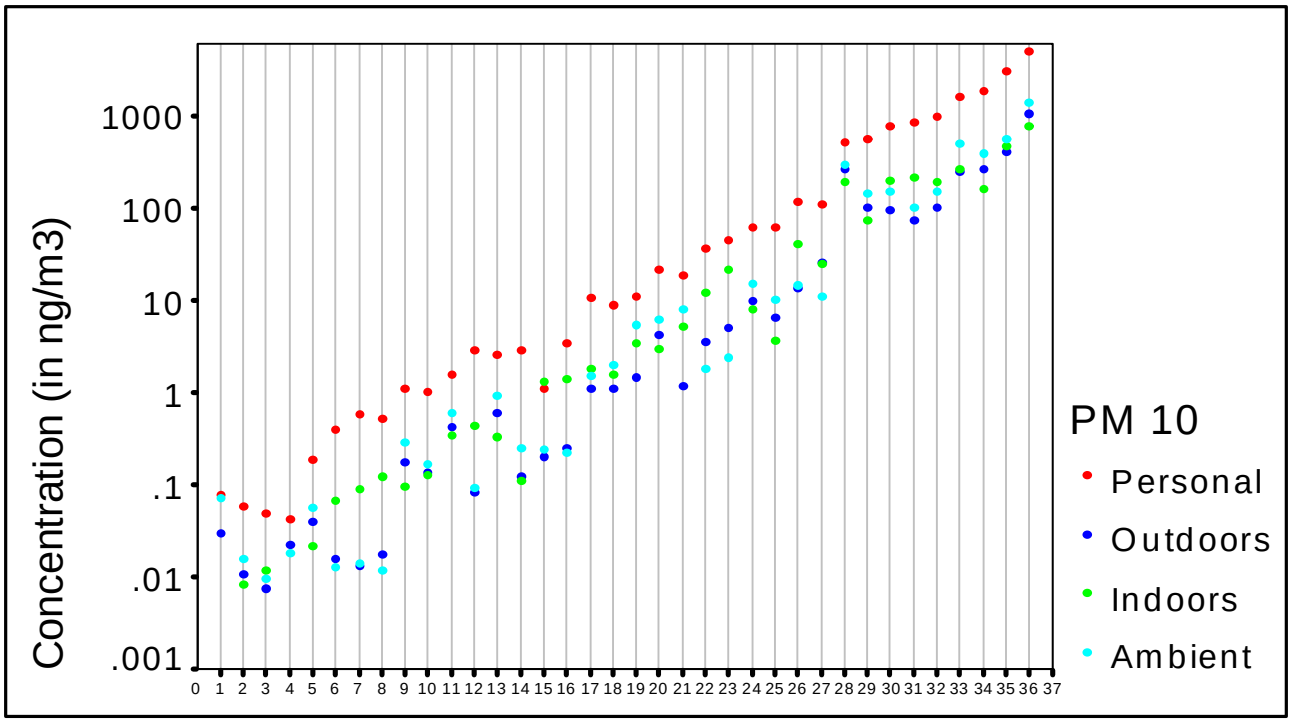


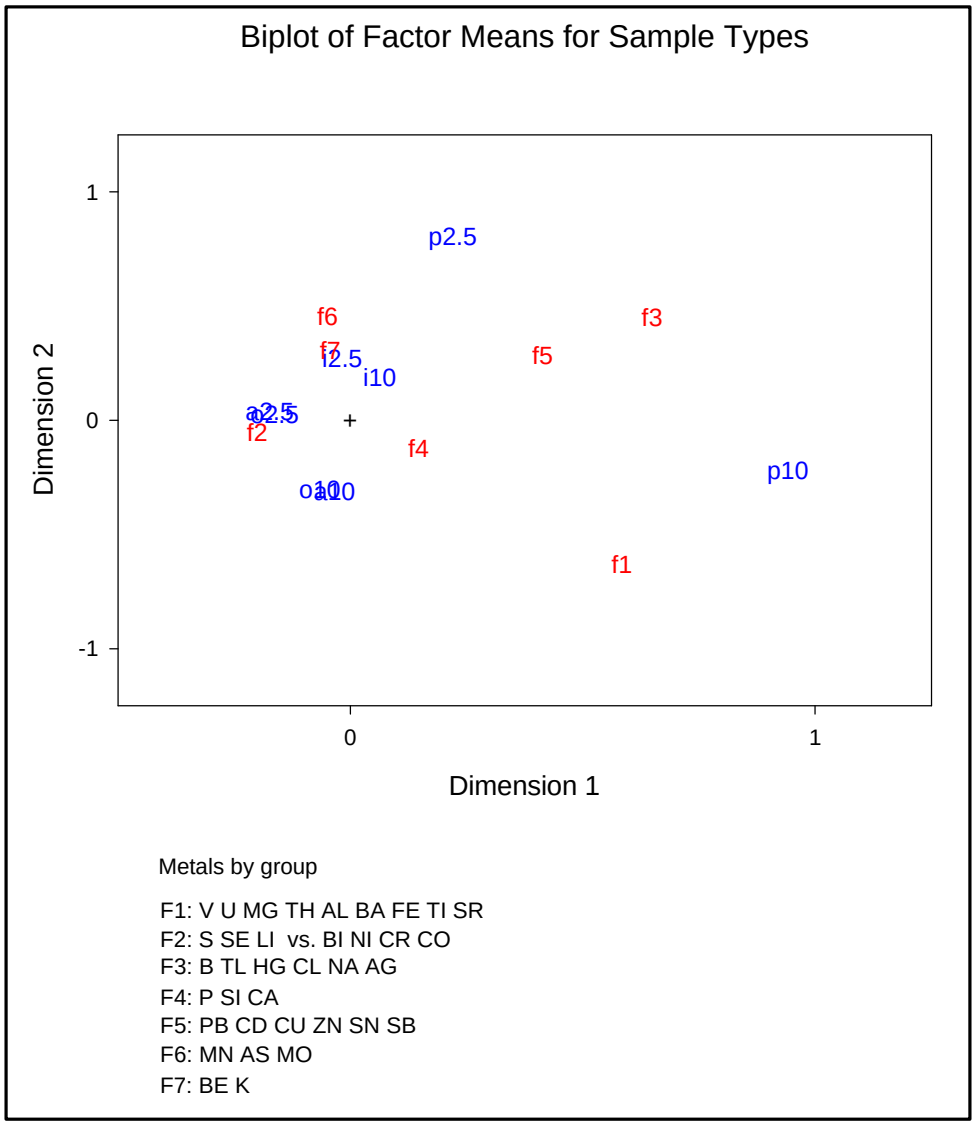
Figure 79: Concentrations of Metals in PM_{10}



A final analysis of the composition of particulates was performed to attempt to characterize the groupings of metals, and the differences between sample sites. First, a principal component analysis was conducted on the concentrations of metals across both sample types and all four-sample locations. This resulted in seven groupings of metals. Each of the metals in each group tend to rise and/or fall in concentration levels at the same time within samples across sample types and sites. An exception is the second grouping which brings together two groups of metals which seem to rise or fall relative to each other (i.e., higher levels of the first group are associated with lower levels of the second, and vice versa). The chemicals in each group are presented in Figure 80 (annotated f1 to f7).

A group score was calculated for each group of chemicals, and the mean group score was calculated for each sample type ($PM_{2.5}$, PM_{10}) and each sample site (personal, indoor, outdoor, ambient). Figure 80 represents the differences between these sample sites and types (annotated p2.5, p10, i2.5, i10, etc.).

Figure 80: Differences between Sample Types and Sites



Specifically, the chemical groups and sample types/sites are plotted along the first two dimensions of a singular value decomposition. The graph is interpreted as follows: if one mentally draws a line from a particular sample type/site through the cross at co-ordinates 0,0 and then mentally projects the locations of the chemical groups perpendicular to that line, one gets a reconstruction of the relative ordering of the chemical groups in samples of that type/site. Any chemical group that projects farther than the central cross has lower levels while those projecting between the cross and the sample type/site have higher levels than the sample set considered as a whole. Thus, for example, p10 (for Personal Sample of PM_{10}) has relatively higher levels of groups f3, f1, f5; similar levels of f4, f6, f7; and slightly lower levels of f2 than the samples taken as a whole. On the other hand, both ambient $PM_{2.5}$ and outdoor $PM_{2.5}$ (a2.5 & o2.5 on the graph) have higher levels of f2, lower levels of f3 and f5, and average levels of f1, f4, f6, f7 than the samples taken as a whole.

An additional side study was conducted over a 6-week period in collaboration with Environment Canada that examined fine particulate size distribution and composition using a cascade sampler (refer to *Appendix A: Fine Aerosol Chemistry at Dissimilar Non-urban Sites*). As expected, the study identified differences in the fine particulate composition when comparing Fort McMurray with a control site in rural Alberta.

7.2.1 Electron Microscopy

Airborne particulate pollution has been linked to respiratory morbidity in the form of increased admissions to hospital for cardiopulmonary diseases.[82, 83, 84] These epidemiologic observations are strong and coherent and thus particulate sampling is an important component of any epidemiologic study of lung health. Particulate matter in the respirable range (<10 µm in diameter) comes from three major sources: natural sources (e.g., moulds, pollen, and wind-borne dust); industrial activity (e.g., fly ash, acid particulates, and particles specific to the oil sands industries); and from personal sources (e.g., cigarette smoke, fragments of clothing, dander and particles derived from pets, etc.). In view of the diverse origin of particles and before conclusions can be drawn concerning the role of industrial pollutants on lung health, it is important to characterise the types and relative frequencies of particles in the air. Data was obtained from the analysis of 30 filter samples taken in the Fort McMurray region. Twelve of the samples were taken from outdoor locations, 12 from indoors, and 6 were personal samples.

Morphology of Particles

A variety of particles were observed by scanning microscopy. Some of these had easily identifiable shapes, such as pollen grains, mould spores, hairs, fragments of carpet and clothing and fly ash particles. Other particles had irregular borders or crystalline structures consistent with minerals and metals of various kinds. In general, the proportion of organic material was greater in the indoor samples than the outdoor samples. Representative examples of the types of particles that are found are shown in the following figures.

Figure 81 shows the appearance of a blank filter sample seen under the secondary electron mode of the scanning electron microscope. The filter has a woven appearance; however, no particles are seen on the surface or embedded in the filter structure.

Figure 81: Blank Filter Sample

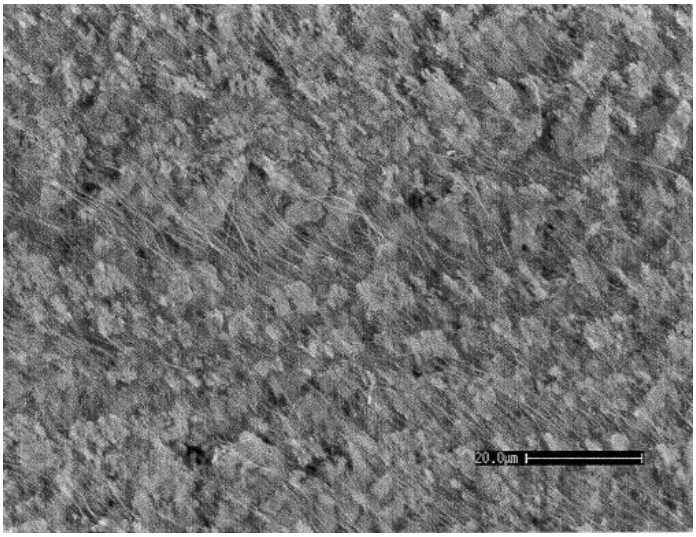
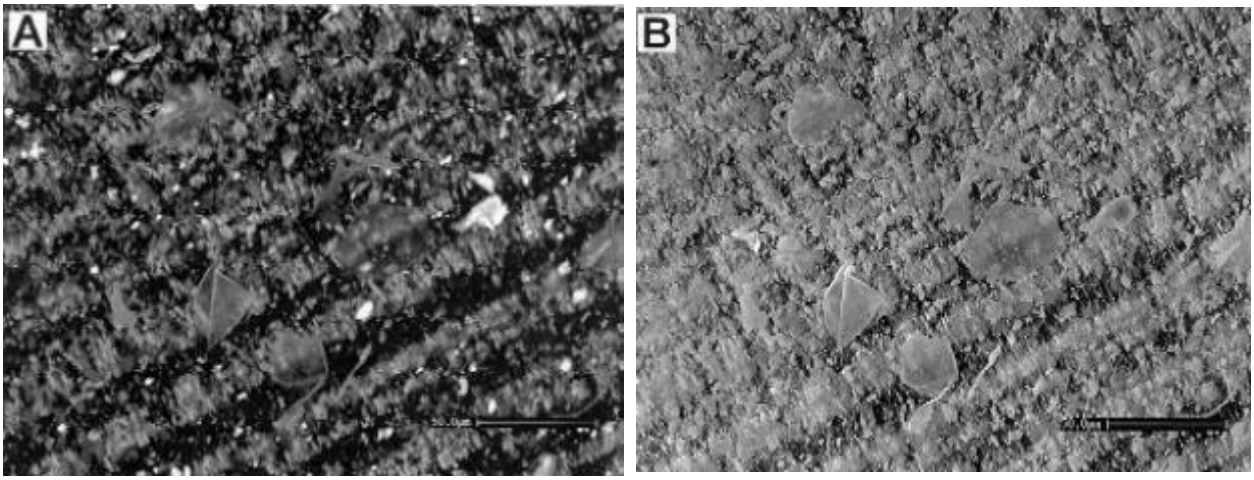


Figure 82 shows a comparison of low power scanning electron micrographs of an indoor sample in back-scattered electron (A) and secondary electron (B) modes. In the secondary electron mode (B), particles of various shapes and size are seen scattered across the surface of the filter. Some of the platey particles are extremely thin and other particles can be seen through them. Note that these particles are much larger than the cut-off for the filter (10 µm). This is because the filter works on aerodynamic principles, thus particles that are thin and platey, such as are seen here, will have low aerodynamic diameters and thus will pass into the filter system. Many of these particles appear to be flakes of skin or dander. In Figure 82B, the same specimen examined in the back-scattered electron detector, shows variability in the brightness of the particles. In this mode, particles of higher atomic number (mostly minerals and metals) appear bright, whereas organic particles appear grey. This mode is particularly useful for identifying particles for x-ray microanalysis (see later section).

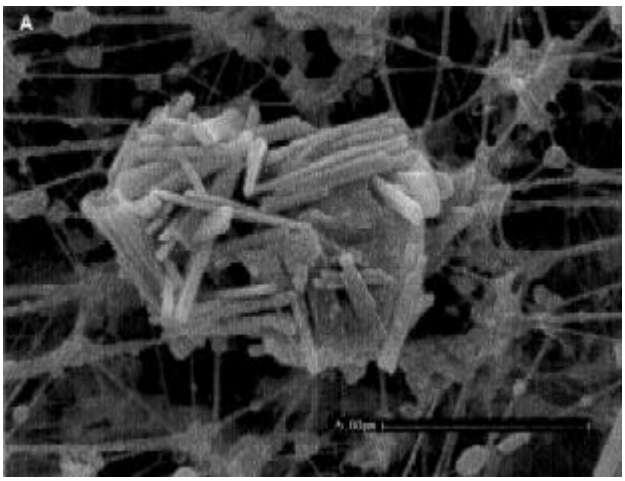
Figure 82: Low Power Scanning Electron Micrographs of Indoor Sample



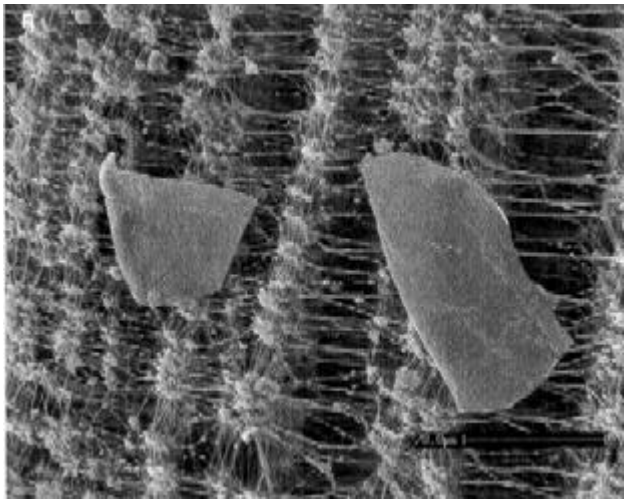
A: Back-scattered electron mode

B: Secondary electron mode

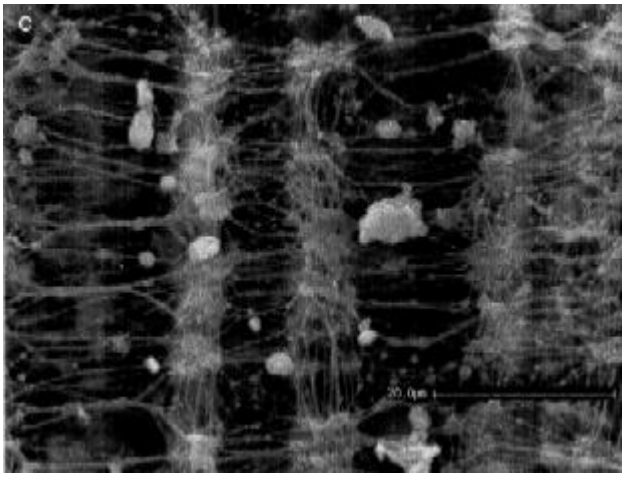
Figure 83: Higher Magnification Views of Particles



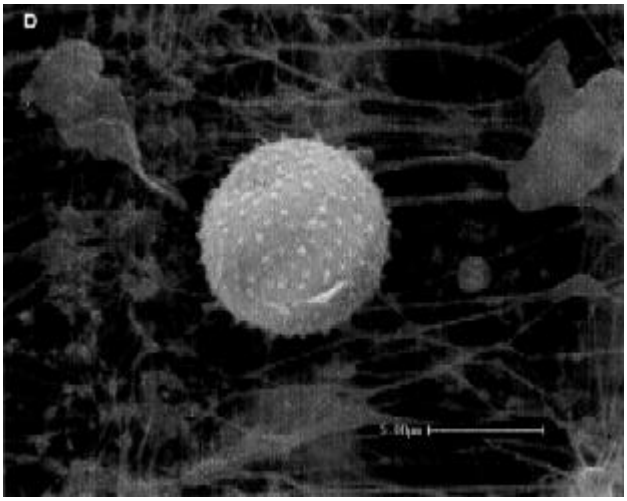
a: Clusters of crystalline particles. These particles have x-ray spectra of calcium and sulfur and were most likely gypsum crystals.



b: These platey particles, which in this photomicrograph, are over 20 µm in greatest length, probably represent fragments of skin.

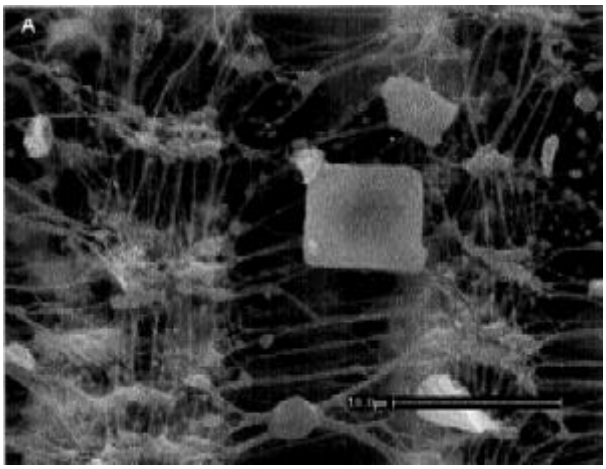


c: The smaller globular particles seen in this photomicrograph were mineral and metal particles.

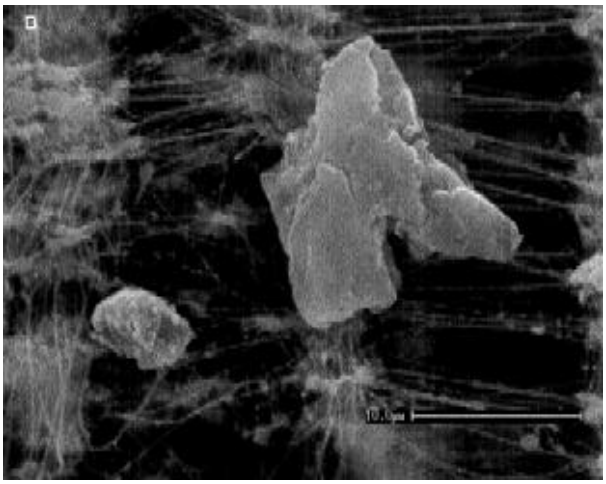


d: The large particle shown is characteristic of a pollen grain.

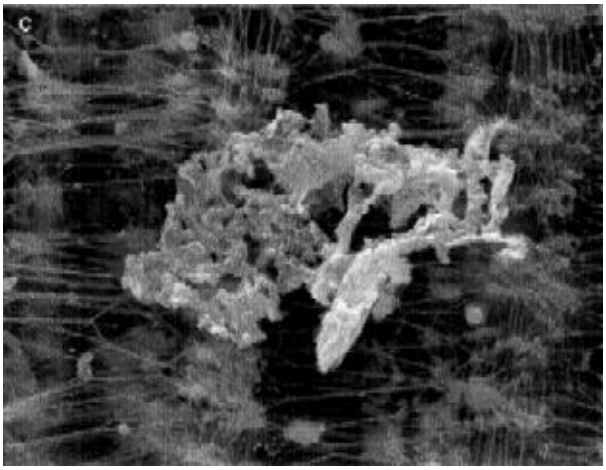
Figure 84: More Electron Photomicrographs of Interest



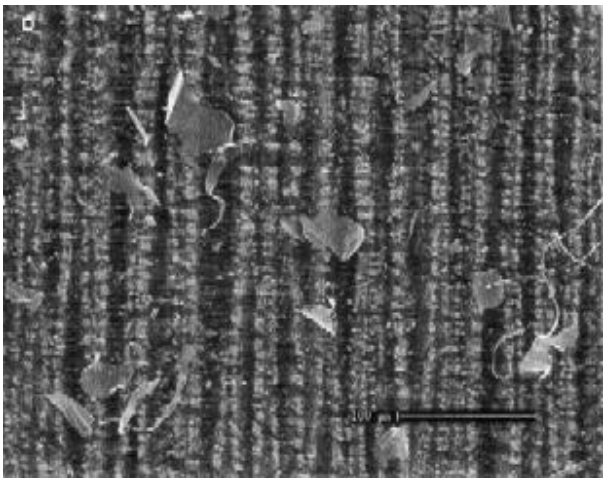
a: A crystalline particle with an elemental composition consistent with common salt.



b: A cluster of angular particles. Particles of this shape and size often had x-rays indicative of a silicate mineralogy.

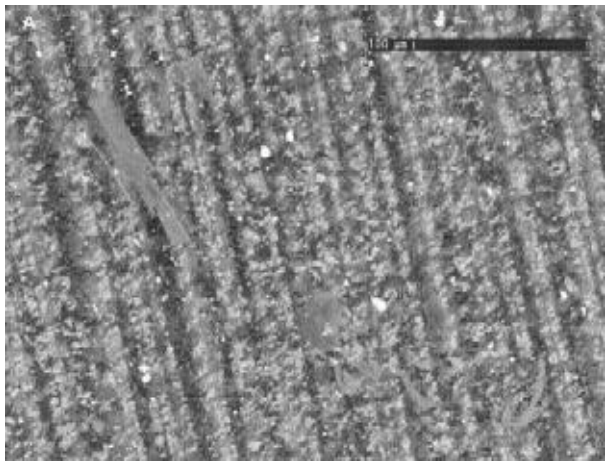


c: Fenestrated and irregular particles shown in this photograph often had high x-ray counts for iron or other metals.

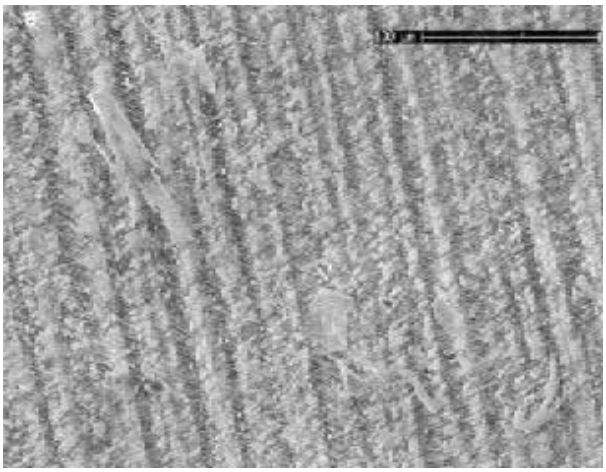


d: Low magnification view of a filter taken within a home showing flaky particles and fibrous strands consistent with man-made fibres.

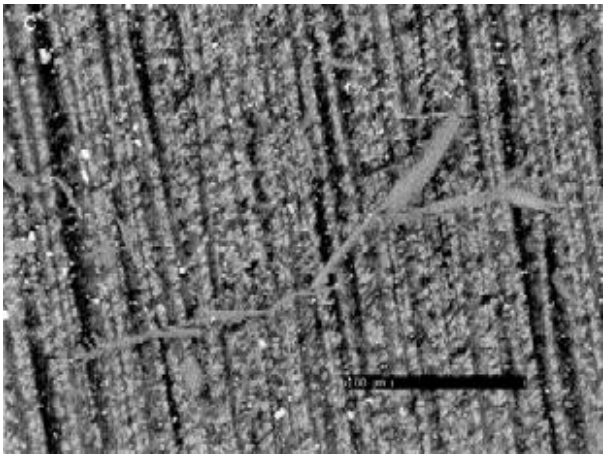
Figure 85: A Personal PM_{10} Filter Sample



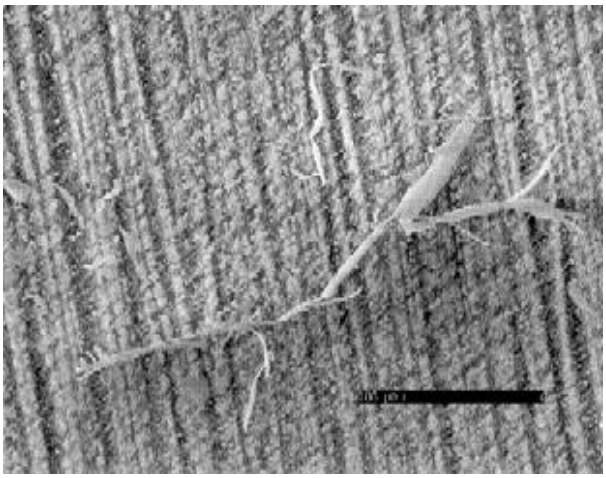
a: Low-power view shown in back-scattered electron mode. The bright particles seen are minerals or metals.



b: Secondary electron mode



c: Higher-power view in back-scattered mode of the same particle, showing characteristic fragments of cloth or carpet.



d: The same particle in secondary electron mode.

X-ray Microanalysis

Figures 86 through 89 show examples of areas of filters from outdoor, indoor and personal samplers showing some characteristic findings by x-ray analysis. Figure 86 is an outdoor filter sample. Included in the field of view is a cluster of crystals of gypsum, a pollen spore, a mould spore and several different types of silicate mineral. Occasional fly ash particles were identified in the outdoor samples, although these were relatively infrequent. Figure 87, an indoor sample, shows some amorphous particles with x-ray spectra. In this particular view, a particle of quartz is seen, as are particles with spectra of iron and aluminum oxides. Several silicate minerals are also seen.

Figure 86: Outdoor Filter Sample

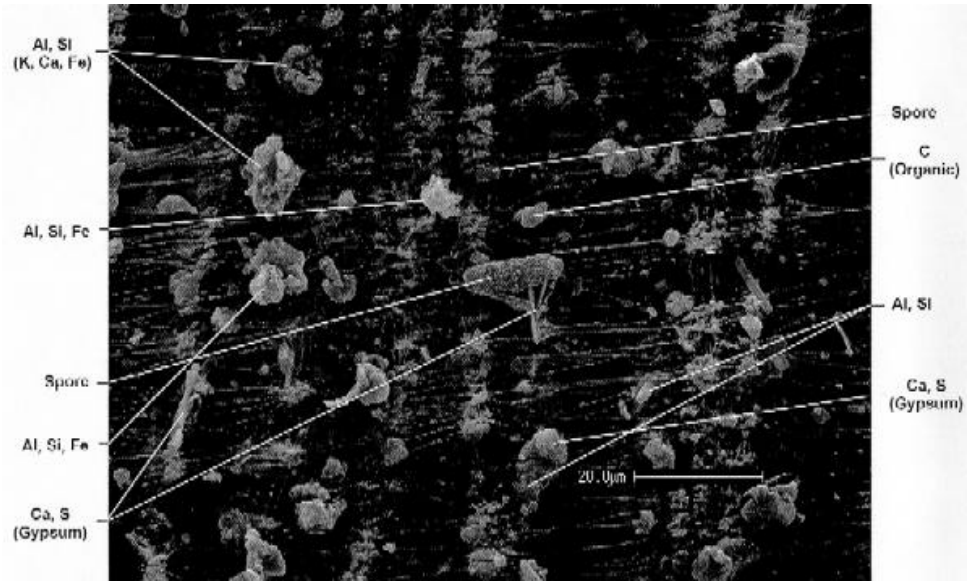


Figure 87: Indoor Filter Sample

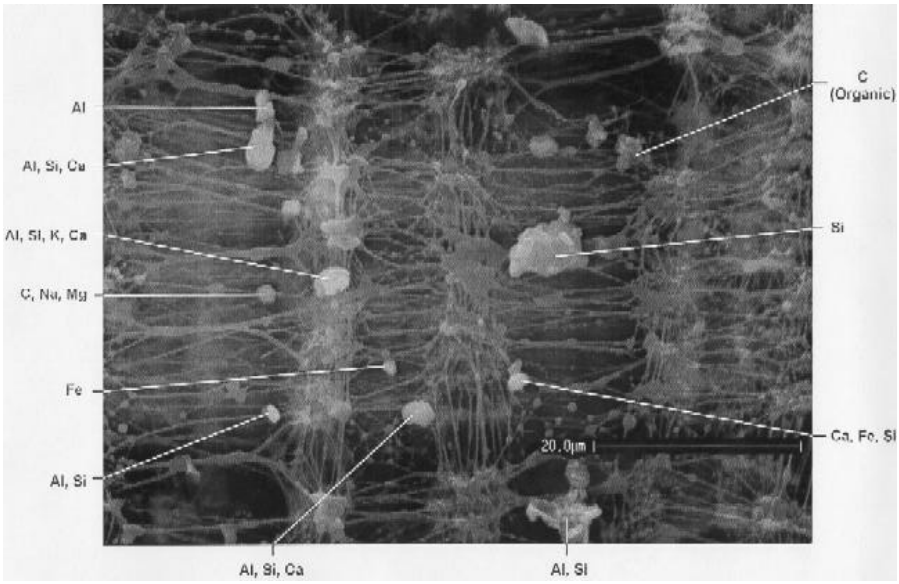


Figure 88 is a filter from a personal sampler showing fragments of skin with predominantly carbon-based spectra, as well as minerals of various kinds. The particle shown at bottom left has high x-ray counts for aluminum, silicon and phosphorous, consistent with a detergent washing powder. Figure 89 is a higher-powered magnification of a conglomerate particle seen by back-scattered electron imaging. The high intensity inclusions consist largely of copper and zinc, which is consistent with brass. The matrix consists of calcium, chlorine, silicon, sulfur, potassium and calcium. A characteristic salt particle is seen at top right.

Figure 88: Personal Filter Sample

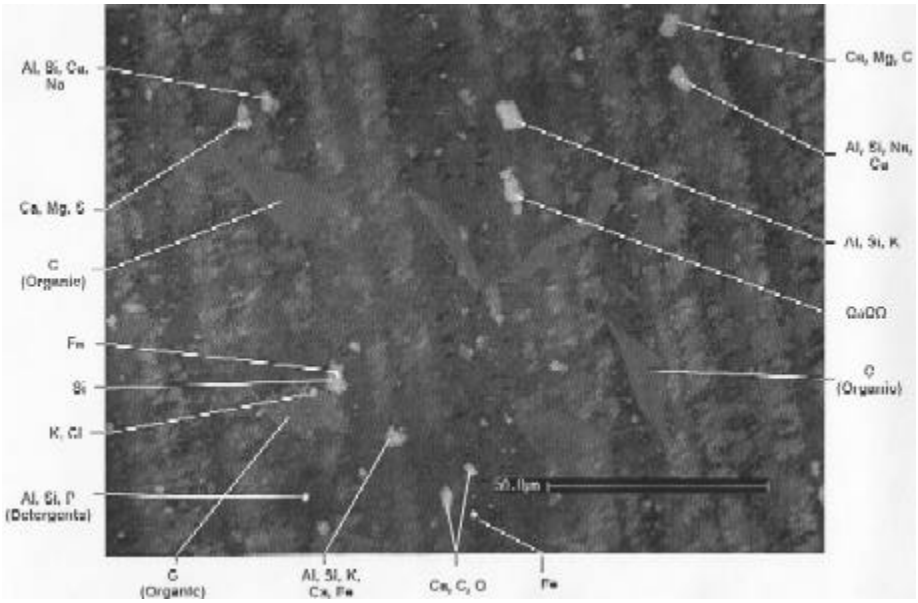
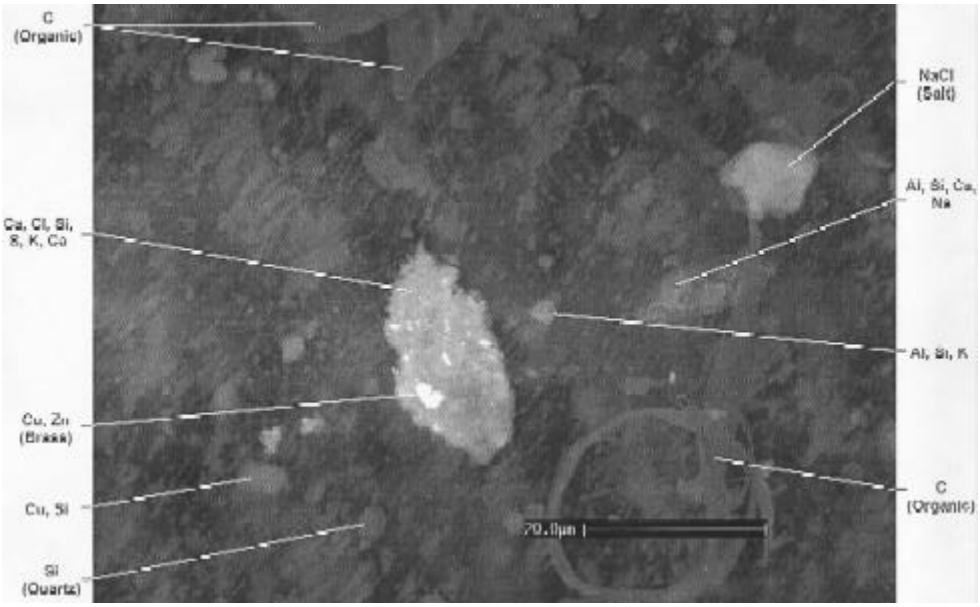


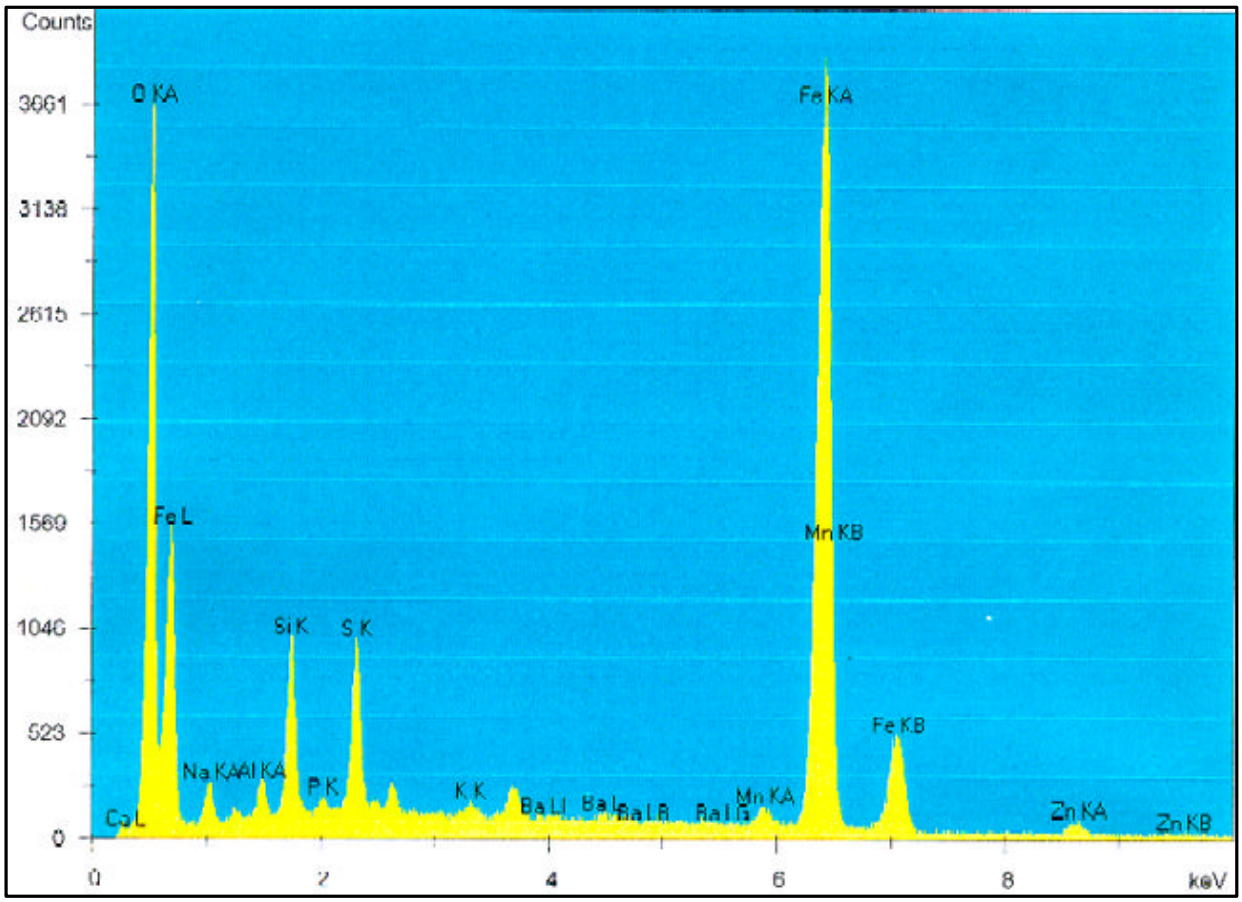
Figure 89: Higher-powered Magnification of a Conglomerate Particle from a Personal Sampler Seen by Back-scattered Electron Imaging



Semi-quantitative X-ray Microanalysis

Figure 90 shows a characteristic x-ray spectra of a particle. The number of x-ray counts shown on the vertical scale determines the amount of a given element. Elemental identification is given by the characteristic energy of the element given on the horizontal scale. For semi-quantitative analyses, 100 particles were selected at random at a magnification of 2000 times.

Figure 90: Characteristic X-ray Spectra of a Particle



Element	Percent concentration by Weight
Oxygen	30.83
Sodium	2.34
Aluminum	1.14
Silicon	4.02
Phosphorus	0.38
Sulfur	3.75
Potassium	0.33
Calcium	0.00
Manganese	1.08
Iron	53.71
Zinc	2.05
Barium	0.38

Figure 91 shows two examples of outdoor particulate samples. Although there were considerable variations from sample to sample, this pair illustrates that a majority of mineral particles had an elemental composition consistent with aluminum silicates. Particles with a pure silicon peak (probably quartz) and calcium-rich particles were also common in most samples.

Figure 91: Two Examples of Outdoor Particulate Samples

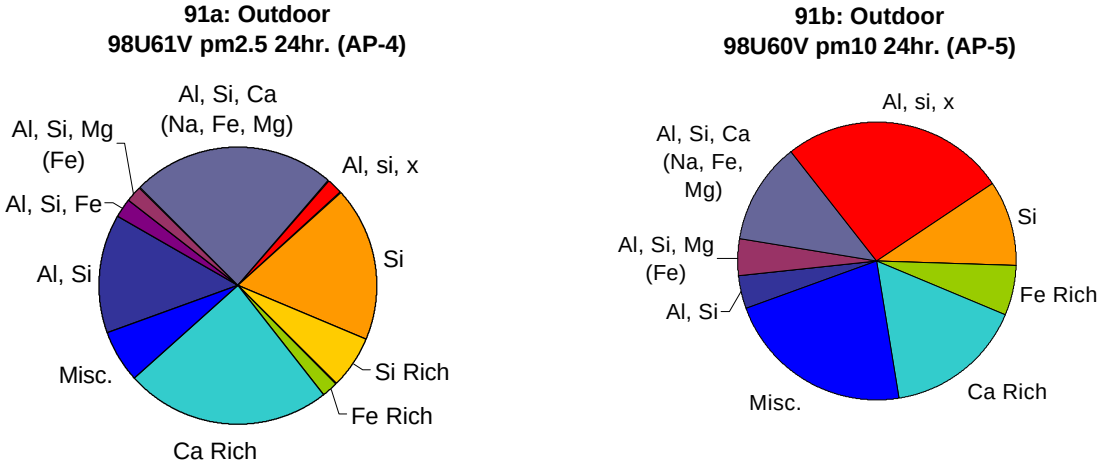


Figure 92A shows a personal sample and 92B an indoor sample. Again, silica, silicates and calcium-rich particles tend to predominate.

Figure 92: Personal and Indoor Particulate Samples

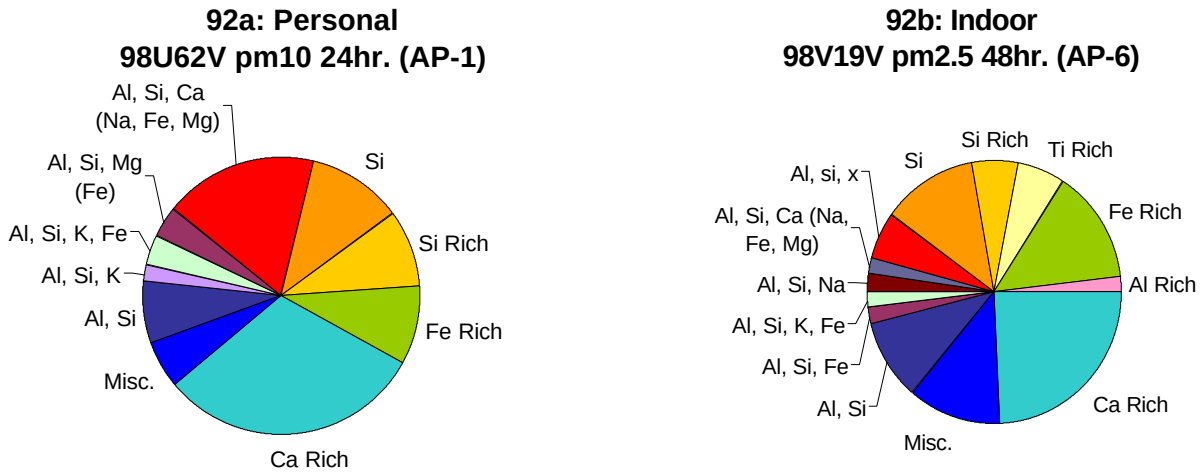
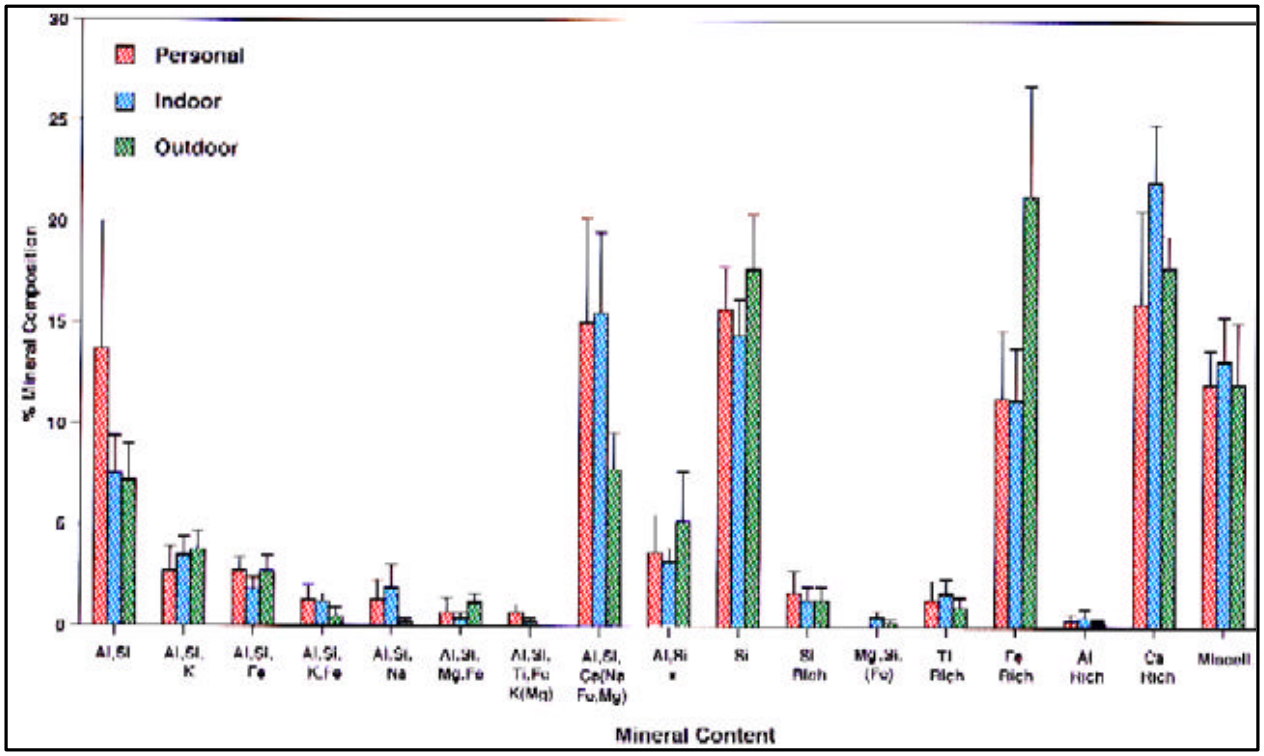


Figure 93 shows a summary of the statistical data for the three types of filters. For all three types of sample, particles in classes 1, 8, 10, 14, 16 and 17 predominated. Classes 1 and 8 are aluminum silicates and calcium aluminum silicates, respectively. Class 10 contains particles with a chemistry consistent with silica (quartz). Class 14 contains iron-rich compounds. Particles in class 16 are calcium rich. And particles in class 17 are miscellaneous. Although there is considerable variation in the data, none of the differences seen in Figure 93 are statistically significant. Hence, it would appear that for mineral and metal particles, indoor (including personal) samples are very similar to that observed outdoors.

Figure 93: Statistical Data for Personal, Indoor, and Outdoor Filters



Electron Microscopy Findings

No differences were found in broad chemical categories of mineral and metal dusts between indoor, personal, and outdoor samples or in the PM 2.5 versus PM 10 size classes. For all sampler types and locations, aluminum silicates, silica, and calcium salts predominated. No particles of vanadium, cerium, or other rare earth elements were identified. This does not mean that they were not present in small quantities. The ability to detect low amounts of elements (< 1%) is easily overlooked with this type of analytic method. Occasional particles consisting of copper, zinc, and aluminum were detected in all sampler types and locations. Presumably these result from industrial and/or domestic activities. The major difference between the indoor and outdoor air samples was in the proportion and types of organic materials. In the outdoor samples, mineral dusts and metals predominated. Organic particles tended to be largely pollen and mould spores. In the indoor environment, organic materials constituted about 50% of all particles, predominantly flaky materials consistent with squames or dander, fragments of hair, and fragments of man-made fabrics (carpets and/or clothing). Pollen grains were seen in these samples but were infrequent, whereas mould spores were more frequent than in the outdoor samples. Particles of

large physical dimension (i.e. > 10 μm) were seen in filters with a cut-off of less than 10 μm. This reflected the low aerodynamic diameters of some types of organic particles. Occasional fly ash particles were also identified. The types of mineral particles and their relative frequencies were similar to those described for atmospheric samples taken in rural Alberta.[85]

8.0 Exposure Relationships

8.1 A General Model of Potential Relationships

The factors that determine the level of chemicals to which an individual is exposed are numerous, and may be very specific. The current study measured personal exposure levels integrated over 24-hour periods, and did not measure moment to moment ambient concentration levels of the chemicals being monitored. This restricts the ability to provide definitive evidence of the exact causes of fluctuations in personal exposure levels. Nevertheless, a number of potential contributors to personal exposure levels were monitored and could be examined in the context of a general model of the potential causes of fluctuations in personal exposure levels. The statements below summarize some of the general expectations about relationships between exposure levels and other factors. The "→" symbol is used to postulate a causal relationship.

Concentration Interrelations:

Indoor concentration levels → Personal concentration levels
Outdoor concentration levels → Indoor concentration levels
Outdoor concentration levels→ Personal concentration levels

Climatic Variation:

Season of the Year → Outdoor, Personal, Indoor concentration levels

Activity Variations:

Fluctuations in Daily Activity Pattern → Personal concentration levels (includes Job Status and Day of Week especially for full-time job holders)
Specific Exposure sources → Personal, Indoor concentration levels
Smoking Activity → Personal, Indoor concentration levels

Residence Characteristics:

Characteristics of the principal residence → Indoor, Personal concentration levels

For each of these potential relationships, variables were available. They are briefly described below, and a label is provided for use in interpreting the tables of results that follow. (Variables in brackets are reference categories against which other category members are compared).

Exposure:

PCON - Personal concentration levels
ICON - Indoor concentration levels
OCON - Outdoor levels

Seasonal Variation:

q_1	Tested in January, February, or March
q_2	Tested in April, May, or June
(q_3)	Tested in July, August, or September
q_4	Tested in October, November, or December

Time-Activity:

ih	Proportion of time inside the home
oh	Proportion of time outside at home
iw	Proportion of time inside at work
ow	Proportion of time outside at work
ia	Proportion of time other indoor activities
oa	Proportion of time other outdoor activities
t	Proportion of time in travel

Job Status:

gender	Female or Male
jobft	Has a full time job
jobpt	Has a part time job
plant	Has a full time job at an Oil Sands industry
weekend	Indicates a weekend day
jftxwkn	Indicates a weekend day for a full time job holder
jptxwkn	Indicates a weekend day for a part time job holder

Specific Exposure:

smoking	Indicates a day on which exposed to tobacco smoke
painting	Indicates a day on which painting was performed
gas	Indicates a day on which automobile refueling occurred
housecln	Indicates a day on which house cleaning occurred
burning	Indicates a day on which exposure to burning occurred
miscchem	Indicates a day on which exposure to other chemicals occurred

Smoking:

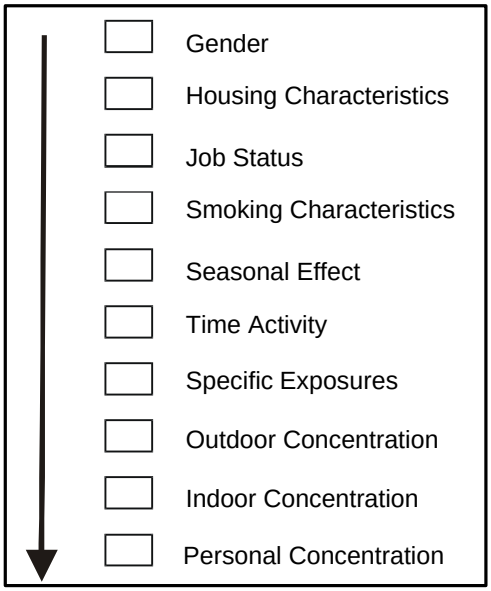
smkhome	Indicates if smoking occurs in the home
smkcar	Indicates if smoking occurs in the vehicle
smkamt	Number of cigarettes smoked per day (divided by 10)
smkexp2	Hours per day exposed to cigarette smoke

Housing Characteristics:

trailor	Mobile home
mult2	Multiple housing (apartment or townhouse)
(single)	Single family detached dwelling
new	Built after 1985
med	Built between 1975 and 1985
(old)	Built before 1975
nfcdair	Indicates heating other than forced air
caret	Indicates presence of a cold air return
urea	Indicates urea formaldehyde insulation

Further consideration of these variables and the hypothesized relationships led to the postulation of the following general recursive model to guide analysis and interpretation.

Figure 94: A General Ordering of Factors Influencing Exposure



A recursive ordering, such as this, is intended to capture a causal ordering among sets of variables. Specifically, as a hypothesis, it suggests that variables earlier (or higher) in the chain can have a causal effect on variables later (or lower) in the chain, but not vice versa. In addition, no reciprocal causal relations are postulated. Finally, for variables within a set, no causal ordering or priority is postulated.

There are various intuitive relationships that are captured by this ordering such as the notion that gender will influence job status, that job status will influence time and activity patterns and exposures to particular chemicals, and that indoor concentrations will influence personal concentrations. There are a number of relationships that might be taken to be implied by the model which are not specifically intended, and which in a more detailed model could be explicitly left out (i.e., placing housing characteristics ahead of smoking characteristics in the model). There are also some relationships that may be excluded by this ordering which might nevertheless appear to obtain under some circumstances, for example, the relationship between the season of the year and job status. In the current model, for ease of analysis and interpretation, all characteristics of the individual that could be considered to be fixed over

the duration of the individuals' participation in the study (i.e., gender, housing characteristics, job status, and smoking characteristics) were considered together, while seasonal effects were considered to be essentially independent of these. In a similar fashion, it may be postulated that indoor concentrations might have an effect on outdoor concentrations rather than the reverse, especially in the event that indoor concentrations were substantially higher than outdoor concentrations. In the current model, however, outdoor concentrations were placed ahead of indoor concentrations since many of the chemicals examined were known to have higher outdoor concentrations than indoor concentrations.

This recursive ordering was used as a heuristic device to structure the specific analyses of the concentrations of the individual chemicals. The data are blind to this ordering, and alternate hypotheses could be examined either by independent analysts or as a later follow-up to the current analyses. What the heuristic model does allow is a hypothetical partitioning of causal influence between total and direct effects within the model. Direct effects refer to the strength of relationships directly between an independent variable or variable set and a dependent variable, while total effects include relationships between the independent variables or variable sets and the dependent variables that include other independent variables as mediators of the influence. For example, 'having a full time job' might have a total effect on 'personal exposure to octane', even though the causal force might be carried by a relationship between 'having a full time job' and 'amount of time travelling in a car' and by a relationship 'amount of time travelling in a car' and 'personal exposure to octane'. It should be noted that in the model presented in Figure 94, there are a large number of ways in which a variable group or factor may have an indirect effect on personal exposure levels.

8.2 Methods of Analysis

The analysis of each contaminant used regression analyses to quantify the amount of the variability in personal exposure that could be attributed to variability in each factor. The traditional measure used for this purpose is a proportion of variance, R^2, derived from the correlation, r, or multiple correlation, R, of the variable(s) to personal levels when the effects of including other variables in the model are taken into account. The measure R^2 will vary from 0.0 when there is no effect to 1.0 when personal levels can be perfectly predicted by variation in some other factor or factors. In the simplest case, where only two variables are being considered, a scatterplot of these two variables can be presented which shows the degree of relationship between them. It is usually accompanied by a correlation coefficient that quantifies the strength of that relationship and, which when squared, represents the proportion of variance measure R^2. Unfortunately, simple scatterplots are not available as a tool when many variables are being simultaneously considered.

In general, the analysis of each contaminant proceeded in two general steps. First, a hierarchical set regression analysis[86] was performed in which variables were entered into the regression equation by set in the order specified by the recursive ordering and intermediate results were generated to give information about the relationships between variable sets. This form of analysis closely follows the logic of the recursive model in Figure 94. It can identify variables which have an indirect effect upon personal exposure levels by effecting changes in other variable sets intermediate between them and personal exposure in the recursive ordering. Such a multi-step procedure is necessary since a single analysis of all variables will obscure the intermediate relationships.

Second, a more detailed analysis was performed on the regression of all variables to more precisely determine levels of statistical significance of individual variables. Since the general finding across all examined chemicals was that the indoor concentration levels are the largest single predictors of personal exposure levels, full models of indoor exposure levels were also solved in this stage.

Further complexities of the data set had an influence on the precise form of the analyses. First, the concentration of exposures was typically positively skewed. In all cases, a generalized linear model was used in which the concentrations were assumed to follow a log normal distribution. Second, for most exposures, four measures taken on consecutive days are available for a single individual subject. Because these measures are not expected to be independent of each other, special steps are required to account for this inter-correlation. Two methods were applied on the full regression analyses in attempt to account for this dependence in deriving conclusions about statistical significance. First, the regressions were solved by generalized estimating equations[87] that give improved estimates of standard errors of parameters in the presence of dependence between measures. Second, nonparametric bootstrap procedures[88] were applied to each analysis. Specifically, 500 bootstrap replications were conducted in which the bootstrapped unit was the single subject. In general, the standard error estimates derived from the generalized estimating equation procedure and the bootstrap re-sampling procedure were similar, and both were larger than the estimates obtained from uncorrected generalized linear model solutions. Because some variables did not appear to follow the log normal distribution at all closely, the bootstrap estimates for standard errors are reported throughout. Approximate significance levels are reported by assuming that the bootstrap distributions were approximately normal. Caution should be exercised in interpreting the results of these analyses. Since a large number of analyses were undertaken, and considered as a whole, it is likely that some parameters have been identified as statistically significant which would not withstand replication.

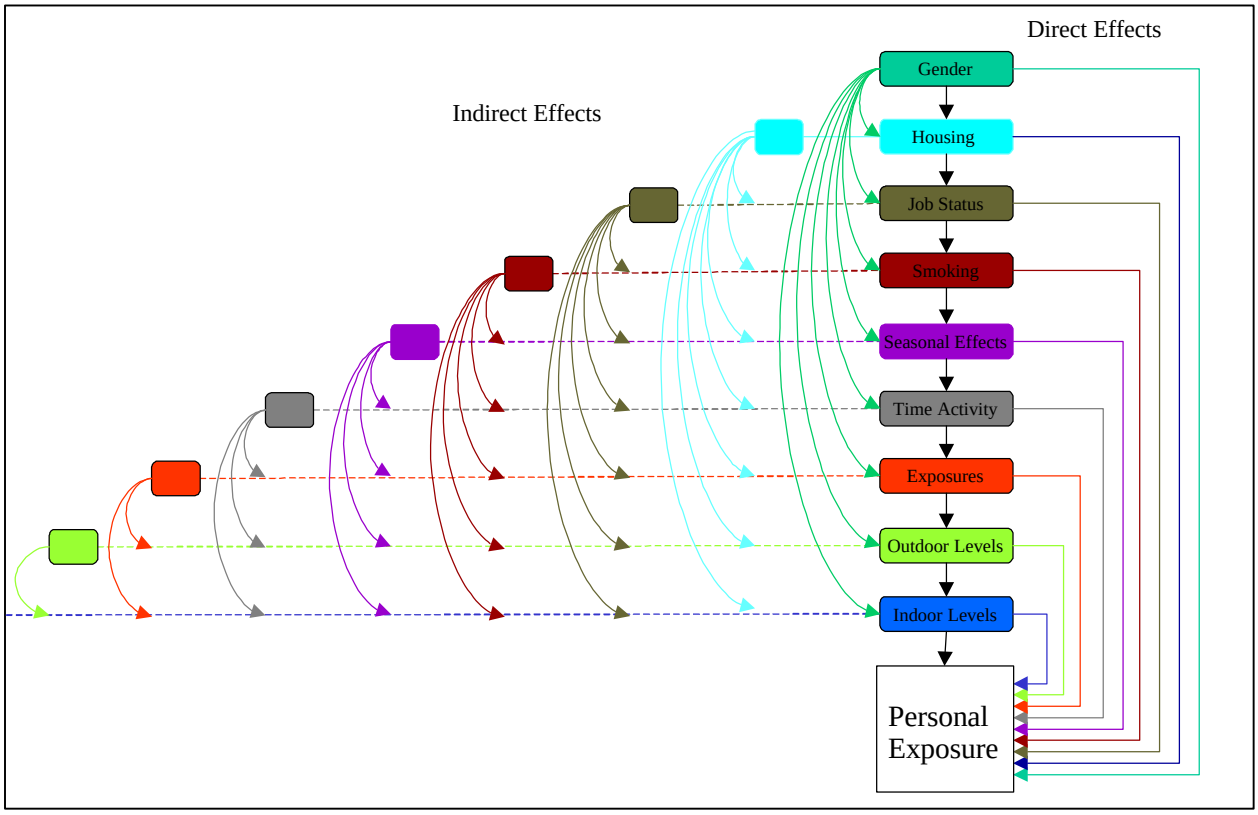
The generalized estimating equation and bootstrap analyses were applied only to the full regression analysis. The results reported for the hierarchical set regressions were based on single replications of the analyses using generalized linear regressions. Standard errors are not reported for these statistics; interpretation of patterning is considered paramount for these analyses.

All analyses of passive samplers were conducted on 275 Fort McMurray residents for whom complete data (i.e., four daily replicates of concentration data as well as values for all covariates) were available. Analyses of particulate concentrations were conducted on 48 Fort McMurray residents for whom complete data was available. In the case of particulates, only two replicates for each of PM_{10} and $PM_{2.5}$ concentrations were generally available. Furthermore, seasonal estimation could not be performed on the $PM_{2.5}$ data as all complete data sets were collected during the third quarter.

8.3 Presentation of Results

Comparing the effect of many factors simultaneously on personal exposure can become very complex, not only because of the increased number of factors but also because of the numerous potential pathways between the factors. Communicating the results can also be difficult if the goal is to describe effects due to each factor (direct effects) as well as the numerous interrelationships between the factors (indirect effects) that may be noteworthy. In an effort to communicate these results clearly, a pictorial description of the general model used in this analysis was developed and is presented in Figure 95. The figure, which is an extension of the recursive model presented in Figure 94, shows the factor groups in colored boxes interconnected with black arrows to the box representing personal exposure. A colored arrow connecting the factor and personal exposure on the right side of the figure represents the potential direct effect of each factor group on personal exposure. The potential indirect effects of each factor on personal exposure acting through the subsequent factors is shown by the cascading colored arrows on the left of the figure. The arrows are color coded to represent the factor groups. In subsequent sections of this report when this model is displayed for a contaminant only the largest effects and factor groups are displayed. The magnitude of the effect is written beside the arrow as a percentage and is reflected in the size of the arrow. The summations of the percentages on the figures will roughly total the variation in personal exposure described by the model and that is also noted on the figure.

Figure 95: General Model of Personal Exposure Used to Investigate Direct and Indirect Effects of Factors



In addition to figures such as Figure 95 that are presented for a selection of the contaminant models, four tables of results are provided for each chemical analyzed. The first two tables present the results of the hierarchical set regression conducted on each contaminant and provide the information required to construct the summary figure.

The first table presents comparative multiple correlation coefficients (Rs) derived from the hierarchical set analysis. The first column shows the total effect of the variable set in a regression analysis of personal exposure on this set of variables alone. The second column shows the total effect of the variable set with all variable sets higher in the causal ordering already entered into the regression. A decrease in the values from the first to the second column indicates that the variable sets higher in the recursive ordering had an effect on the variable set under consideration. Conversely, small differences suggest that a variable set is independent of those higher in the recursive ordering. The third column indicates the effect of a variable set (called the semi-partial R) with all other variable sets already in the regression. It indicates the direct effects of the variable set. If there is a decrease in the third column from the second column, this indicates that a variable set influences a variable set lower in the recursive ordering (and hence has an indirect effect). Small values in all columns indicate small effects. Though a detailed examination of confidence intervals was not performed, in general, multiple correlation coefficients in excess of 0.07 are likely to differ significantly from 0.0 and indicate a real effect. Clearly, the validity of this table depends upon the validity of the chosen recursive ordering, and alternative orderings would change the values in the second column (and likely the ordering of the table which follows the recursive ordering) as well.

The square of the third column of this table (multiplied by 100) represents the percentage of the variation in personal exposure accounted for directly by a particular factor as presented on the right side of the summary figure. The total indirect effects (from which the figures on the left of the summary figure are derived) are obtained by subtracting this figure from the square of the value in the second column.

The second table reports the β weights and multiple correlation coefficient for each variable from each variable set for each stage in the recursive ordering analysis. The β weights give a method of comparing relative size of effects of different variables, though the range of variation within the sample of individuals studied, especially if small, may need to be considered in interpreting these weights. The main value of the table is that it provides insight into the relative importance of individual variables within each of the variable sets, and can also suggest direct and indirect effects for individual variables.

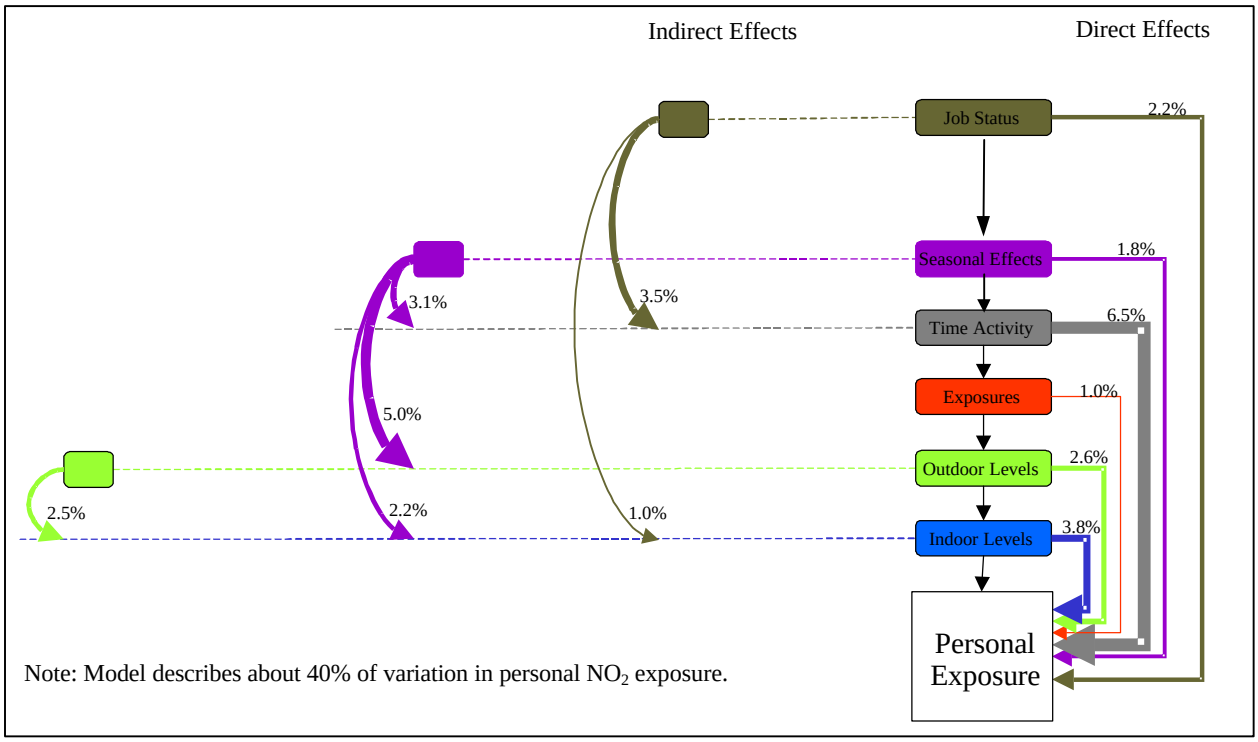
This table is used to partition the indirect effects of a factor between alternate pathways presented in a summary diagram. The change in the sum of the squared coefficients for the variables in a single group from column to column indicate the relative proportion of variance due to a particular set of indirect pathways (specifically that indirect pathway that is present in only one of the columns under consideration).

The third and fourth table for each contaminant presents the results of the full regression analyses of personal and indoor exposure. The third table shows the full regression analysis of personal exposure levels and is equivalent to the final stage of the hierarchical set regression shown in the second table. The fourth table shows the full regression analysis of indoor exposure levels. In each of these, the regression weight and its bootstrap standard error are presented for each predictor variable and an indication is given of those variables which appear to have statistically significant direct effects on exposure levels. The β weights are also presented to allow for comparative examination.

8.4 Nitrogen Dioxide (NO_2)

The results of the hierarchical set regression of personal exposure to NO_2 are summarized pictorially in Figure 96. Only effects with R^2 values greater than 0.01 (i.e., 1%) are displayed.

Figure 96: Results of Model of Personal Exposure to NO_2 Showing Direct and Indirect Effects of Factors



The major effects on personal exposure levels identified in this diagram were:

- ***Time activity,*** directly (6.5%)
- ***Seasonal variation,*** operating indirectly through effects on outdoor levels (5.0%)
- ***Indoor levels,*** directly (3.8%)
- ***Job status,*** operating indirectly through effects on time activity patterns (3.5%)
- ***Seasonal variation,*** operating indirectly through effects on time activity (3.1%)
- ***Outdoor levels,*** directly (2.6%)
- ***Outdoor levels,*** operating indirectly through effects on indoor levels (2.5%)
- ***Seasonal variation,*** operating indirectly through effects on indoor levels (2.2%)
- ***Job status,*** directly (2.2%)
- ***Seasonal variation,*** directly (1.8%)

Overall, seasonal variation accounted for over one-third of the variation in personal exposure described by the model. Its largest influence was exerted through its effects on outdoor concentrations, time activity patterns, and indoor concentrations, and only directly influenced personal levels to a lesser degree. Variation in outdoor and indoor levels also accounted for roughly one quarter of the measured variation in personal exposure. Time activity was also an important driver of personal exposure.

As previously presented, personal exposures to NO_2 were higher than those measured either indoors or outdoors. Additionally, the amount of time spent indoors at locations other than home (as some of the variables describing time activity patterns) was identified as important. Therefore, it seems likely that personal exposures were increased because individuals were exposed to higher NO_2 levels at other indoor sites. Further study is required to confirm this inference.

Tables 47 and Table 48 present the information on which the summary diagram is based.

Table 47: Comparative Multiple Regression Coefficients for Variable Sets

Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	.069	.069	.034
Housing Characteristics	.137	.138	.060
Job Status	.297	.283	.147
Smoking Characteristics	.143	.138	.074
Seasonal Effect	.381	.349	.135
Time Activity	.423	.249	.254
Specific Exposures	.232	.128	.102
Outdoor Concentration	.405	.226	.162
Indoor Concentration	.357	.195	.195

A detailed examination of Table 48 also suggests relationships among individual variables within the direct and indirect relationships of the variable groups including:

- Within time-activity patterns, increased time indoors or outdoors at work increased NO_2 exposures while increases in time outdoors at home decreased these levels.
- Job status effects are complex and non-intuitive. Personal exposure is higher on the weekends, but only for those not holding jobs. Explanations of this effect need to be independent of changes in activity level between weekday and weekend as these are already accounted for in the model. Less difficult to understand is an increase in exposure for individuals who work at the Oil Sands plants.
- Among specific exposures, only painting and smoking appear to effect personal exposure.
- Gender appears to effect job status, which in turn effects exposure (assuming that housing characteristics do not effect job status).
- Smoking effects act indirectly, likely through the specific exposure variable indicating smoking exposure on a day-to-day basis.

Table 48: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	-.05	-.06	-.06	-.08	-.10	-.06	-.05	.07	.07
TRAILOR	.02	-.01	-.02	-.02	-.01	.04	.04	.03	
MULT2	.04	.06	.07	.07	.10	.12	.13	.12	
NEW	.03	.04	.02	.02	.02	.06	.05	.09	
MED	.01	.00	-.02	-.03	-.02	-.01	-.01	-.03	
NFCDAIR	-.03	-.03	-.01	-.02	-.03	-.05	-.04	-.03	
CARET	.04	.04	.06	.04	.03	.04	.02	.05	
UREA	-.03	-.04	-.02	-.01	-.01	-.01	.00	-.01	
WEEKEND	.31	.32	.30	.30	.28	.27	.26		
PLANT	.08	.08	.12	.11	.15	.18	.17		
JOBFT	-.01	.02	.04	.05	.18	.23	.27		
JOBPT	-.01	.02	.03	.05	.08	.16	.17		
JFTXWKN	-.36	-.38	-.37	-.37	-.47	-.46	-.46		
JPTXWKN	-.09	-.10	-.10	-.09	-.08	-.05	-.06		
SMKHOME	-.02	.01	.01	.01	.05	.03			
SMKCAR	.05	.05	.05	.07	.01	.02			
SMKAMT	.02	.04	.06	.05	.08	.08			
SMKEXP2	.06	.06	.06	.08	.09	.07			
Q_1	.18	.22	.33	.33	.40				
Q_2	.08	.09	.08	.08	.09				
Q_4	.08	.05	.10	.10	.13				
IH	-.08	-.08	-.08	-.08					
OH	-.06	-.05	-.06	-.05					
IW	.25	.24	.24	.24					
OW	.07	.06	.04	.05					
IA	.17	.14	.14	.15					
OA	-.01	-.01	-.01	-.00					
T	-.03	-.05	-.04	-.03					
SMOKING	.05	.06	.07						
PAINTING	.09	.08	.10						
GAS	.01	.01	.01						
HOUSECLN	.02	.00	.01						
BURNING	-.01	-.01	.01						
MISCCHEM	.01	.01	.03						
OCON3	.20	.26							
ICON3	.23								
R	.64	.61	.57	.56	.50	.36	.32	.15	.07

Tables 49 and Table 50 present the findings of the full regression analyses of personal and indoor exposure and give a more specific indication of which particular variables may have statistically significant relationships with personal and indoor exposure levels.

Table 49: Weights and Standard Errors for Analysis of Personal Concentration Levels

		B	β	Bootstrap Se	P
Gender	GENDER	-.08	-.05	.06	
Housing	TRAILOR	.09	.02	.15	
	MULT2	.09	.04	.06	
	NEW	.07	.03	.09	
	MED	.01	.01	.06	
	NFCDAIR	-.06	-.03	.07	
	CARET	.08	.04	.06	
	UREA	-.16	-.03	.13	
Job Status	WEEKEND	.55	.31	.16	<0.05
	PLANT	.14	.08	.07	<0.05
	JOBFT	-.01	-.01	.09	
	JOBPT	-.02	-.01	.10	
	JFTXWKN	-.69	-.36	.17	<0.05
	JPTXWKN	-.33	-.09	.18	
Smoking	SMKHOME	-.03	-.02	.06	
	SMKCAR	.10	.05	.06	
	SMKAMT	.02	.02	.02	
	SMKEXP2	.02	.06	.01	
Season	Q_1	.40	.18	.07	<0.05
	Q_2	.17	.08	.06	<0.05
	Q_4	.18	.08	.09	<0.05
Activity	IH	-.35	-.08	.26	
	OH	-.84	-.06	.39	<0.05
	IW	1.22	.25	.29	<0.05
	OW	1.08	.07	.66	<0.05
	IA	1.45	.17	.36	<0.05
	OA	-.12	-.01	.43	
	T	-.65	-.03	.82	
Chemicals	SMOKING	.10	.05	.05	<0.05
	PAINTING	.37	.09	.11	<0.05
	GAS	.04	.01	.07	
	HOUSECLN	.05	.02	.07	
	BURNING	-.03	-.01	.06	
	MISCCHEM	.01	.01	.06	
Outdoor	OCON3	.19	.20	.03	<0.05
Indoor	ICON3	.24	.23	.04	<0.05
	(Constant)	.50	.	.27	

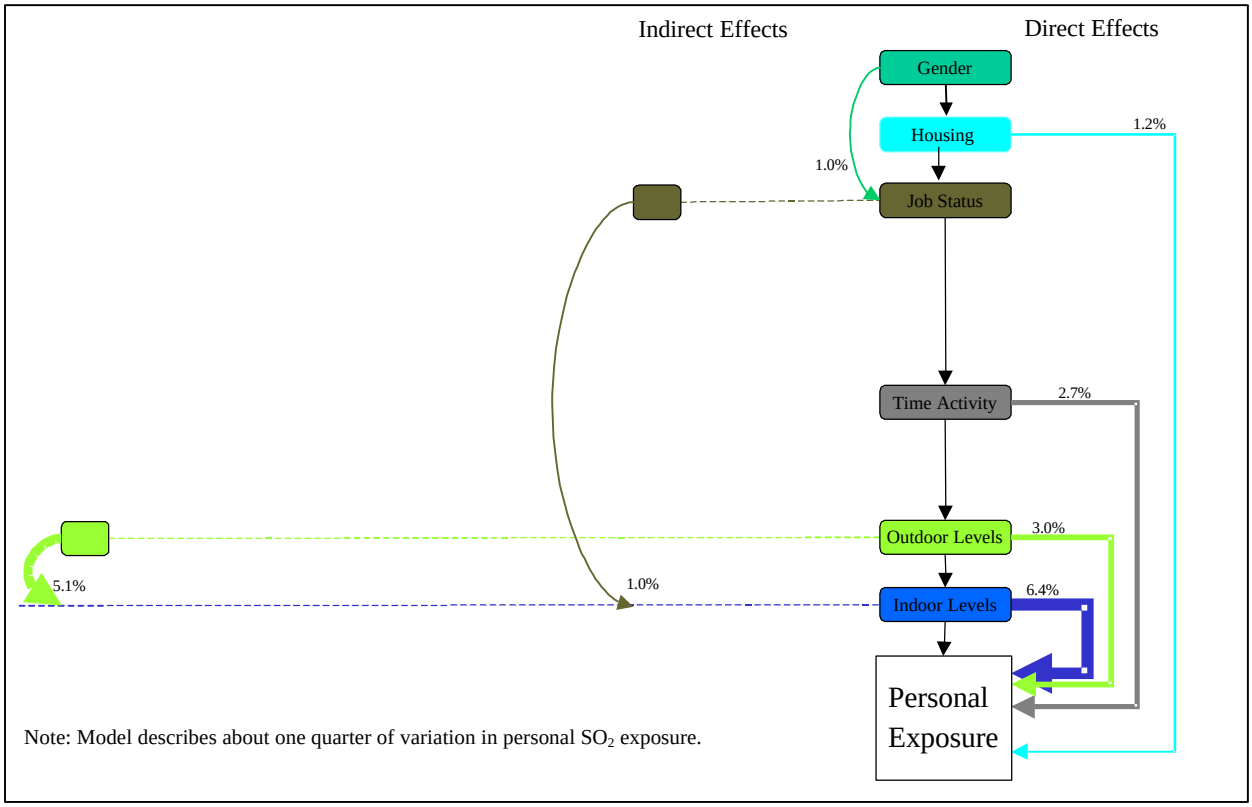
Table 50: Weights and Standard Errors for Analysis of Indoor Concentration Levels

		B	β	Bootstrap Se	P
Gender	GENDER	-.01	-.01	.08	
Housing	TRAILOR	-.38	-.10	.17	<0.05
	MULT2	.11	.06	.08	
	NEW	.02	.01	.10	
	MED	-.08	-.05	.06	
	NFCDAIR	-.01	.00	.09	
	CARET	-.01	-.01	.07	
	UREA	.09	.02	.26	
Job Status	WEEKEND	.16	.10	.10	
	PLANT	-.08	-.05	.09	
	JOBFT	.17	.09	.11	
	JOBPT	.08	.04	.13	
	JFTXWKN	-.20	-.11	.12	<0.10
	JPTXWKN	-.21	-.06	.15	
Smoking	SMKHOME	.14	.09	.07	<0.10
	SMKCAR	-.02	-.01	.08	
	SMKAMT	.04	.06	.02	
	SMKEXP2	.00	-.01	.01	
Season	Q_1	.36	.19	.10	<0.05
	Q_2	.11	.06	.07	
	Q_4	-.33	-.17	.09	<0.05
Activity	IH	.05	.01	.20	
	OH	.35	.02	.42	
	IW	-.08	-.02	.24	
	OW	-.50	-.04	.61	
	IA	.02	.00	.32	
	OA	-.27	-.02	.51	
	T	-.48	-.02	.97	
Chemicals	SMOKING	.11	.06	.06	<0.10
	PAINTING	-.04	-.01	.08	
	GAS	.01	.00	.07	
	HOUSECLN	-.11	-.05	.08	
	BURNING	.02	.01	.07	
	MISCCHEM	.10	.05	.05	<0.10
Outdoor	OCON3	.23	.27	.04	<0.05
	(Constant)	.17	.	.23	

8.5 Sulfur Dioxide (SO_2)

The results of the hierarchical set regression of personal exposure to SO_2 are summarized pictorially in Figure 97. Only effects with R^2 values greater than 0.01 (i.e., 1%) are displayed.

Figure 97: Results of Model of Personal Exposure to SO_2 Showing Direct and Indirect Effects of Factors



The major effects identified in the analysis were as follows:

- ***Indoor levels,*** directly (6.4%)
- ***Outdoor levels,*** operating indirectly through effects on indoor levels (5.1%)
- ***Outdoor levels,*** directly (3.0%)
- ***Time activity,*** directly (2.7%)
- ***Housing characteristics,*** directly (1.2%)
- ***Gender,*** operating indirectly through effects on job status (1.0%)
- ***Job status,*** operating indirectly through effects on indoor levels (1.0%)

Overall, variations across houses for indoor levels (under the influence of outdoor levels) and temporal variability of outdoor levels account for roughly three-quarters of the variation in personal exposure accounted for by the model. Note that this does not mean that there were indoor sources of SO_2, rather it suggests that differences between houses resulted in different SO_2 levels. Outdoor levels, indoor levels under the influence of outdoor levels, and time activity were also factors affecting personal exposure.

The two tables on which Figure 97 is based follow below (Table 51 and Table 52); and the tables presenting the findings of the full regression analyses of personal (Table 53) and indoor (Table 54) exposure follow.

Table 51: Comparative Multiple Regression Coefficients for Variable Sets

Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	.146	.146	.088
Housing Characteristics	.183	.172	.109
Job Status	.183	.137	.054
Smoking Characteristics	.102	.073	.081
Seasonal Effect	.132	.126	.079
Time Activity	.184	.147	.165
Specific Exposures	.126	.061	.081
Outdoor Concentration	.281	.284	.172
Indoor Concentration	.388	.252	.252

Table 52: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	.12	.11	.10	.09	.10	.09	.09	.15	.15
TRAILOR	.03	.04	.05	.05	.05	.05	.05	.04	
MULT2	.08	.11	.13	.12	.11	.11	.11	.10	
NEW	-.00	-.00	-.01	-.01	-.02	-.03	-.03	-.03	
MED	.04	.05	.06	.05	.05	.05	.06	.06	
NFCDAIR	-.07	-.08	-.10	-.10	-.09	-.09	-.09	-.10	
CARET	-.07	-.07	-.07	-.08	-.08	-.08	-.08	-.07	
UREA	-.01	-.01	-.01	-.02	-.01	-.02	-.01	-.02	
WEEKEND	-.09	-.15	-.14	-.15	-.16	-.17	-.18		
PLANT	.04	.04	.04	.05	.08	.07	.07		
JOBFT	-.09	-.08	-.07	-.06	.00	.00	-.01		
JOBPT	-.03	-.07	-.08	-.08	-.06	-.07	-.07		
JFTXWKN	.09	.13	.11	.12	.07	.08	.09		
JPTXWKN	.04	.07	.07	.07	.07	.07	.07		
SMKHOME	.01	-.01	-.03	-.04	-.03	-.03			
SMKCAR	-.02	-.02	.00	.01	.01	.01			
SMKAMT	.07	.07	.06	.06	.07	.07			
SMKEXP2	-.04	-.02	-.02	-.02	-.01	-.02			
Q_1	-.08	-.12	-.08	-.08	-.10				
Q_2	.01	-.01	-.04	-.04	-.04				
Q_4	.02	.01	.03	.04	.02				
IH	.04	.02	.01	.02					
OH	.09	.10	.10	.10					
IW	.20	.18	.15	.16					
OW	.09	.07	.06	.06					
IA	.02	.01	-.02	-.01					
OA	.04	.04	.04	.05					
T	.04	.04	.03	.04					
SMOKING	-.00	.01	.01						
PAINTING	.04	.02	.02						
GAS	-.01	-.02	-.02						
HOUSECLN	.01	-.01	-.02						
BURNING	.05	.05	.07						
MISCCHEM	.05	.03	.01						
OCON3	.19	.29							
ICON3	.28								
R	.50	.43	.32	.32	.27	.25	.24	.21	.15

Table 53: Weights and Standard Errors for Analysis of Personal Concentration Levels

	B	β	Bootstrap Se	P
GENDER	.31	.12	.11	<0.05
TRAILOR	.15	.03	.19	
MULT2	.23	.08	.10	<0.05
NEW	-.01	.00	.13	
MED	.12	.05	.09	
NFCDAIR	-.21	-.07	.11	<0.10
CARET	-.18	-.07	.10	<0.10
UREA	-.10	-.01	.19	
WEEKEND	-.24	-.09	.15	
PLANT	.11	.04	.11	
JOBFT	-.26	-.09	.13	<0.10
JOBPT	-.08	-.02	.16	
JFTXWKN	.27	.09	.18	
JPTXWKN	.21	.04	.23	
SMKHOME	.02	.01	.10	
SMKCAR	-.06	-.02	.11	
SMKAMT	.07	.07	.03	<0.05
SMKEXP2	-.02	-.04	.02	
Q_1	-.24	-.08	.11	<0.05
Q_2	.03	.01	.11	
Q_4	.05	.02	.11	
IH	.27	.04	.23	
OH	2.29	.09	.73	<0.05
IW	1.49	.21	.31	<0.05
OW	1.91	.09	1.00	<0.10
IA	.22	.02	.38	
OA	1.01	.04	.70	
T	1.29	.04	.95	
SMOKING	-.01	-.01	.09	
PAINTING	.21	.04	.14	
GAS	-.06	-.01	.13	
HOUSECLN	.02	.00	.10	
BURNING	.20	.05	.11	<0.10
MISCCHEM	.15	.05	.09	<0.10
OCON3	.19	.18	.03	<0.05
ICON3	.30	.29	.03	<0.05
(Constant)	-.60	.	.26	<0.05

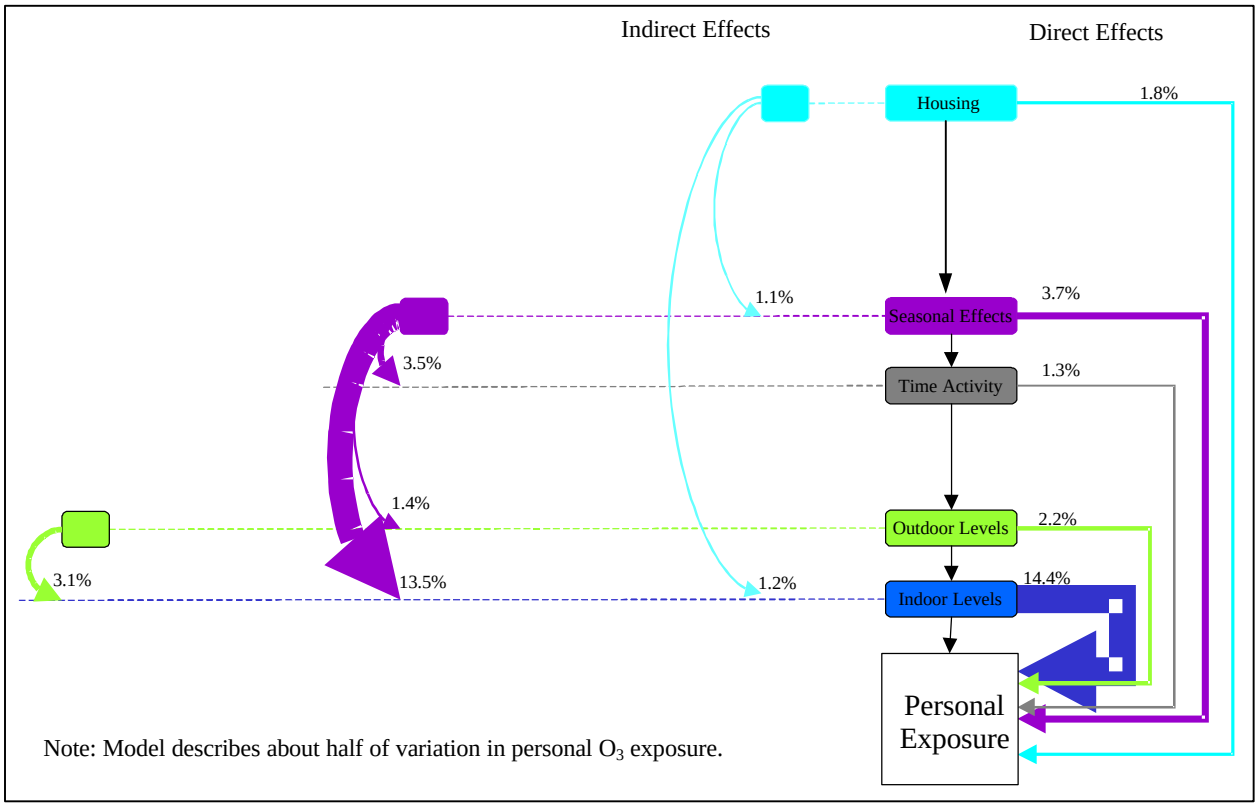
Table 54: Weights and Standard Errors for Analysis of Indoor Concentration Levels

	B	β	Bootstrap Se	P
GENDER	-.08	-.04	.12	
TRAILOR	.18	.03	.18	
MULT2	.22	.08	.11	<0.05
NEW	.05	.01	.14	
MED	.07	.03	.09	
NFCDAIR	-.08	-.03	.12	
CARET	-.01	-.01	.09	
UREA	-.11	-.02	.30	
WEEKEND	-.47	-.19	.16	<0.05
PLANT	-.01	.00	.12	
JOBFT	-.01	.00	.18	
JOBPT	-.45	-.13	.19	<0.05
JFTXWKN	.29	.11	.19	
JPTXWKN	.50	.09	.21	<0.05
SMKHOME	-.17	-.07	.11	
SMKCAR	.07	.03	.12	
SMKAMT	.00	.00	.03	
SMKEXP2	.01	.02	.02	
Q_1	-.47	-.16	.11	<0.05
Q_2	-.19	-.07	.12	<0.10
Q_4	-.04	-.01	.12	
IH	-.28	-.05	.26	
OH	.86	.04	.67	
IW	-.50	-.07	.33	
OW	-1.47	-.07	.83	<0.10
IA	-.49	-.04	.44	
OA	-.08	.00	.84	
T	-.26	-.01	1.10	
SMOKING	.21	.07	.09	<0.05
PAINTING	-.24	-.04	.15	
GAS	-.16	-.03	.12	
HOUSECLN	-.21	-.05	.12	<0.10
BURNING	.06	.02	.09	
MISCCHEM	-.22	-.08	.08	<0.05
OCON3	.33	.35	.03	<0.05
(Constant)	.04	.	.30	

8.6 Ozone (O_3)

The results of the hierarchical set regression of personal exposure to O_3 are summarized pictorially in Figure 98.

Figure 98: Results of Model of Personal Exposure to O_3 Showing Direct and Indirect Effects of Factors



The model predicted about half of the variation in personal O_3 exposure across individuals and days. Important factors influencing variations in O_3 exposures were as follows:

- ***Indoor levels,*** directly (14.4%)
- ***Seasonal variation,*** operating indirectly through effects on indoor levels (13.5%)
- ***Seasonal variation,*** directly (3.7%)
- ***Seasonal variation,*** operating indirectly through effects on time activity (3.5%)
- ***Outdoor levels,*** operating indirectly through effects on indoor levels (3.1%)
- ***Outdoor levels,*** directly (2.2%)
- ***Housing characteristics,*** directly (1.8%)
- ***Seasonal variation,*** operating indirectly through effects on outdoor air (1.4%)

- ***Time activity,*** directly (1.3%)
- ***Housing characteristics,*** operating indirectly through effects on indoor air (1.2%)
- ***Housing characteristics,*** operating indirectly through effects on seasonal effects (1.1%)

The majority of variations in personal exposure described by the model were due to indoor concentrations that were heavily influenced by seasonal effects (lower concentrations in winter) and influenced to a lesser degree by outdoor concentrations. Overall, indoor and outdoor levels explained over 30% and under 5% of the variance in personal O_3 levels respectively. Seasonal variation was an important effect that appears to impact personal exposure independently of outdoor concentrations (i.e., by affecting time activity, specific exposures and indoor concentration).

It cannot be over emphasized that outdoor concentrations were not found to be a good surrogate measure of personal exposures in this study. As described previously, personal levels were only 10% of outdoor levels and changes in outdoor concentrations accounted for less than 5% of the variation in personal exposures.

The two tables on which Figure 98 is based follow below (Table 55 and Table 56); and the tables presenting the findings of the full regression analyses of personal (Table 57) and indoor (Table 58) exposure follow.

Table 55: Comparative Multiple Regression Coefficients for Variable Sets

Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	.078	.078	.019
Housing Characteristics	.238	.235	.136
Job Status	.088	.072	.061
Smoking Characteristics	.063	.063	.074
Seasonal Effect	.484	.470	.193
Time Activity	.298	.149	.115
Specific Exposures	.108	.085	.083
Outdoor Concentration	.345	.230	.149
Indoor Concentration	.607	.380	.380

Table 56: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	.03	.02	.00	.01	.02	-.11	-.11	-.07	-.08
TRAILOR	-.04	-.06	-.06	-.06	-.05	-.09	-.09	-.09	
MULT2	-.06	-.07	-.08	-.08	-.09	-.13	-.13	-.14	
NEW	-.08	-.08	-.06	-.06	-.06	-.11	-.10	-.11	
MED	.07	.11	.14	.14	.15	.09	.10	.11	
NFCDAIR	.02	.02	-.00	-.01	-.00	.00	.00	.00	
CARET	-.06	-.07	-.08	-.07	-.08	-.12	-.13	-.13	
UREA	.03	.03	.01	.01	.03	.07	.07	.06	
WEEKEND	.02	.04	.05	.05	.04	.06	.05		
PLANT	-.01	-.03	-.04	-.05	-.04	.00	.01		
JOBFT	.10	.12	.12	.13	.09	.07	.06		
JOBPT	.06	.06	.07	.08	.05	-.01	-.01		
JFTXWKN	-.02	-.04	-.04	-.05	-.01	-.04	-.03		
JPTXWKN	-.03	-.05	-.04	-.04	-.02	-.03	-.03		
SMKHOME	-.01	-.02	-.04	-.04	-.04	-.04			
SMKCAR	.01	.04	.05	.05	.06	.05			
SMKAMT	.02	.00	-.00	-.00	-.00	-.03			
SMKEXP2	-.08	-.06	-.07	-.08	-.08	-.04			
Q_1	-.14	-.30	-.29	-.28	-.31				
Q_2	.05	.04	.15	.15	.15				
Q_4	-.19	-.32	-.32	-.32	-.36				
IH	.03	.05	.05	.05					
OH	.10	.12	.13	.14					
IW	.03	-.00	.01	.01					
OW	.05	.05	.06	.06					
IA	.05	.03	.04	.04					
OA	.08	.07	.07	.08					
T	.01	.03	.03	.04					
SMOKING	.01	.00	-.01						
PAINTING	.03	.00	.01						
GAS	.07	.07	.08						
HOUSECLN	-.01	-.00	-.02						
BURNING	-.00	.01	.00						
MISCCHEM	.02	.00	.01						
OCON3	.17	.26							
ICON3	.44								
R	.72	.61	.57	.56	.54	.27	.26	.25	.08

Table 57: Weights and Standard Errors for Analysis of Personal Concentration Levels

	B	β	Bootstrap Se	P
GENDER	.08	.03	.11	
TRAILOR	-.31	-.04	.20	
MULT2	-.22	-.06	.11	<0.05
NEW	-.38	-.08	.15	<0.05
MED	.21	.07	.09	<0.05
NFCDAIR	.10	.03	.11	
CARET	-.18	-.06	.10	<0.10
UREA	.26	.03	.34	
WEEKEND	.06	.02	.22	
PLANT	-.02	-.01	.11	
JOBFT	.35	.10	.15	<0.05
JOBPT	.25	.06	.18	
JFTXWKN	-.08	-.02	.24	
JPTXWKN	-.21	-.03	.28	
SMKHOME	-.03	-.01	.09	
SMKCAR	.04	.01	.11	
SMKAMT	.02	.02	.04	
SMKEXP2	-.05	-.08	.02	<0.05
Q_1	-.54	-.14	.13	<0.05
Q_2	.19	.05	.11	<0.10
Q_4	-.71	-.19	.13	<0.05
IH	.27	.04	.25	
OH	2.85	.10	.57	<0.05
IW	.25	.03	.33	
OW	1.25	.05	.74	<0.10
IA	.66	.05	.40	<0.10
OA	2.76	.08	.74	<0.05
T	.45	.01	1.08	
SMOKING	.02	.01	.09	
PAINTING	.21	.03	.17	
GAS	.44	.07	.12	<0.05
HOUSECLN	-.03	-.01	.10	
BURNING	-.01	.00	.11	
MISCCHEM	.06	.02	.08	
OCON3	.42	.17	.07	<0.05
ICON3	.42	.44	.03	<0.05
(Constant)	-1.32	.	.40	<0.05

Table 58: Weights and Standard Errors for Analysis of Indoor Concentration Levels

	B	β	Bootstrap Se	P
GENDER	-.07	-.02	.19	
TRAILOR	-.36	-.05	.26	
MULT2	-.06	-.02	.16	
NEW	.02	.00	.24	
MED	.32	.10	.15	<0.05
NFCDAIR	.00	.00	.18	
CARET	-.10	-.03	.14	
UREA	.04	.00	.35	
WEEKEND	.19	.06	.26	
PLANT	-.18	-.05	.19	
JOBFT	.21	.06	.26	
JOBPT	.06	.01	.28	
JFTXWKN	-.18	-.05	.28	
JPTXWKN	-.32	-.04	.33	
SMKHOME	-.13	-.04	.15	
SMKCAR	.22	.06	.19	
SMKAMT	-.04	-.03	.06	
SMKEXP2	.03	.04	.03	
Q_1	-1.46	-.36	.19	<0.05
Q_2	-.12	-.03	.20	
Q_4	-1.19	-.30	.18	<0.05
IH	.20	.02	.38	
OH	1.44	.05	1.25	
IW	-.61	-.07	.46	
OW	.39	.01	1.06	
IA	-.60	-.04	.59	
OA	-1.41	-.04	1.15	
T	1.44	.03	1.48	
SMOKING	-.02	.00	.12	
PAINTING	-.47	-.06	.21	<0.05
GAS	.01	.00	.17	
HOUSECLN	.05	.01	.14	
BURNING	.16	.03	.15	
MISCCHEM	-.11	-.03	.12	
OCON3	.52	.20	.12	<0.05
(Constant)	-.99	.	.59	<0.10

8.7 Volatile Organic Compounds (VOCs)

Based upon results from the pilot study and upon examination of the data, it was decided to attempt to combine the information from all of the volatile organic compounds into a smaller number of variables for examination, since the relationships between exposure levels from the various compounds were strong. Since an analysis similar to the ones reported above was desired for these compounds, it was important that the combination of variables into composite measures be conducted in a similar manner for composites of measures of personal, indoor, and outdoor exposures. Consequently, a confirmatory factor analysis model was employed on log normalized exposure levels[89] to simultaneously fit a single model across these three domains. Starting with a Principal Component analysis of the personal exposure data, a sequence of model fitting and constraint adjustment resulted in a set of three factors that fit acceptably across the three groups simultaneously. (The Goodness of fit indices exceeded 0.90 for personal and indoor exposure levels, and was above 0.85 for outdoor levels). Table 59 shows the resulting factor loading matrix. (Note that 0 values were fixed by the design while other coefficients were allowed to vary).

Table 59: Factor Loadings for VOC on 3-Group Simultaneous Factor Analysis

	Factor 1	Factor 2	Factor 3
Benzene	.24	-.38	.00
Toluene	.49	-.38	-.17
Ethylbenzene	.78	.08	.00
M-P-Xylene	.51	-.40	.14
O-Xylene	.51	.08	.00
Octane	.50	.11	-.19
Nonane	.70	.11	.00
Decane	.39	.11	.00
Butanone	.24	.08	.14
Heptane	.50	-.39	-.63
Limonene	.00	-.22	.14
Methylhexane	.49	-.38	-.62

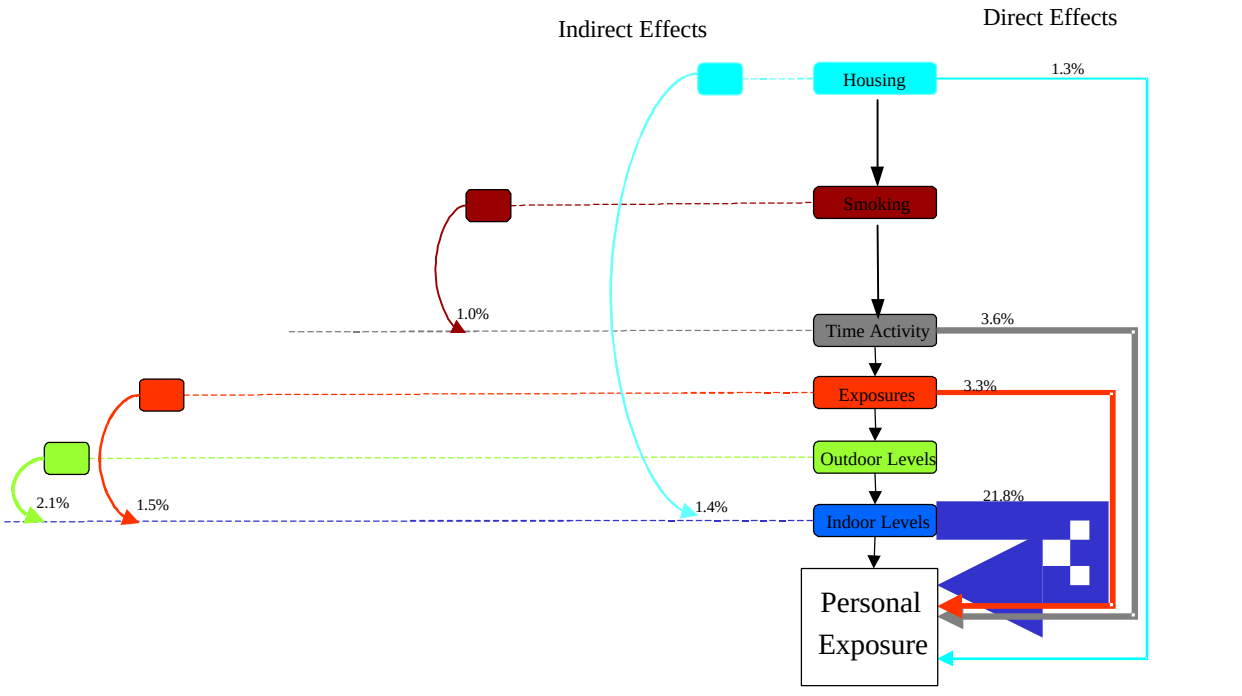
Examination of the matrix suggested that the first factor accounted for a substantial amount of the variability in all variables (except for limonene and possibly for benzene). Factor scores for all three factors were calculated. Hexane had been excluded from the initial analysis because it had not been analyzed for a sufficient number of individuals. For those that remained, an extension analysis was performed which confirmed that hexane levels also correlated with the scores on the first factor. These correlations are shown in Table 60. Further analysis proceeded with the scores for the first factor.

Table 60: Extension Analysis of Hexane

	Hexane Personal	Hexane Indoor	Hexane Outdoor
Factor 1 Personal	.36		
Factor 2 Personal	-.08		
Factor 3 Personal	.12		
Factor 1 Indoor		.30	
Factor 2 Indoor		-.15	
Factor 3 Indoor		.05	
Factor 1 Outdoor			.20
Factor 1 Outdoor			-.21
Factor 1 Outdoor			-.16

The results of the hierarchical set regression of personal exposure to VOCs (considered as a group) are summarized pictorially in Figure 99.

Figure 99: Results of Model of Personal Exposure to VOCs Showing Direct and Indirect Effects of Factors



Note: Model describes about 40% of variation in personal VOCs exposure.

The final model predicted about 40% of the variation in personal VOCs exposure across individuals and days. Indoor concentrations were the predominant factor affecting personal exposure; the other factors

were of only minor relative importance. This suggests that exposure to these chemicals were predominantly from sources affecting indoor levels. Outdoor concentrations did not have a significant direct effect on personal exposure but had a small indirect effect through indoor air, accounting for about 2% of the variation in personal exposure.

Additional investigations during the study had located high VOCs concentrations in some house garages and in service stations. This agrees with other studies that found that attached garages had a significant impact on indoor and personal benzene levels.

The two tables on which Figure 99 is based follow below (Table 61 and Table 62); and the tables presenting the findings of the full regression analyses of personal (Table 63) and indoor (Table 64) exposure follow.

Table 61: Comparative Multiple Regression Coefficients for Variable Sets

Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	.132	.132	.071
Housing Characteristics	.183	.188	.113
Job Status	.158	.086	.063
Smoking Characteristics	.153	.144	.098
Seasonal Effect	.106	.080	.086
Time Activity	.263	.218	.191
Specific Exposures	.263	.226	.181
Outdoor Concentration	.166	.150	.035
Indoor Concentration	.533	.467	.467

Table 62: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	.10	.04	.06	.08	.09	.11	.12	.14	.13
TRAILOR	.03	-.03	-.03	-.03	-.01	-.00	-.01	-.01	
MULT2	-.07	-.11	-.11	-.11	-.09	-.08	-.08	-.08	
NEW	-.04	.01	.01	.03	.04	.04	.03	.04	
MED	-.08	-.11	-.10	-.09	-.09	-.09	-.11	-.11	
NFCDAIR	-.02	-.01	-.01	-.03	-.04	-.04	-.03	-.03	
CARET	-.05	.02	.02	.03	.03	.04	.05	.06	
UREA	-.03	-.04	-.05	-.04	-.03	-.04	-.04	-.04	
WEEKEND	-.05	-.01	.02	.02	.01	-.00	-.01		
PLANT	.03	.07	.06	.04	.08	.08	.06		
JOBFT	-.08	-.11	-.10	-.08	.01	.02	.04		
JOBPT	-.01	-.01	-.00	.01	.04	.05	.06		
JFTXWKN	.09	.07	.04	.04	-.05	-.04	-.03		
JPTXWKN	.04	.05	.04	.05	.05	.05	.04		
SMKHOME	-.00	-.03	-.02	-.03	-.01	-.01			
SMKCAR	-.05	.01	.01	.01	-.02	-.02			
SMKAMT	.03	.06	.05	.05	.08	.08			
SMKEXP2	.10	.09	.09	.09	.13	.12			
Q_1	-.01	-.02	-.00	-.01	.02				
Q_2	-.05	-.06	-.01	-.01	-.01				
Q_4	.06	.06	.09	.09	.08				
IH	-.08	-.11	-.13	-.14					
OH	.02	-.02	-.01	.00					
IW	.05	.06	.04	.03					
OW	.14	.14	.13	.13					
IA	.01	.03	.01	.03					
OA	-.02	-.01	-.00	-.01					
T	.09	.07	.06	.07					
SMOKING	.02	.00	.00						
PAINTING	.14	.20	.21						
GAS	.10	.08	.08						
HOUSECLN	-.03	-.04	-.04						
BURNING	-.03	-.02	-.02						
MISCCHEM	.00	-.01	-.00						
OCON3	.04	.16							
ICON3	.51								
R	.65	.46	.43	.37	.30	.28	.25	.23	.13

Table 63: Weights and Standard Errors for Analysis of Personal Concentration Level

	B	β	Bootstrap Se	P
GENDER	.79	.10	.35	<0.05
TRAILOR	.52	.03	.58	
MULT2	-.67	-.08	.28	<0.05
NEW	-.54	-.04	.41	
MED	-.62	-.08	.26	<0.05
NFCDAIR	-.24	-.02	.36	
CARET	-.39	-.05	.27	
UREA	-.80	-.03	.49	
WEEKEND	-.40	-.05	.40	
PLANT	.23	.03	.31	
JOBFT	-.73	-.08	.42	<0.10
JOBPT	-.07	-.01	.48	
JFTXWKN	.81	.09	.45	<0.10
JPTXWKN	.70	.04	.60	
SMKHOME	-.01	.00	.27	
SMKCAR	-.49	-.05	.33	
SMKAMT	.11	.03	.09	
SMKEXP2	.17	.10	.06	<0.05
Q_1	-.08	-.01	.35	
Q_2	-.52	-.06	.31	<0.10
Q_4	.57	.06	.40	
IH	-1.53	-.08	.95	
OH	1.29	.02	2.40	
IW	1.12	.05	1.11	
OW	9.39	.14	2.26	<0.05
IA	.53	.01	1.42	
OA	-1.41	-.02	2.40	
T	9.88	.09	3.89	<0.05
SMOKING	.18	.02	.31	
PAINTING	2.72	.14	.69	<0.05
GAS	1.53	.10	.39	<0.05
HOUSECLN	-.32	-.03	.27	
BURNING	-.39	-.03	.27	
MISCCHEM	.04	.00	.22	
OCON3	.10	.04	.07	
ICON3	.65	.51	.04	<0.05
(Constant)	4.00	.	1.01	<0.05

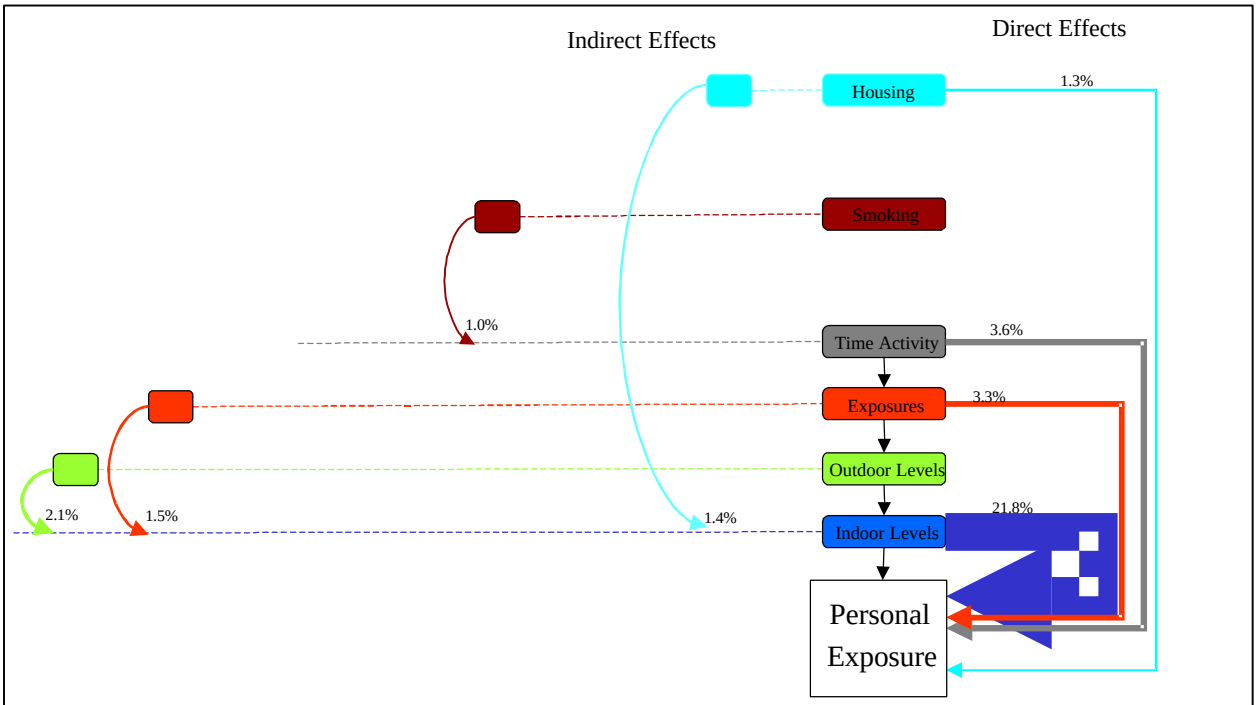
Table 64: Weights and Standard Errors for Analysis of Indoor Concentration Levels

	B	β	Bootstrap Se	P
GENDER	-.71	-.12	.38	<0.10
TRAILOR	-1.71	-.12	.56	<0.05
MULT2	-.45	-.06	.35	
NEW	1.10	.11	.71	
MED	-.34	-.06	.31	
NFCDAIR	.30	.04	.36	
CARET	.84	.13	.33	<0.05
UREA	-.17	-.01	.97	
WEEKEND	.48	.07	.67	
PLANT	.49	.08	.36	
JOBFT	-.46	-.06	.61	
JOBPT	.02	.00	.72	
JFTXWKN	-.29	-.04	.69	
JPTXWKN	.42	.03	.82	
SMKHOME	-.32	-.05	.33	
SMKCAR	.94	.13	.40	<0.05
SMKAMT	.11	.05	.13	
SMKEXP2	-.03	-.02	.06	
Q_1	-.12	-.02	.44	
Q_2	-.09	-.01	.42	
Q_4	-.02	.00	.42	
IH	-1.12	-.07	1.06	
OH	-4.04	-.07	2.92	
IW	.53	.03	1.22	
OW	.04	.00	1.89	
IA	.74	.03	1.38	
OA	.57	.01	2.35	
T	-3.77	-.04	2.99	
SMOKING	-.26	-.04	.25	
PAINTING	1.63	.11	.71	<0.05
GAS	-.40	-.03	.32	
HOUSECLN	-.22	-.02	.38	
BURNING	.24	.02	.37	
MISCCHEM	-.18	-.03	.28	
OCON3	.50	.24	.08	<0.05
(Constant)	3.89	.	1.21	<0.05

8.7.1 Limonene

The summary figure and tables from a separate analysis of limonene, which did not appear to have a pattern similar to the other VOCs, are presented below. The major difference in the models of exposure to limonene appears to be its larger relationship to indoor levels.

Figure 100: Results of Model of Personal Exposure to Limonene Showing Direct and Indirect Effects of Factors



Note: Model describes about 40% of variation in personal VOCs exposure.

Table 65: Comparative Multiple Regression Coefficients for Variable Sets

Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	.165	.165	.012
Housing Characteristics	.106	.100	.106
Job Status	.202	.154	.096
Smoking Characteristics	.136	.134	.070
Seasonal Effect	.232	.182	.049
Time Activity	.219	.175	.182
Specific Exposures	.153	.115	.124
Outdoor Concentration	.032	.092	.023
Indoor Concentration	.603	.531	.531

Table 66: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	-.02	.05	.05	.04	.05	.08	.09	.17	.17
TRAILOR	-.01	.04	.04	.04	.05	.05	.05	.04	
MULT2	.10	.08	.08	.09	.09	.10	.10	.09	
NEW	.00	-.04	-.04	-.05	-.05	-.03	-.04	-.02	
MED	.05	-.02	-.02	-.03	-.03	-.03	-.05	-.05	
NFCDAIR	-.07	-.08	-.07	-.06	-.06	-.06	-.06	-.07	
CARET	-.03	-.05	-.04	-.04	-.04	-.04	-.03	-.01	
UREA	-.02	.03	.02	.02	.03	.03	.04	.03	
WEEKEND	.03	-.08	-.07	-.07	-.08	-.07	-.08		
PLANT	.08	.13	.13	.14	.17	.20	.19		
JOBFT	-.10	-.23	-.22	-.22	-.15	-.14	-.13		
JOBPT	-.01	-.08	-.08	-.09	-.07	-.04	-.03		
JFTXWKN	.04	.16	.16	.16	.09	.09	.10		
JPTXWKN	-.01	.04	.03	.03	.02	.02	.02		
SMKHOME	-.01	-.03	-.03	-.02	-.01	-.00			
SMKCAR	-.04	.03	.03	.03	.01	.00			
SMKAMT	.04	.08	.08	.08	.10	.11			
SMKEXP2	.06	.06	.06	.05	.08	.06			
Q_1	.04	.20	.19	.20	.21				
Q_2	.02	.14	.12	.12	.11				
Q_4	-.02	.13	.10	.10	.11				
IH	.04	.04	.05	.05					
OH	.00	-.05	-.04	-.04					
IW	.14	.12	.13	.13					
OW	.16	.14	.14	.14					
IA	.02	-.00	-.00	-.01					
OA	.01	.01	.02	.02					
T	.08	.07	.07	.07					
SMOKING	.01	.00	.01						
PAINTING	-.12	-.12	-.12						
GAS	.01	.00	-.00						
HOUSECLN	.00	-.00	-.01						
BURNING	.05	.02	.02						
MISCCHEM	.03	-.00	-.01						
OCON3	.03	.10							
ICON3	.59								
R	.67	.41	.40	.38	.34	.28	.25	.19	.17

Table 67: Weights and Standard Errors for Analysis of Personal Concentration Levels

	B	β	Bootstrap Se	P
GENDER	-.054	-.017	.134	
TRAILOR	-.052	-.007	.253	
MULT2	.351	.095	.112	<0.05
NEW	.015	.003	.162	
MED	.168	.052	.122	
NFCDAIR	-.299	-.073	.136	<0.05
CARET	-.086	-.026	.097	
UREA	-.182	-.018	.303	
WEEKEND	.109	.032	.224	
PLANT	.270	.083	.129	<0.05
JOBFT	-.376	-.100	.169	<0.05
JOBPT	-.026	-.006	.169	
JFTXWKN	.165	.044	.261	
JPTXWKN	-.106	-.014	.264	
SMKHOME	-.046	-.014	.109	
SMKCAR	-.153	-.041	.119	
SMKAMT	.055	.044	.038	
SMKEXP2	.038	.056	.023	<0.10
Q_1	.146	.036	.142	
Q_2	.092	.024	.129	
Q_4	-.092	-.023	.176	
IH	.295	.035	.422	
OH	.153	.005	.964	
IW	1.343	.144	.595	<0.05
OW	4.449	.157	1.356	<0.05
IA	.258	.017	.605	
OA	.316	.009	.840	
T	3.833	.084	1.814	<0.05
SMOKING	.040	.011	.099	
PAINTING	-.911	-.117	.265	<0.05
GAS	.033	.005	.193	
HOUSECLN	.008	.002	.108	
BURNING	.247	.048	.123	<0.05
MISCCHEM	.098	.026	.086	
OCON3	.036	.025	.032	
ICON3	.561	.591	.044	<0.05
(Constant)	3.590	.	.566	<0.05

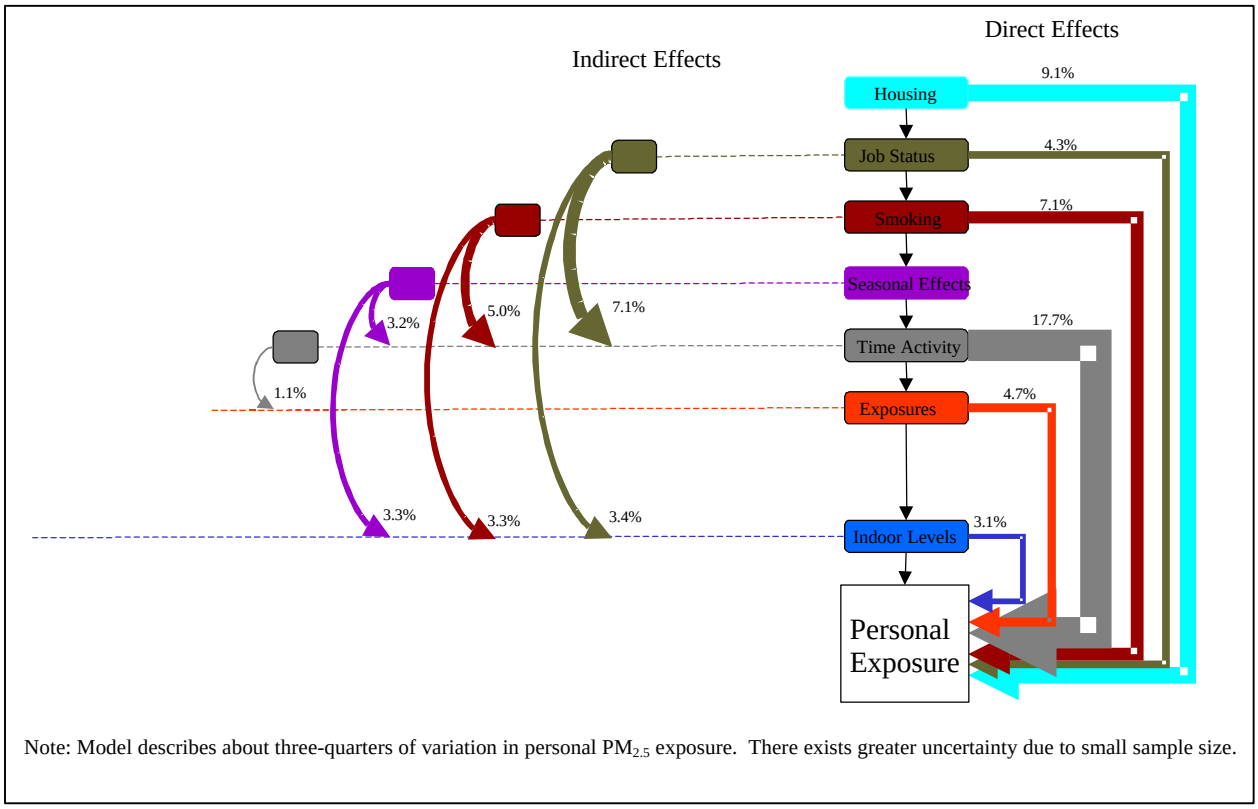
Table 68: Weights and Standard Errors for Analysis of Indoor Concentration Levels

	B	β	Bootstrap Se	P
GENDER	.375	.110	.231	
TRAILOR	.655	.082	.368	<0.10
MULT2	-.101	-.026	.231	
NEW	-.390	-.072	.308	
MED	-.414	-.121	.157	<0.05
NFCDAIR	-.021	-.005	.225	
CARET	-.156	-.045	.173	
UREA	.834	.078	.454	<0.10
WEEKEND	-.658	-.181	.324	<0.05
PLANT	.308	.090	.239	
JOBFT	-.865	-.219	.320	<0.05
JOBPT	-.650	-.132	.365	<0.10
JFTXWKN	.753	.191	.352	<0.05
JPTXWKN	.679	.085	.408	<0.10
SMKHOME	-.087	-.024	.181	
SMKCAR	.464	.119	.212	<0.05
SMKAMT	.087	.066	.070	
SMKEXP2	.001	.001	.033	
Q_1	1.180	.278	.230	<0.05
Q_2	.780	.192	.219	<0.05
Q_4	1.075	.259	.264	<0.05
IH	.076	.009	.487	
OH	-3.317	-.098	1.200	<0.05
IW	-.419	-.043	.667	
OW	-.957	-.032	1.069	
IA	-.493	-.031	.653	
OA	.078	.002	1.347	
T	-.851	-.018	1.820	
SMOKING	-.036	-.009	.138	
PAINTING	.016	.002	.283	
GAS	-.050	-.007	.204	
HOUSECLN	-.041	-.008	.159	
BURNING	-.278	-.051	.198	
MISCCHEM	-.198	-.051	.135	
OCON3	.187	.123	.050	<0.05
(Constant)	8.035	.	.591	<0.05

8.8 Particulate Analysis: $PM_{2.5}$

The results of the analysis of relationships between personal exposures and the factors that may affect exposure are presented pictorially in Figure 101. The model examined the relationship between the combined variability of all factors and the variation in personal exposure. The model accounted for about three-quarters of the variation in personal exposure. However, because the sample size is very small for this analysis, there is greater uncertainty associated with these estimates. The unexplained variation in personal exposure is likely due to sampler error and other factors that were not included in the model.

Figure 101: Results of Model of Personal Exposure to $PM_{2.5}$ Showing Direct and Indirect Effects of Factors



Note: Model describes about three-quarters of variation in personal $PM_{2.5}$ exposure. There exists greater uncertainty due to small sample size.

Important factors influencing variations in $PM_{2.5}$ exposures were as follows:

- ***Time activity,*** directly (17.7%)
- ***Housing characteristics,*** directly (9.1%)
- ***Job status,*** operating indirectly through effects on time activity (7.1%)
- ***Smoking characteristics,*** directly (7.1%)
- ***Smoking characteristics,*** operating indirectly through effects on time activity (5.0%)
- ***Specific exposures,*** directly (4.7%)
- ***Job Status,*** directly (4.3%)
- ***Job Status,*** operating indirectly through effects on indoor air (3.4%)
- ***Smoking characteristics,*** operating indirectly through effects on indoor air (3.3%)
- ***Seasonal Effect,*** operating indirectly through effects on indoor air (3.3%)
- ***Seasonal Effect,*** operating indirectly through effects on indoor air (3.2%)
- ***Indoor levels,*** directly (3.1%)
- ***Time activity,*** operating indirectly through effects on specific exposures (1.1%)

Variability in time activity, smoking, and job status were the dominant factors explaining variation in personal exposure to $PM_{2.5}$ accounting for over two thirds of the variation explained by the model. Time activity had an important impact on personal exposures both directly (17%) and as a pathway through which for other factors act (about 15%). Variation in the time spent outdoors at work was the most important component of the time activity effect. In addition to smoking being an important factor alone (15.4%), variables related to smoke were mainly responsible for the effect of specific exposures (4.7%). Outdoor concentrations were not important as either a driver or a pathway of personal exposure to $PM_{2.5}$.

The two tables on which Figure 101 is based follow below (Table 69 and Table 70); and the tables presenting the findings of the full regression analyses of personal (Table 71) and indoor (Table 72) exposure follow.

Table 69: Comparative Multiple Regression Coefficients for Variable Sets

Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	.003	.003	.061
Housing Characteristics	.298	.301	.354
Job Status	.276	.396	.208
Smoking Characteristics	.493	.394	.267
Seasonal Effect	.293	.282	.049
Time Activity	.541	.435	.421
Specific Exposures	.336	.204	.216
Outdoor Concentration	.027	.061	.080
Indoor Concentration	.343	.175	.175

Table 70: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	-.13	-.21	-.21	-.24	-.42	-.18	-.08	.04	-.00
TRAILOR	.03	.01	.02	.05	.16	.17	.19	.19	
MULT2	.18	.19	.18	.25	.18	.20	.25	.18	
NEW	-.06	-.01	-.02	-.04	-.05	-.11	-.23	-.19	
MED	.25	.27	.25	.20	.20	.15	.03	.03	
NFCDAIR	-.49	-.40	-.38	-.36	-.21	-.29	-.15	-.16	
CARET	-.36	-.41	-.40	-.34	-.35	-.22	-.22	-.09	
WEEKEND	.28	.36	.35	.36	.46	.49	.40		
PLANT	.17	.33	.33	.33	.58	.34	.41		
JOBFT	-.32	-.22	-.19	-.08	.03	.03	-.04		
JOBPT	.08	.13	.15	.25	.22	.22	.42		
JFTXWKN	.06	-.04	-.05	-.08	-.37	-.41	-.32		
JPTXWKN	-.18	-.20	-.20	-.17	-.23	-.25	-.22		
SMKHOME	-.03	.09	.11	.09	.16	.18			
SMKCAR	.06	.04	.01	.06	-.03	.15			
SMKAMT	.03	.05	.06	.07	.08	.06			
SMKEXP2	.38	.41	.40	.39	.44	.30			
Q_1	-.02	-.01	-.02	-.03	.10				
Q_2	-.07	-.10	-.11	-.15	-.23				
Q_4	-.00	.10	.10	.06	.19				
IH	-.18	-.39	-.40	-.65					
OH	.05	-.00	-.01	-.12					
IW	.11	-.20	-.22	-.40					
OW	.48	.34	.33	.28					
IA	.16	-.02	-.03	-.09					
OA	-.07	-.13	-.12	-.22					
T	.07	.04	.04	-.10					
SMOKING	.17	.20	.19						
PAINTING	.10	.10	.09						
GAS	-.02	-.01	-.00						
HOUSECLN	.04	.01	-.00						
BURNING	-.22	-.19	-.18						
MISCCHEM	.06	.02	.02						
OCON3	-.10	-.07							
ICON3	.30								
R	.86	.85	.84	.82	.69	.63	.50	.30	.00

Table 71: Weights and Standard Errors for Analysis of Personal Concentration Levels

	B	β	Bootstrap Se	P
GENDER	-12.010	-.133	13.060	
TRAILOR	3.760	.029	14.620	
MULT2	20.010	.185	9.580	<0.05
NEW	-8.060	-.062	9.210	
MED	21.750	.249	9.230	<0.05
NFCDAIR	-46.100	-.485	11.590	<0.05
CARET	-27.410	-.364	9.400	<0.05
WEEKEND	22.060	.279	14.020	
PLANT	16.860	.173	18.620	
JOBFT	-22.480	-.315	16.020	
JOBPT	8.160	.080	13.570	
JFTXWKN	2.600	.056	19.840	
JPTXWKN	-30.890	-.179	16.150	<0.10
SMKHOME	-3.780	-.030	10.820	
SMKCAR	3.520	.059	12.620	
SMKAMT	.550	.028	2.600	
SMKEXP2	6.450	.384	2.040	<0.05
Q_1	-3.150	-.021	12.200	
Q_2	-9.910	-.074	9.590	
Q_4	-4.090	-.002	11.290	
IH	-27.410	-.183	86.620	
OH	28.170	.048	131.970	
IW	28.960	.113	96.920	
OW	379.360	.484	94.970	<0.05
IA	78.440	.155	122.700	
OA	-58.080	-.074	92.250	
T	56.660	.066	216.300	
SMOKING	21.690	.171	10.130	<0.05
PAINTING	22.220	.099	15.290	
GAS	-2.210	-.017	14.100	
HOUSECLN	6.250	.041	9.360	
BURNING	-25.230	-.219	8.840	<0.05
MISCCHEM	6.630	.064	10.100	
OCON3	-.230	-.097	.140	<0.10
ICON3	.560	.298	.200	<0.05
(Constant)	44.740	.	85.230	

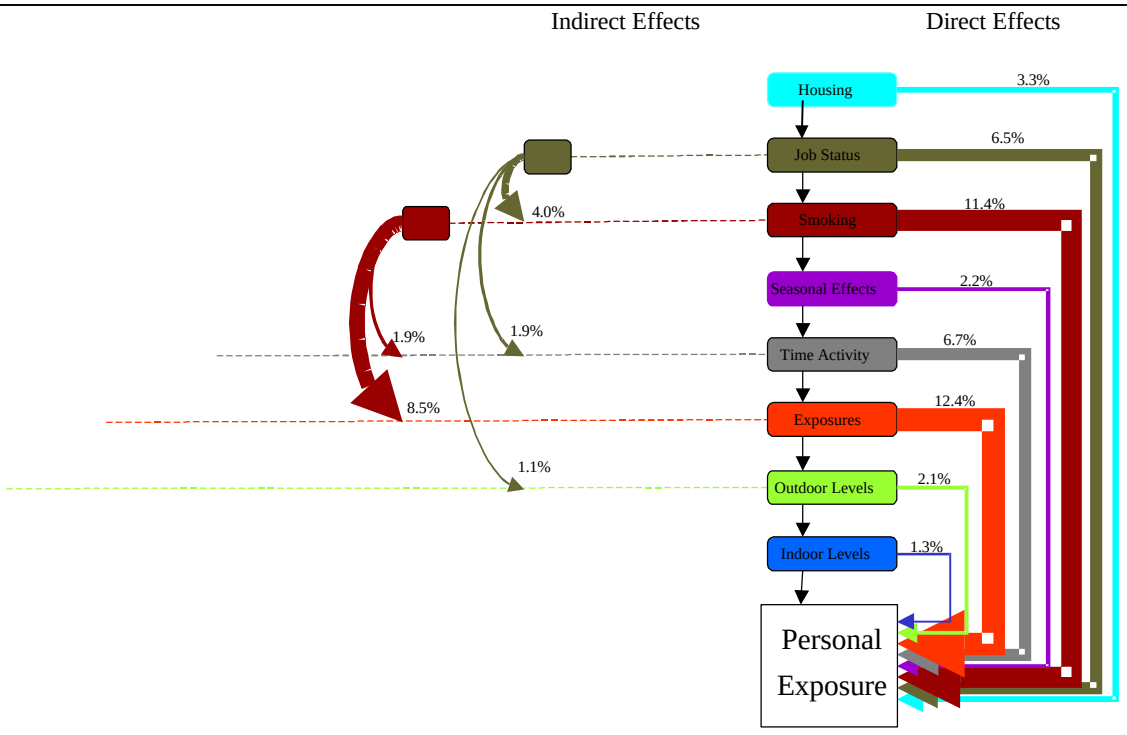
Table 72: Weights and Standard Errors for Analysis of Indoor Concentration Levels

	B	β	Bootstrap Se	P
GENDER	8.930	.093	15.860	
TRAILOR	-6.710	-.017	17.260	
MULT2	28.990	.204	14.670	<0.05
NEW	41.880	.239	17.350	<0.05
MED	-6.560	-.068	8.850	
NFCDAIR	5.490	.062	17.290	
CARET	-4.840	-.034	12.090	
WEEKEND	-26.690	-.205	21.810	
PLANT	-15.510	-.133	19.230	
JOBFT	-23.320	-.191	23.380	
JOBPT	-20.470	-.095	24.000	
JFTXWKN	50.190	.342	30.710	
JPTXWKN	40.830	.137	24.650	<0.10
SMKHOME	17.910	.151	11.720	
SMKCAR	2.170	-.002	15.320	
SMKAMT	9.070	.258	3.840	<0.05
SMKEXP2	-2.680	-.127	2.220	
Q_1	41.990	.198	19.860	<0.05
Q_2	1.120	.008	14.460	
Q_4	8.480	.050	14.080	
IH	-29.410	-.106	23.670	
OH	345.980	.271	229.150	
IW	-40.180	-.113	26.770	
OW	-40.880	-.047	74.150	
IA	-54.320	-.088	49.250	
OA	-155.720	-.105	116.440	
T	86.560	.049	111.650	
SMOKING	-4.950	-.052	8.090	
PAINTING	26.440	.067	19.150	
GAS	-16.490	-.061	17.660	
HOUSECLN	-15.370	-.090	11.500	
BURNING	28.230	.127	13.400	<0.05
MISCCHEM	4.560	.018	11.080	
OCON3	-.120	-.015	.230	
(Constant)	39.950	.	34.750	

8.9 *Particulate Matter: PM_{10}*

The results of the analysis of relationships between personal exposures and the factors that may affect exposure is shown pictorially in Figure 102. The model examined the relationships between all factors combined and personal exposure and accounted for about 65% of the variation in personal exposure. However, because the sample size is very small for this analysis, there is greater uncertainty associated with these estimates. The unexplained variation in personal exposure is likely due to important factors that were not included in the model.

Figure 102: Results of Model of Personal Exposure to PM_{10} Showing Direct and Indirect Effects of Factors



Note: Model describes about 65% of variation in personal PM_{10} exposure. There exists greater uncertainty due to small sample size.

Important factors influencing variations in PM_{10} exposures were as follows:

- ***Specific exposures,*** directly (12.4%)
- ***Smoking characteristics,*** directly (11.4%)
- ***Smoking characteristics,*** operating indirectly through effects on specific exposures (8.5%)
- ***Time activity,*** directly (6.7%)
- ***Job status,*** directly (6.5%)
- ***Job status,*** operating indirectly through effects on smoking characteristics (4.0%)
- ***Housing characteristics,*** directly (3.3%)
- ***Seasonal effects,*** directly (2.2%)
- ***Outdoor levels,*** directly (2.1%)
- ***Smoking characteristics,*** operating indirectly through effects on time activity (1.9%)
- ***Job status,*** operating indirectly through effects on time activity (1.8%)
- ***Indoor levels,*** directly (1.3%)

The model demonstrates that smoking characteristics, job status and specific exposures were important factors affecting PM_{10} personal exposures and accounted for roughly three-quarters of the variation explained by the model. Indoor and outdoor levels were responsible for less than 5% of the variance in personal PM_{10}. Important factors influencing variation in personal exposure did not exert effects through indoor and outdoor concentration levels.

The two tables on which Figure 102 is based follow below (Table 73 and Table 74); and the tables presenting the findings of the full regression analyses of personal (Table 75) and indoor (Table 76) exposure follow.

Table 73: Comparative Multiple Regression Coefficients for Variable Sets

Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	.115	.115	.036
Housing Characteristics	.146	.131	.181
Job Status	.347	.374	.254
Smoking Characteristics	.419	.469	.337
Seasonal Effect	.223	.189	.148
Time Activity	.278	.262	.259
Specific Exposures	.331	.339	.352
Outdoor Concentration	.176	.158	.146
Indoor Concentration	.224	.113	.113

Table 74: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	-.08	-.09	-.12	-.26	-.32	-.21	-.05	-.10	-.11
TRAILOR	-.10	-.09	-.10	-.14	-.03	-.06	.02	-.00	
MULT2	-.16	-.12	-.08	-.10	-.15	-.13	-.01	.02	
NEW	-.10	-.09	-.09	.03	-.01	-.02	-.16	-.12	
MED	.02	.05	.03	.09	.13	.13	-.04	-.03	
NFCDAIR	-.17	-.15	-.20	-.10	-.14	-.27	-.04	-.04	
CARET	-.28	-.24	-.19	-.29	-.39	-.35	-.21	-.07	
WEEKEND	-.10	-.08	-.14	.01	.08	.10	.10		
PLANT	-.07	.01	.02	.13	.26	.12	.10		
JOBFT	.07	.11	.15	.13	.10	.03	.06		
JOBPT	.22	.25	.24	.17	.15	.13	.35		
JFTXWKN	.26	.26	.25	.16	.09	.11	.13		
JPTXWKN	.13	.13	.16	.16	.17	.19	.05		
SMKHOME	.30	.30	.34	.28	.34	.39			
SMKCAR	-.21	-.18	-.12	-.16	-.18	-.07			
SMKAMT	.15	.17	.22	.25	.24	.20			
SMKEXP2	.45	.44	.41	.51	.49	.41			
Q_1	.10	.10	.08	.03	.08				
Q_2	-.22	-.24	-.22	-.27	-.24				
Q_4	-.08	-.09	-.21	-.11	-.01				
IH	.03	.00	-.00	-.03					
OH	-.02	-.04	-.06	-.04					
IW	-.04	-.07	-.13	-.08					
OW	.33	.32	.33	.28					
IA	.13	.10	.09	.04					
OA	.07	.11	.14	.15					
T	.08	.08	.08	.08					
SMOKING	.22	.21	.18						
PAINTING	.19	.16	.17						
GAS	-.14	-.15	-.15						
HOUSECLN	.22	.24	.25						
BURNING	-.08	-.06	-.05						
MISCCHEM	-.37	-.36	-.36						
OCON3	.21	.22							
ICON3	.17								
R	.80	.80	.78	.70	.65	.62	.41	.17	.11

Table 75: Weights and Standard Errors for Analysis of Personal Concentration Levels

	B	β	Bootstrap Se	P
GENDER	-.100	-.075	.247	
TRAILOR	-.229	-.103	.305	
MULT2	-.244	-.157	.165	
NEW	-.187	-.102	.221	
MED	.028	.021	.142	
NFCDAIR	-.267	-.172	.229	
CARET	-.365	-.276	.239	
WEEKEND	-.147	-.103	.292	
PLANT	-.097	-.072	.267	
JOBFT	.106	.074	.288	
JOBPT	.491	.221	.291	<0.10
JFTXWKN	.427	.256	.328	
JPTXWKN	.512	.128	.546	
SMKHOME	.413	.296	.178	<0.05
SMKCAR	-.307	-.205	.255	
SMKAMT	.061	.146	.049	
SMKEXP2	.134	.454	.035	<0.05
Q_1	.214	.096	.236	
Q_2	-.334	-.216	.235	
Q_4	-.120	-.080	.216	
IH	.089	.031	.294	
OH	-.334	-.024	1.545	
IW	-.170	-.042	.369	
OW	10.137	.326	5.033	<0.05
IA	.768	.126	.670	
OA	1.217	.067	2.546	
T	1.464	.075	2.366	
SMOKING	.359	.221	.139	<0.05
PAINTING	1.074	.191	.547	<0.05
GAS	-.362	-.140	.271	
HOUSECLN	.382	.216	.173	<0.05
BURNING	-.235	-.082	.351	
MISCCHEM	-.781	-.373	.207	<0.05
OCON3	.163	.209	.064	<0.05
ICON3	.114	.172	.067	<0.10
(Constant)	1.451	.	.398	<0.05

Table 76: Weights and Standard Errors for Analysis of Indoor Concentration Levels

	B	β	Bootstrap Se	P
GENDER	-.078	-.042	.233	
TRAILOR	.325	.103	.216	
MULT2	.177	.077	.203	
NEW	.291	.111	.252	
MED	.193	.103	.188	
NFCDAIR	.130	.058	.291	
CARET	.249	.133	.254	
WEEKEND	.409	.203	.261	
PLANT	.526	.278	.325	
JOBFT	.570	.284	.303	<0.10
JOBPT	.744	.268	.337	<0.05
JFTXWKN	-.240	-.104	.313	
JPTXWKN	-.288	-.060	.312	
SMKHOME	.309	.161	.259	
SMKCAR	.394	.188	.255	
SMKAMT	.096	.154	.055	<0.10
SMKEXP2	-.061	-.148	.055	
Q_1	.361	.115	.296	
Q_2	-.110	-.050	.282	
Q_4	.226	.105	.264	
IH	-.330	-.073	.310	
OH	-.779	-.044	1.002	
IW	-1.353	-.251	.559	<0.05
OW	-1.904	-.087	1.125	<0.10
IA	-.312	-.032	.688	
OA	.486	.023	1.149	
T	-1.736	-.056	2.164	
SMOKING	-.071	-.031	.220	
PAINTING	-.213	-.026	.467	
GAS	-.084	-.019	.267	
HOUSECLN	.318	.128	.168	<0.10
BURNING	.303	.084	.195	
MISCCHEM	-.284	-.100	.254	
OCON3	.209	.189	.087	<0.05
(Constant)	-.562	.	.419	

8.10 Regression Analysis of Individual BTEX Chemicals

The discussion below shows analysis of individual chemicals in the BTEX complex group compared to the analysis performed on the single factor expressing the concentrations of volatile organic compounds (VOCs) as a group. Analyses for both personal and indoor exposures are presented for benzene, toluene, ethylbenzene, m-p-xylene, and o-xylene. The final column in each table indicates the significance of each

variable (**=p<0.05, *=p<0.10) in the analysis of the single factor derived from the factor analysis for comparative purposes. In general, the pattern of overlap is greater for personal exposure, but reasonable for all compounds for both indoor and outdoor concentrations.

8.10.1 Benzene

Table 77: Weights and Standard Errors of Personal Exposure Concentrations

	B	β	Bootstrap Se	P	
GENDER	.11	.05	.11		**
TRAILOR	-.24	-.04	.17		
MULT2	.11	.04	.11		**
NEW	.07	.02	.12		
MED	-.04	-.01	.08		**
NFCDAIR	-.26	-.09	.11	<0.05	
CARET	-.20	-.08	.09	<0.05	
UREA	-.16	-.02	.21		
WEEKEND	.17	.07	.22		
PLANT	-.14	-.06	.11		
JOBFT	-.18	-.06	.16		*
JOBPT	-.09	-.03	.17		
JFTXWKN	-.05	-.02	.23		*
JPTXWKN	-.14	-.03	.26		
SMKHOME	.04	.02	.09		
SMKCAR	-.12	-.04	.11		
SMKAMT	.05	.05	.03		
SMKEXP2	.04	.09	.02	<0.05	**
Q_1	.32	.11	.10	<0.05	
Q_2	.01	.00	.10		*
Q_4	.24	.08	.11	<0.05	
IH	-.37	-.06	.24		
OH	.98	.04	.74		
IW	-.28	-.04	.29		
OW	.41	.02	.56		**
IA	.25	.02	.40		
OA	-.22	-.01	.61		
T	2.09	.06	.91	<0.05	**
SMOKING	.21	.07	.08	<0.05	
PAINTING	.24	.04	.12	<0.05	**
GAS	.38	.08	.12	<0.05	**
HOUSECLN	-.12	-.03	.09		
BURNING	.03	.01	.09		
MISCCHEM	-.04	-.01	.07		
OCON3	.11	.11	.03	<0.05	
ICON3	.42	.45	.04	<0.05	**
(Constant)	4.15	.	.35	<0.05	**

Table 78: Weights and Standard Errors for Analysis of Indoor Concentrations

	B	β	Bootstrap Se	P	
GENDER	-.19	-.08	.14		*
TRAILOR	-.14	-.02	.18		**
MULT2	.18	.06	.12		
NEW	.40	.10	.21	<0.10	
MED	.15	.06	.10		
NFCDAIR	-.12	-.04	.12		
CARET	.02	.01	.11		**
UREA	-.09	-.01	.30		
WEEKEND	.18	.07	.28		
PLANT	.06	.02	.14		
JOBFT	-.14	-.05	.21		
JOBPT	-.19	-.05	.23		
JFTXWKN	-.02	-.01	.30		
JPTXWKN	.05	.01	.32		
SMKHOME	.31	.12	.13	<0.05	
SMKCAR	.02	.01	.14		**
SMKAMT	.06	.06	.05		
SMKEXP2	.05	.09	.02	<0.05	
Q_1	.64	.20	.13	<0.05	
Q_2	-.03	-.01	.14		
Q_4	.20	.06	.16		
IH	-.91	-.14	.31	<0.05	
OH	-1.64	-.07	.93	<0.10	
IW	-.49	-.07	.37		
OW	-.42	-.02	.87		
IA	-.61	-.05	.41		
OA	.13	.01	.83		
T	-.50	-.01	1.21		
SMOKING	-.09	-.03	.10		
PAINTING	.13	.02	.17		**
GAS	.03	.01	.15		
HOUSECLN	.20	.05	.11	<0.10	
BURNING	.16	.04	.10		
MISCCHEM	.02	.01	.10		
OCON3	.38	.35	.04	<0.05	**
(Constant)	5.02	.	.53	<0.05	**

8.10.2 Toluene

Table 79: Weights and Standard Errors for Analysis of Personal Concentrations

	B	β	Bootstrap Se	P	
GENDER	.25	.09	.11	<0.05	**
TRAILOR	.33	.05	.31		
MULT2	-.09	-.03	.11		**
NEW	-.02	.00	.12		
MED	-.13	-.05	.10		**
NFCDAIR	-.09	-.03	.14		
CARET	-.04	-.01	.10		
UREA	-.43	-.05	.22	<0.05	
WEEKEND	-.09	-.03	.12		
PLANT	-.10	-.04	.12		
JOBFT	-.19	-.06	.15		*
JOBPT	.10	.03	.17		
JFTXWKN	.08	.03	.16		*
JPTXWKN	.22	.04	.21		
SMKHOME	-.04	-.01	.11		
SMKCAR	-.22	-.07	.11	<0.10	
SMKAMT	.04	.04	.03		
SMKEXP2	.05	.08	.02	<0.05	**
Q_1	-.09	-.03	.12		
Q_2	.09	.03	.12		*
Q_4	.28	.09	.13	<0.05	
IH	.11	.02	.36		
OH	.25	.01	.74		
IW	.45	.06	.44		
OW	.74	.03	.61		**
IA	.18	.01	.55		
OA	-.16	-.01	.71		
T	2.17	.06	1.10	<0.05	**
SMOKING	.00	.00	.08		
PAINTING	.66	.10	.25	<0.05	**
GAS	.54	.10	.17	<0.05	**
HOUSECLN	-.02	-.01	.09		
BURNING	-.14	-.03	.12		
MISCCHEM	.18	.06	.08	<0.05	
OCON3	.10	.09	.03	<0.05	
ICON3	.45	.44	.04	<0.05	**
(Constant)	4.40	.	.52	<0.05	**

Table 80: Weights and Standard Errors for Analysis of Indoor Concentrations

	B	β	Bootstrap Se	P	
GENDER	-.05	-.02	.15		*
TRAILOR	-.20	-.03	.24		**
MULT2	-.28	-.10	.13	<0.05	
NEW	-.11	-.03	.22		
MED	-.19	-.07	.12		
NFCDAIR	.11	.03	.14		
CARET	.13	.05	.12		**
UREA	.10	.01	.28		
WEEKEND	.19	.07	.24		
PLANT	.20	.08	.15		
JOBFT	-.15	-.05	.24		
JOBPT	.15	.04	.26		
JFTXWKN	-.20	-.07	.26		
JPTXWKN	-.03	-.01	.30		
SMKHOME	-.04	-.01	.14		
SMKCAR	.17	.06	.14		**
SMKAMT	.02	.02	.05		
SMKEXP2	.00	.00	.03		
Q_1	-.07	-.02	.16		
Q_2	.40	.13	.16	<0.05	
Q_4	.49	.16	.16	<0.05	
IH	-.57	-.09	.28	<0.05	
OH	-1.45	-.06	1.00		
IW	-.30	-.04	.37		
OW	.17	.01	.86		
IA	.36	.03	.46		
OA	.23	.01	.95		
T	-1.42	-.04	1.26		
SMOKING	-.15	-.05	.11		
PAINTING	.22	.04	.24		**
GAS	-.18	-.03	.16		
HOUSECLN	.06	.02	.12		
BURNING	.03	.01	.13		
MISCCHEM	-.01	.00	.11		
OCON3	.28	.27	.03	<0.05	**
(Constant)	7.22	.	.44	<0.05	**

8.10.3 Ethylbenzene

Table 81: Weights and Standard Errors for Analysis of Personal Concentrations

	B	β	Bootstrap Se	P	
GENDER	.44	.13	.15	<0.05	**
TRAILOR	-.08	-.01	.22		
MULT2	-.32	-.08	.12	<0.05	**
NEW	-.20	-.04	.20		
MED	-.27	-.08	.11	<0.05	**
NFCDAIR	-.01	.00	.15		
CARET	-.11	-.03	.12		
UREA	-.69	-.07	.21	<0.05	
WEEKEND	-.15	-.04	.20		
PLANT	-.15	-.05	.13		
JOBFT	-.32	-.08	.20		*
JOBPT	-.15	-.03	.23		
JFTXWKN	.32	.08	.24		*
JPTXWKN	.27	.03	.29		
SMKHOME	.00	.00	.12		
SMKCAR	-.25	-.07	.14	<0.10	
SMKAMT	.02	.01	.04		
SMKEXP2	.07	.09	.03	<0.05	**
Q_1	-.02	-.01	.15		
Q_2	-.06	-.02	.13		*
Q_4	.37	.09	.17	<0.05	
IH	-.56	-.06	.44		
OH	1.19	.04	1.10		
IW	.12	.01	.48		
OW	3.32	.11	1.06	<0.05	**
IA	.23	.01	.65		
OA	-.06	.00	1.03		
T	1.75	.04	1.77		**
SMOKING	.11	.03	.13		
PAINTING	1.35	.17	.36	<0.05	**
GAS	.62	.09	.20	<0.05	**
HOUSECLN	-.13	-.02	.11		
BURNING	-.04	-.01	.13		
MISCCHEM	.02	.01	.10		
OCON3	.10	.02	.10		
ICON3	.67	.53	.04	<0.05	**
(Constant)	2.47	.	.69	<0.05	**

Table 82: Weights and Standard Errors for Analysis of Indoor Concentrations

	B	β	Bootstrap Se	P	
GENDER	-.52	-.19	.17	<0.05	*
TRAILOR	-.56	-.09	.23	<0.05	**
MULT2	-.01	.00	.16		
NEW	.55	.13	.31	<0.10	
MED	-.15	-.06	.13		
NFCDAIR	.03	.01	.16		
CARET	.43	.16	.15	<0.05	**
UREA	.21	.03	.50		
WEEKEND	.11	.04	.32		
PLANT	.27	.10	.15	<0.10	
JOBFT	-.31	-.10	.28		
JOBPT	-.30	-.08	.32		
JFTXWKN	-.04	-.01	.33		
JPTXWKN	.38	.06	.36		
SMKHOME	-.13	-.05	.14		
SMKCAR	.36	.12	.18	<0.05	**
SMKAMT	.05	.05	.05		
SMKEXP2	-.01	-.02	.03		
Q_1	-.39	-.12	.17	<0.05	
Q_2	-.06	-.02	.19		
Q_4	-.20	-.06	.17		
IH	-.67	-.10	.49		
OH	-1.12	-.04	1.36		
IW	.10	.01	.52		
OW	-.42	-.02	.82		
IA	.19	.02	.59		
OA	.03	.00	1.06		
T	-1.62	-.04	1.30		
SMOKING	-.17	-.05	.11		
PAINTING	.36	.06	.33		**
GAS	-.01	.00	.15		
HOUSECLN	-.03	-.01	.17		
BURNING	.11	.03	.17		
MISCCHEM	.00	.00	.12		
OCON3	.42	.13	.15	<0.05	**
(Constant)	4.35	.	.94	<0.05	**

8.10.4 O-Xylene

Table 83: Weights and Standard Errors for Analysis of Personal Concentrations

	B	β	Bootstrap Se	P	
GENDER	.22	.06	.21		**
TRAILOR	.54	.06	.38		
MULT2	-.30	-.07	.15	<0.05	**
NEW	-.09	-.01	.22		
MED	-.16	-.04	.14		**
NFCDAIR	-.13	-.03	.19		
CARET	-.25	-.06	.15	<0.10	
UREA	.17	.01	.30		
WEEKEND	.00	.00	.21		
PLANT	.29	.07	.18		
JOBFT	-.16	-.04	.18		*
JOBPT	-.08	-.01	.22		
JFTXWKN	.09	.02	.24		*
JPTXWKN	.17	.02	.29		
SMKHOME	.07	.02	.14		
SMKCAR	-.27	-.06	.17		
SMKAMT	.07	.05	.05		
SMKEXP2	.08	.09	.03	<0.05	**
Q_1	-.08	-.02	.20		
Q_2	-.28	-.06	.16	<0.10	*
Q_4	.30	.06	.21		
IH	-.97	-.10	.41	<0.05	
OH	1.16	.03	1.00		
IW	.84	.08	.48	<0.10	
OW	4.66	.14	1.28	<0.05	**
IA	-.06	.00	.65		
OA	-.84	-.02	1.07		
T	1.94	.04	1.71		**
SMOKING	.00	.00	.16		
PAINTING	1.07	.12	.36	<0.05	**
GAS	.80	.10	.22	<0.05	**
HOUSECLN	.09	.02	.13		
BURNING	-.18	-.03	.13		
MISCCHEM	.11	.03	.11		
OCON3	.09	.02	.12		
ICON3	.72	.54	.04	<0.05	**
(Constant)	2.24	.	.79	<0.05	**

Table 84: Weights and Standard Errors for Analysis of Indoor Concentrations

	B	β	Bootstrap Se	P	
GENDER	-.16	-.05	.20		*
TRAILOR	-.85	-.13	.20	<0.05	**
MULT2	-.35	-.11	.14	<0.05	
NEW	.09	.02	.26		
MED	-.02	-.01	.14		
NFCDAIR	.07	.02	.16		
CARET	-.07	-.02	.16		**
UREA	.41	.05	.63		
WEEKEND	.35	.12	.26		
PLANT	.14	.05	.19		
JOBFT	-.04	-.01	.27		
JOBPT	.10	.02	.31		
JFTXWKN	-.28	-.08	.28		
JPTXWKN	-.08	-.01	.33		
SMKHOME	-.20	-.07	.15		
SMKCAR	.23	.07	.19		**
SMKAMT	.01	.01	.06		
SMKEXP2	-.01	-.02	.03		
Q_1	-.13	-.04	.23		
Q_2	-.32	-.09	.17	<0.10	
Q_4	-.19	-.06	.18		
IH	-.30	-.04	.54		
OH	-1.29	-.05	1.28		
IW	-.08	-.01	.64		
OW	.05	.00	1.00		
IA	.32	.02	.75		
OA	-.71	-.02	1.19		
T	-2.24	-.06	1.32	<0.10	
SMOKING	.11	.03	.12		
PAINTING	1.35	.20	.31	<0.05	**
GAS	-.23	-.04	.17		
HOUSECLN	-.11	-.02	.17		
BURNING	.01	.00	.16		
MISCCHEM	-.22	-.07	.13	<0.10	
OCON3	.45	.11	.21	<0.05	**
(Constant)	4.12	.	1.19	<0.05	**

8.10.5 M-, P-Xylene

Table 85: Weights and Standard Errors for Analysis of Personal Concentrations

	B	β	Bootstrap Se	P	
GENDER	.24	.11	.09	<0.05	**
TRAILOR	.07	.01	.11		
MULT2	-.22	-.09	.07	<0.05	**
NEW	-.07	-.02	.10		
MED	-.20	-.09	.06	<0.05	**
NFCDAIR	-.04	-.01	.09		
CARET	-.11	-.05	.07		
UREA	-.09	-.01	.17		
WEEKEND	-.11	-.05	.12		
PLANT	-.12	-.06	.08		
JOBFT	-.13	-.05	.12		*
JOBPT	-.04	-.01	.13		
JFTXWKN	.20	.08	.13		*
JPTXWKN	.26	.05	.15	<0.10	
SMKHOME	-.03	-.01	.07		
SMKCAR	-.16	-.07	.09	<0.10	
SMKAMT	.04	.04	.02		
SMKEXP2	.04	.08	.02	<0.05	**
Q_1	-.20	-.07	.08	<0.05	
Q_2	-.27	-.11	.08	<0.05	*
Q_4	.06	.02	.11		
IH	-.26	-.05	.20		
OH	.43	.02	.71		
IW	.08	.01	.23		
OW	.98	.05	.48	<0.05	**
IA	.40	.04	.37		
OA	-.14	-.01	.51		
T	3.37	.11	.91	<0.05	**
SMOKING	.14	.05	.08	<0.10	
PAINTING	.73	.14	.25	<0.05	**
GAS	.48	.11	.12	<0.05	**
HOUSECLN	-.06	-.02	.07		
BURNING	-.11	-.03	.08		
MISCCHEM	.05	.02	.05		
OCON3	.04	.03	.03		
ICON3	.57	.60	.04	<0.05	**
(Constant)	4.12	.	.41	<0.05	**

Table 86: Weights and Standard Errors for Analysis of Indoor Concentrations

	B	β	Bootstrap Se	P	
GENDER	-.23	-.10	.14		*
TRAILOR	-.87	-.16	.26	<0.05	**
MULT2	-.10	-.04	.14		
NEW	.33	.09	.25		
MED	-.18	-.08	.12		
NFCDAIR	.00	.00	.15		
CARET	.29	.13	.14	<0.05	**
UREA	-.03	.00	.42		
WEEKEND	.14	.06	.27		
PLANT	.10	.04	.13		
JOBFT	-.22	-.08	.25		
JOBPT	-.10	-.03	.28		
JFTXWKN	-.13	-.05	.28		
JPTXWKN	.17	.03	.30		
SMKHOME	-.01	.00	.14		
SMKCAR	.31	.12	.15	<0.05	**
SMKAMT	.01	.02	.05		
SMKEXP2	-.01	-.02	.02		
Q_1	.08	.03	.14		
Q_2	.03	.01	.15		
Q_4	.16	.06	.15		
IH	-.55	-.09	.35		
OH	-.74	-.03	1.02		
IW	.00	.00	.38		
OW	.97	.05	.71		
IA	.48	.05	.46		
OA	-.14	-.01	.89		
T	-1.31	-.04	1.10		
SMOKING	-.11	-.04	.09		
PAINTING	.40	.07	.27		**
GAS	-.05	-.01	.12		
HOUSECLN	-.02	-.01	.15		
BURNING	.16	.04	.14		
MISCCHEM	-.12	-.05	.10		
OCON3	.32	.26	.05	<0.05	**
(Constant)	6.53	.	.54	<0.05	**

8.11 Further Analysis of Benzene

In the analysis reported above, the pattern of coefficients for benzene was the least similar to the analysis of the combined VOC chemicals reported previously, and there appears there may be a direct relationship between levels in outdoor air and personal exposure. In addition, in a separate small co-location analysis reported in *Appendix B: The Variation of Air Contaminant Levels in Selected Indoor and Outdoor Environments*, contaminant levels were measured in attached garages, cars, and garage stations. It was noted that benzene levels were relatively higher in residential garages. Taken in combination, these results suggest the possibility that personal exposure to benzene might have multiple sources. To investigate this possibility a hierarchical set regression was performed on benzene levels. A variable indicating the presence of an attached garage was included within the 'housing characteristics' variable set. (Because this variable was available for only 199 participants, this analysis was based on these participants alone leading to a reduced sample size). Figure 103 presents the summary figure for this analysis, and the tables on which the figure is based follow. The model differs from the model for the combined VOCs in that the direct effect of indoor levels on personal levels is reduced, the direct and indirect effects of outdoor levels are increased, as are the effects of smoking and of housing characteristics. The tables show that this last relationship can be attributed largely to the effect of having an attached garage.

Figure 103: Results of Model of Personal Exposure to Benzene

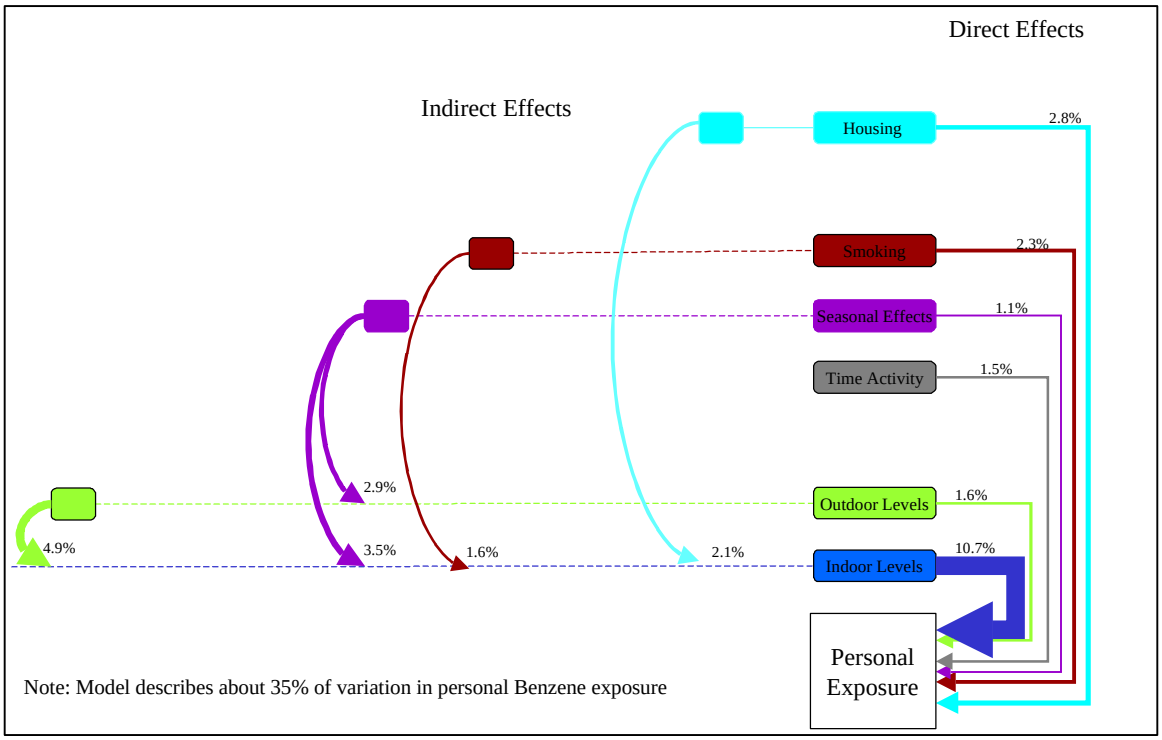


Table 87: Comparative Multiple Regression Coefficients for Variable Sets for Benzene

Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	.063	.063	.014
Housing Characteristics	.235	.238	.168
Job Status	.102	.099	.081
Smoking Characteristics	.193	.210	.151
Seasonal Effect	.301	.288	.105
Time Activity	.229	.161	.122
Specific Exposures	.170	.104	.087
Outdoor Concentration	.321	.255	.127
Indoor Concentration	.539	.327	.327

Table 88: Beta Weights for Hierarchical Set Regression of Benzene Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	.02	.02	.01	.00	.01	.09	.06	.08	.06
TRAILOR	.03	.03	.05	.05	.06	.11	.10	.10	
MULT2	.06	.07	.06	.07	.07	.08	.11	.11	
NEW	-.03	-.05	-.05	-.04	-.04	.03	.03	.03	
MED	-.01	-.01	.01	.00	.00	.02	.02	.02	
NFCDAIR	-.07	-.08	-.09	-.09	-.09	-.12	-.12	-.13	
CARET	-.12	-.14	-.15	-.15	-.15	-.13	-.12	-.12	
UREA	.04	.05	.04	.04	.02	.04	.04	.03	
Attached Garage	.14	.21	.18	.18	.19	.18	.18	.17	
WEEKEND	.01	.05	.07	.07	.05	.08	.07		
PLANT	.05	.04	.04	.04	.05	.06	.06		
JOBFT	-.14	-.19	-.15	-.14	-.13	-.11	-.09		
JOBPT	-.07	-.13	-.11	-.10	-.09	-.06	-.06		
JFTXWKN	.02	.03	.02	.02	.03	.00	.01		
JPTXWKN	-.02	-.02	-.02	-.02	-.01	-.00	-.01		
SMKHOME	.00	.07	.07	.07	.09	.06			
SMKCAR	-.05	-.05	-.06	-.05	-.07	-.03			
SMKAMT	.11	.13	.12	.12	.12	.16			
SMKEXP2	.12	.14	.14	.14	.14	.11			
Q_1	.13	.21	.31	.32	.34				
Q_2	.05	.03	.01	.02	.02				
Q_4	.12	.16	.17	.18	.16				
IH	-.08	-.11	-.14	-.14					
OH	.03	.02	.01	.02					
IW	-.05	-.04	-.09	-.08					
OW	-.03	-.03	-.03	-.02					
IA	.04	.04	.02	.03					
OA	.03	.04	.06	.06					
T	.05	.05	.04	.04					
SMOKING	.05	.05	.03						
PAINTING	.03	.05	.05						
GAS	.05	.06	.06						
HOUSECLN	-.05	-.04	-.04						
BURNING	.01	.01	.02						
MISCCHEM	.01	.02	.02						
OCON3	.15	.28							
ICON3	.39								
R	.64	.55	.48	.47	.44	.34	.27	.25	.06

8.12 Summary of Exposure Relationships

The previous sections have presented a large amount of information about a number of chemicals each analyzed separately. Within each analysis, careful examination of the tables can allow a sophisticated picture of causal influences to be postulated. However, nothing has yet been said about the manner in which the causal influences are similar across chemicals (with the exception of the analysis of the full set of volatile organic compounds considered in a simultaneous analysis). In the current section, a higher order analysis is presented which can allow preliminary statements about the full domain of chemicals.

The starting point of this analysis is the semi-partial correlation coefficients for each of the sets of influences included in the modeling process for each chemical. (These were presented in the last column of the set of tables entitled, “Comparative Multiple Regression Coefficients for Variable Sets” for each analysis of personal exposure, and separately derived for the analysis of indoor concentrations for this analysis). Basically, these numbers were brought together into a single table (with a separate column for each chemical and separate row for each set of influences) for the current analysis. Both the combined VOC analysis and each of the five BTEX compounds considered separately were placed into this table.

Next, a principal component decomposition of this table was performed, and the largest two dimensions of this analysis were used for a single biplot representation. With proper interpretation, this diagram summarizes the information present in the original table (to a substantial degree, though more dimensions would be required to allow complete reconstruction). The advantage of this analysis is that it can represent the relative importance of the causal influences across chemicals, and the relative similarity of chemicals with respect to their causal influence structure within a single graphic representation. The representation of influences on personal exposure concentration is presented in the first diagram while the representation of influences on indoor concentration is presented in the second.

The interpretation of these diagrams is as follows: each causal influence and each chemical has a co-ordinate in the two dimensional space. In absolute terms, the average size of the semi-partial multiple correlation coefficient across all chemicals considered together can be determined by the relative location of the points representing the causal influences on the first dimension. That is, the orderings of the coefficients on the first dimension gives the average ordering of the coefficient across all chemicals. In the current case, it can be seen that the influence of indoor concentrations is far and away the single largest influence on the personal concentrations across this set of chemicals (because it has the highest positive value on the first dimension; it is located to the extreme right). On indoor concentrations, however, outdoor concentration, housing characteristics, and job status variables all have relatively large effects.

Figure 104: Biplot Representation of Semi-Partial R for Determinant Sets of Chemicals (Personal Concentrations)

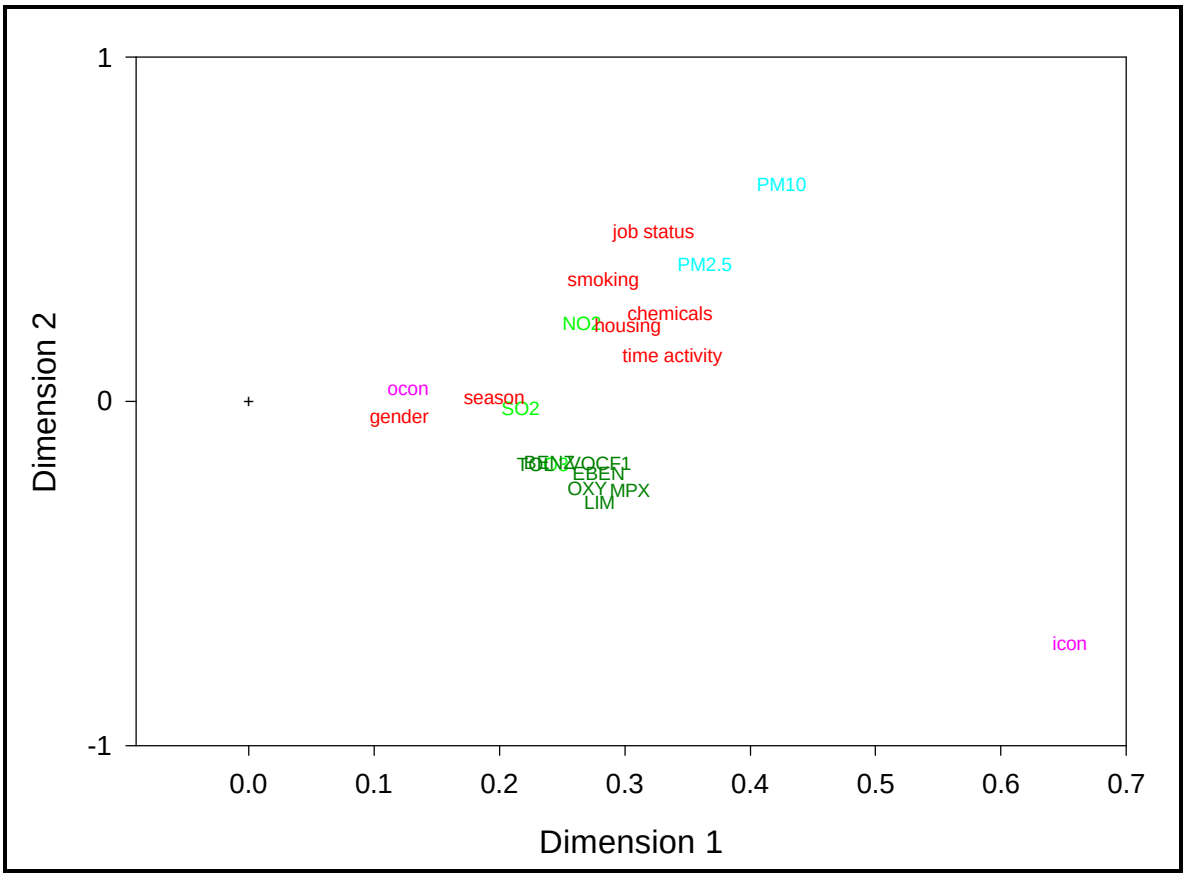
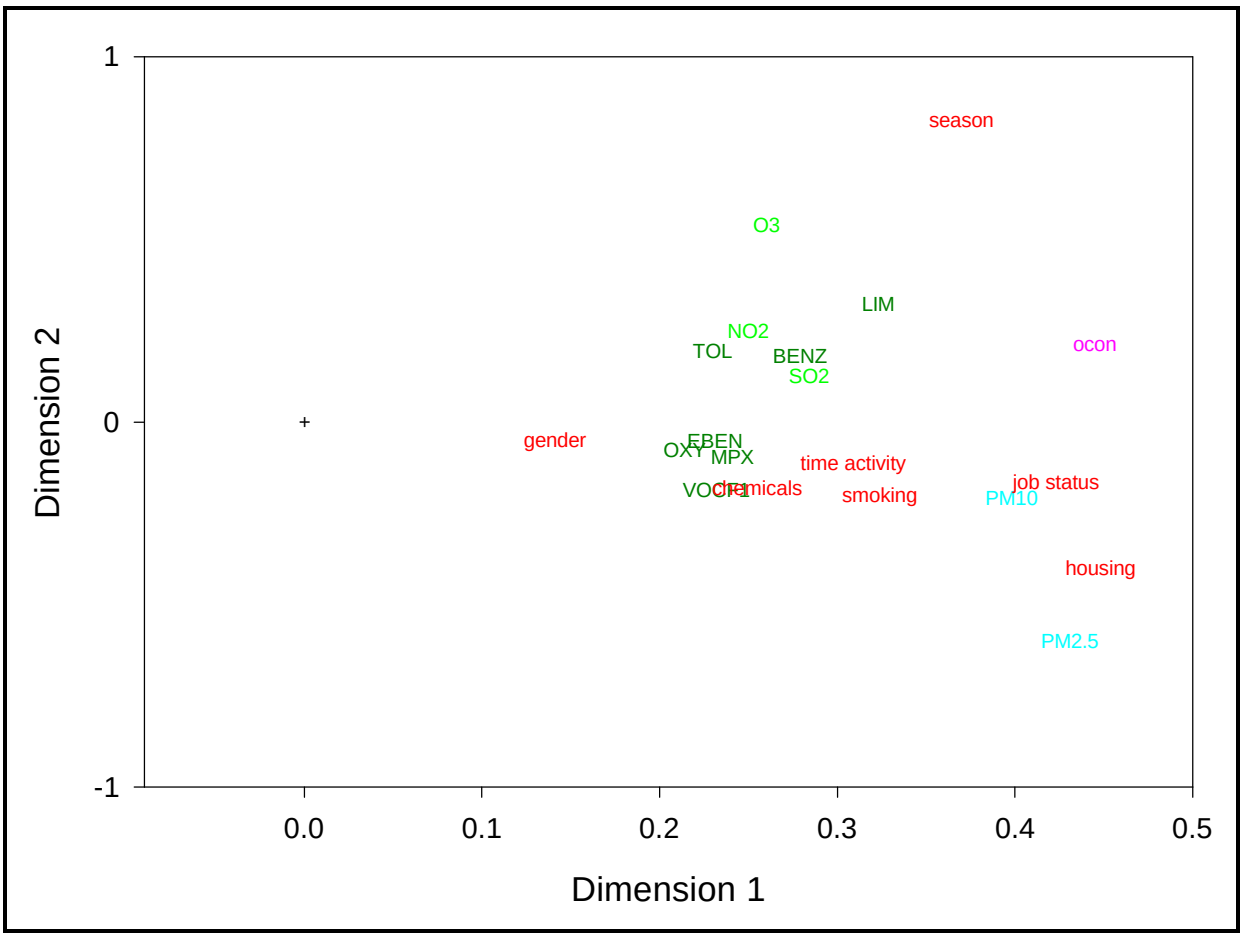


Figure 105: Biplot Representation of Semi-Partial R for Determinant Sets and Chemicals (Indoor Concentrations)



Similarly, the relative predictability of the exposures by chemical (including all influences) can be read from the relative location of the points representing the individual chemicals on the first dimension. In the current analyses, $PM_{2.5}$ and PM_{10} concentrations are predictable to a greater degree with the current sets of predictive variables than are the other chemical concentrations (although because of the small sample sizes involved in the analysis of particulates, this finding might not replicate).

The inclusion of the second dimension on each of the diagrams allows chemicals to be separated based upon differences in the pattern and magnitude of the set of influences. To determine the nature of these differences, follow this basic procedure for each chemical point: mentally draw a line from its co-ordinate through the '+' located on the graph at the 0,0 point (the origin). Consider this line as a new dimension. Values of the causal influences are ordered on this dimension in terms of their order of magnitude in predicting the concentration of that chemical. (Mentally, the operation to determine the values of the influences on this new dimension requires that you draw a perpendicular line from the point to the new point to the axis dimension (technically, "orthogonally project"). This operation is entirely analogous to determining the value of a point on a labeled dimension, as was necessary to determine the magnitudes (described above). Notice that the actual pattern and ordering of the influences will differ for chemicals located in different quadrants of the space. Thus, for PM_{10} (and also $PM_{2.5}$ and NO_2 which are on the same

approximate radial axis) job status is as important as indoor concentration in the prediction of personal concentration levels, while for the VOCs, indoor concentration is substantially more important than any other influence set.

Finally, the analogous procedure can be performed for each set of influences to derive an ordering of chemicals for which this set of influences is relatively more or less important. Thus for personal concentrations, smoking is relatively most important an influence on PM_{10} and $PM_{2.5}$ concentrations as well as NO_2, and relatively less important for all other chemical concentrations.

Finally, a global mode of interpretation is possible by combining all of this information as follows: chemicals in the same radial sector have similar patterns of influence, those farther from the origin (the '+' point) are more predictable than those nearer the origin. For personal concentration levels, this pattern is shown by PM_{10}, $PM_{2.5}$, and NO_2. Chemicals that are very close together on the plot have similar patterns of influence and similar levels of predictability. For personal concentrations, this condition is clearly met for the VOC chemicals, though for indoor concentrations there is slightly more variability.

Further interpretations are left as an exercise for the reader who, to complete his or her understanding, should also look back to the original tables to verify the assertions made.

9.0 Biomarkers of Exposure

Blood and urine samples were collected during the volunteers' participation in the study. The samples were sent to various laboratories that performed a series of tests to measure the levels of various contaminants.

The analysis of the blood samples included measures of nicotine and arsenic speciation, while the analysis of the urine samples included measures of BTEX compounds. The results from the heavy metal analysis in urine and blood were not available at the time of publication. The following table shows the various contaminants and number of samples collected.

Table 89: Urine and Blood Data

Blood Data	Fort McMurray	Lethbridge	Total
Nicotine	214	30	244
Arsenic	101	30	131
Urine Data			
Arsenic (III)	101	29	130
Dimethylarsinic acid (DMAA)	101	29	130
Methylarsonic acid (MMAA)	101	29	130
Muconic acid (metabolite of benzene)	213	29	242
Hippuric acid (metabolite of toluene)	213	29	242
Mandelic acid (metabolite of ethylbenzene)	213	29	242
2-Methylhippuric acid (metabolite of o-xylene)	213	29	242
3-, 4- Methylhippuric acid (metabolite of m-xylene)	213	29	242

9.1 Nicotine

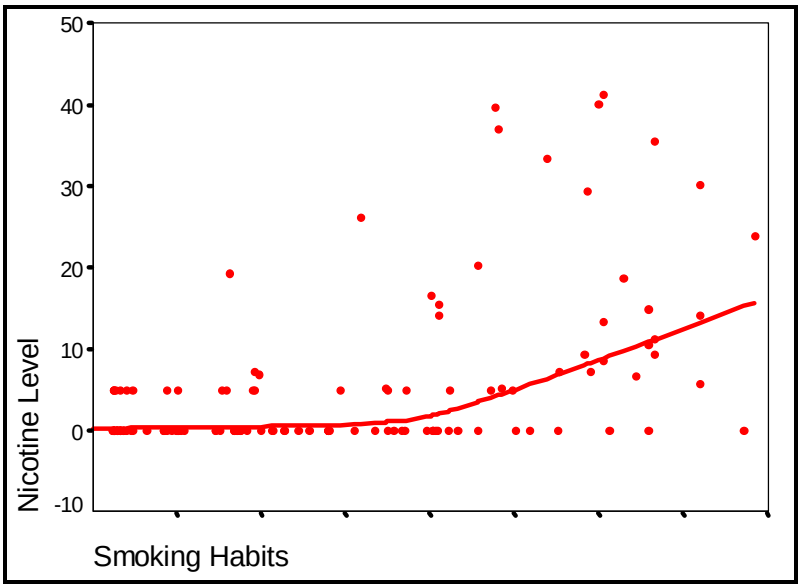
Blood samples from 214 Fort McMurray participants and 30 Lethbridge participants were analyzed for nicotine content. The distribution of levels was as follows:

Table 90: Analysis of Nicotine

Nicotine	No reading	Below Detection Limit	Above Detection Limit
Fort McMurray	157	20	37
Lethbridge	27	20	3
Total	184	20	40

The level of nicotine was clearly related to smoking behavior. A regression analysis of nicotine levels against reported smoking habit variables showed that the following variables were independently related to nicotine levels: amount smoked, allowing smoking in the car, and number of test days exposed to smoke. Allowing smoking in the home was not independently related to blood nicotine levels.

Figure 106: Nicotine Levels in Relation to Smoking



9.2 Arsenic Speciation

Arsenic is naturally present in the environment in different chemical forms (chemical species), both inorganic and organic. While inorganic arsenite [As (III)] and arsenate [As(V)] are very toxic, monomethylarsonic acid (MMAA) and dimethylarsinic acid (DMAA) are much less so. The toxicity, bioavailability, environmental impacts, and human health effects of different chemical species can vary dramatically. Thus, assessments of environmental impact and human health risk strictly based on measurements of total element concentration (i.e., total concentration of arsenic in urine or blood) are not reliable. It is important to identify and quantify individual chemical species of the element.[90]

High Performance Liquid Chromatography (HPLC) with Hydride Generation Atomic Fluorescence Detection (HGAFD) method was used for the speciation of arsenic compounds in urine samples collected from 101 Fort McMurray participants and 30 Lethbridge participants. Four arsenic species were separated including inorganic arsenite [As(III)], inorganic arsenate [As(V)], monomethylarsonic acid (MMAA), and dimethylarsinic acid (DMAA). Detailed methodology has been previously described by Le and Ma, 1998.[91] Additional information regarding the methodology of the analysis can be found in the *Methods Report*.

All 131 urine samples were analyzed three times using the HPLC/HGAFD method. Results were reported as mean ± one standard deviation from triplicate analyses of each sample. Concentrations below detection limit of 0.5 ng/ml (for As(III) and MMAA) and 1 ng/ml (for As(V) and DMAA) were reported as not detected (n.d.).

A summary of arsenic speciation results from the urine samples is shown in Table 91. A correction for creatinine levels was applied and the resulting data is presented in Table 92. Both tables use a value of zero for samples in which the concentration of arsenic species is below detection limits.

Table 91: Concentration of Arsenic Species in Urine

	As(III)	As(V)	MMAA	DMAA	Sum
Mean ± SD	0.4 ± 0.6	0.4 ± 1.3	0.5 ± 0.8	3.7 ± 4.4	5.2 ± 5.6
Median	n.d.	n.d.	n.d.	2.9	4
Lowest value	n.d.	n.d.	n.d.	n.d.	n.d.
Highest value	3.1	11	5.6	42	48

SD: Standard deviation
n.d.: not detected (below detection limit)

Table 92: Concentration of Arsenic Corrected for Creatinine Concentration (µg As/g creatinine)

	As(III)	As(V)	MMAA	DMAA	Sum
Mean ± SD	0.6 ± 0.6	0.5 ± 1.5	0.7 ± 1.0	4.2 ± 3.7	6.1 ± 5.1
Median	n.d.	n.d.	n.d.	3.6	5.1
Lowest value	n.d.	n.d.	n.d.	n.d.	n.d.
Highest value	5.8	11	5.6	25	28

For comparison, Table 93 summarizes literature results for arsenic speciation analysis of urine samples from several other populations. The study by Kalman et al. included only a control group who were not exposed to arsenic. Concentrations of arsenic species in urine samples from both Fort McMurray and Lethbridge participants are similar to the control-group in the U.S. study, reflecting background concentrations. Other groups listed in Table 93 show higher arsenic concentration because these groups had higher arsenic intake from water and food.

Table 93: Comparison of Arsenic Species in Urine from Five Studies

Study	No. of Subjects	Location	As(III) + As(V)	MMAA	DMAA	Total
Kalman et al. (1990)[92]	696	U.S.	1.3 ± 1.1	1.6 ± 1.3	6.4 ± 5.8	9.2 ± 7.5
Lin and Huang (1995[93]	30	Taiwan	1.7 ± 1.1	2.0 ± 1.0	3.3 ± 2.5	20.7 ± 7.0
Foa et al. (1984)[94]	148	Europe	1.9 ± 1.2	1.9 ± 1.4	2.1 ± 1.5	17.2 ± 11.2
Yamauchi et al. (1989)[95]	102	Japan	11.4 ± 5.9	3.6 ± 2.8	35.0 ± 20.8	121 ± 101
Vahter et al. (1995)[96]	11	Argentina	66 ± 41	7.1 ± 12	185 ± 110	274 ± 98

Speciation analysis of arsenic in serum was carried out using the same methodology as described for the urinalysis. From a combined total of 131 serum samples taken from the Fort McMurray and Lethbridge participants, only four samples had detectable arsenic concentrations (3 of 101 from Fort McMurray and 1 of 30 from Lethbridge). The remainder of the serum samples had arsenic concentrations below the detection limit. This is consistent with what the literature reports. Arsenic in the body has very short half time (1-4 hours depending on the arsenic species).

9.3 BTEX Compounds

As shown previously in Table 2, the BTEX compounds include benzene, toluene, ethylbenzene, and xylene. These compounds are constituents of fossil fuels and are released during evaporation and combustion. The products of the metabolism of these compounds can be measured in the urine. A total of 242 samples of urine, 213 from Fort McMurray and 29 from Lethbridge, were analyzed for the metabolites displayed in Table 94.

Table 94: BTEX Compounds and Metabolites

Metabolite (µg/mL in urine)	Compound
Muconic acid	benzene
Hippuric acid	toluene
Mandelic acid	ethylbenzene
3,4-Methylhippuric acid	m-,p-xylene
2-Methylhippuric acid	o-xylene

As shown by Table 95, very few samples had appreciable levels of mandelic acid, 3-, 4-methylhippuric acid, or 2-methylhippuric acid. Further analysis did not reveal any relationship between personal exposure to ethylbenzene or xylene and measured levels of these biomarkers. However, measurable amounts of muconic acid and hippuric acid were discovered. Histograms providing greater detail of the measured levels of these biomarkers are shown in Figure 107 for muconic acid and Figure 108 for hippuric acid in urine.

Table 95: Analysis of Metabolites

Metabolite	No reading	Below Detection Limit	Above Detection Limit
Muconic acid	110	6	97
Hippuric acid	1	4	208
Mandelic acid	164	44	5
3,4-Methylhippuric acid	195	18	0
2-Methylhippuric acid	164	49	0

Figure 107: Muconic Acid in Urine

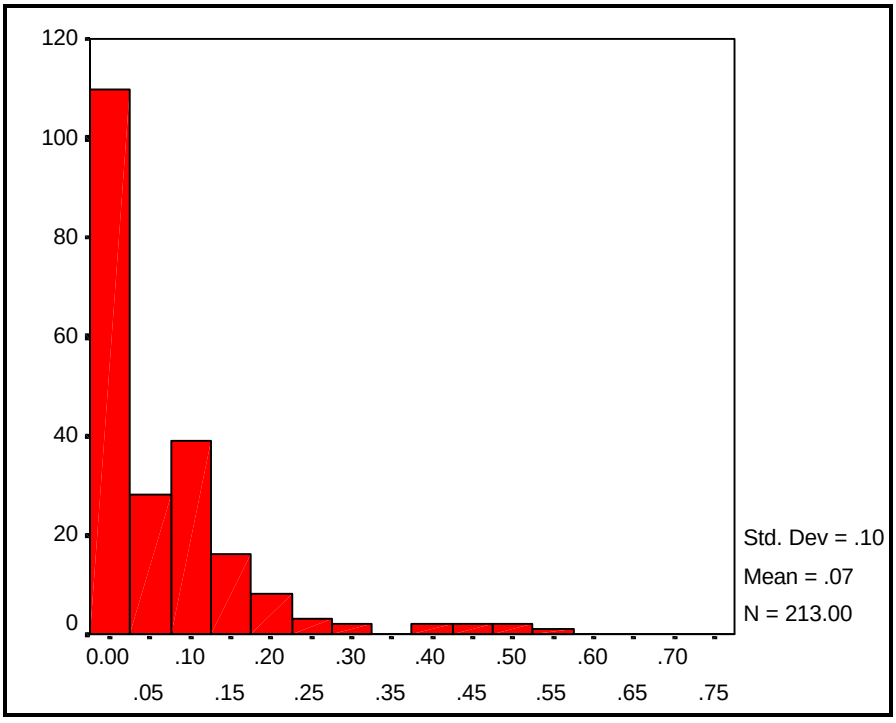
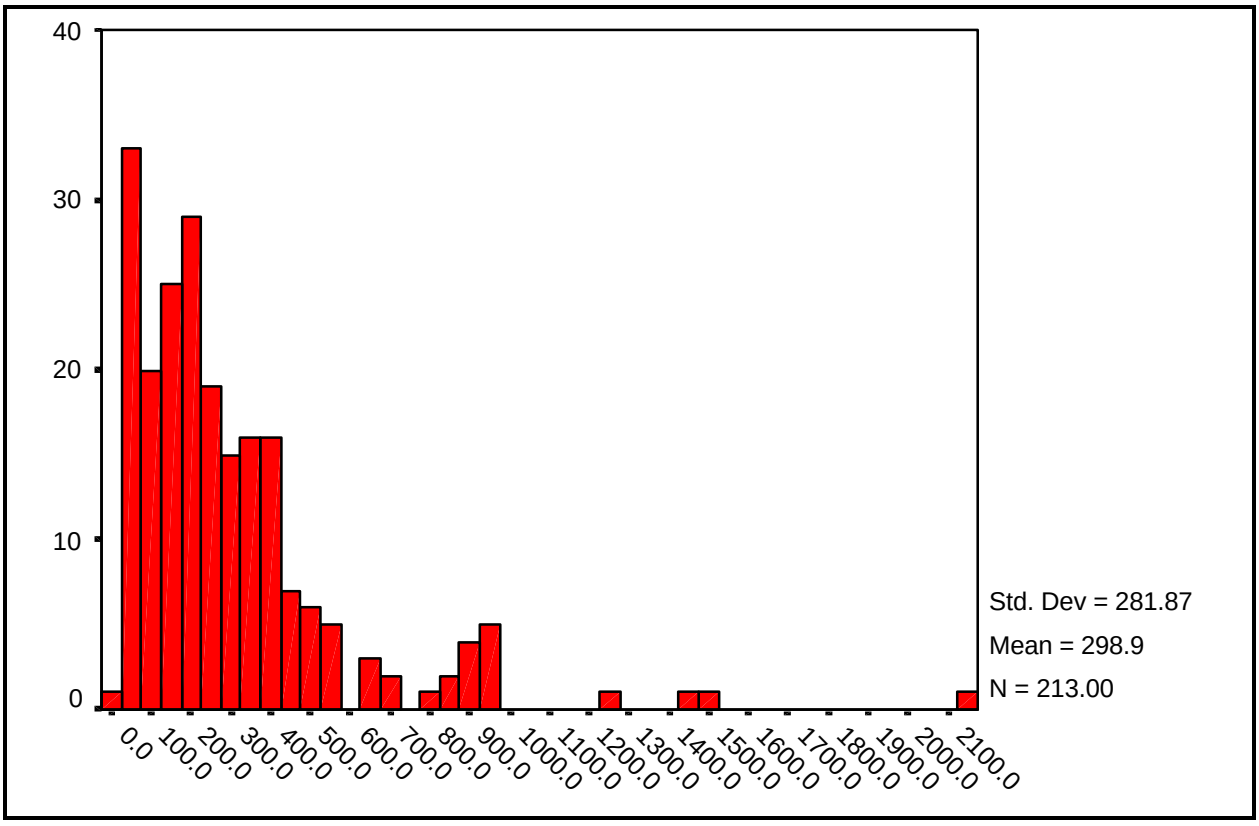


Figure 108: Hippuric Acid in Urine



Relationships between exposure and biomarkers of exposure were examined by combining the personal exposure measurements for each of the four days together for each of benzene (Figure 109) and toluene (Figure 110). Principal Component analysis showed mild relationships in the expected directions, that is, greater measured exposure to benzene and toluene was associated with higher levels of muconic acid and hippuric acid in the urine. However, because exposure levels were all so low, the relationship was not strong enough to be statistically significant.

Figure 109: Combined Personal Exposure to Benzene

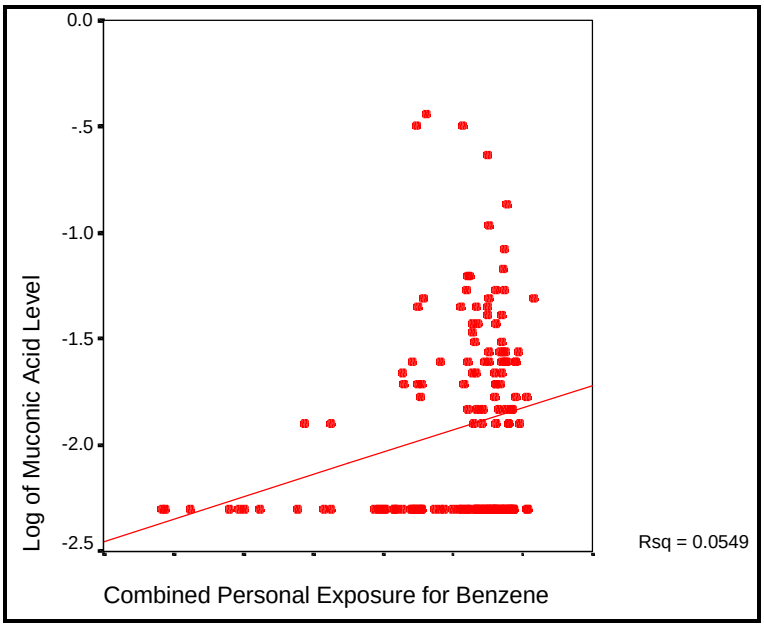
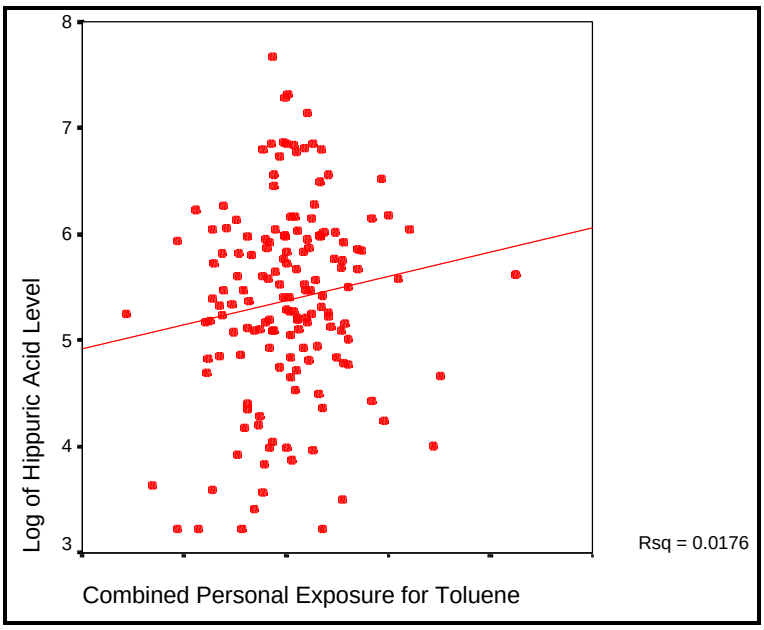


Figure 110: Combined Personal Exposure for Toluene



10.0 Biomarkers of Effect

The biomarkers of effect included in the Alberta Oil Sands Community Exposure and Health Effects Assessment Program consisted of a measure of immune system reaction (autoantibody titers), a neurocognitive assessment, and a respiratory health assessment, including respiratory health survey and spirometry measures.

10.1 Autoantibodies

As mentioned previously, a comparison of the prevalence of antinuclear autoantibodies (ANA) in the two populations and with a healthy population can indicate whether there is evidence of elevated immune system reaction in the sample population.

Immunofluorescence microscopy, utilizing tissue culture cells as the antigen substrate, is the standard method for detecting autoantibodies. Test sera are incubated on the wells containing the cells. After washing away excess serum, the antibody binding to intracellular antigens is detected by a fluorescent-labeled antibody to human immunoglobulin (IgG).

A total of 244 samples were analyzed: 214 from Fort McMurray and 30 from Lethbridge. The percentage of samples that were positive for autoantibodies was 16.4% (n = 244) for the total group, 16.4% (n = 214) for the Fort McMurray samples, and 16.7% (n = 30) of the Lethbridge samples. These values do not differ significantly, and are comparable to the findings of Tan et al., 1997, who found that 13% of healthy individuals have antinuclear antibodies.[97] In this study, positivity was defined as 1+ staining intensity at a dilution of 1:80 or greater; the same definition used in the Advanced Diagnostics Lab for the testing of clinical samples.

The groups were further compared based on the titer of the strongest staining pattern. Table 96 shows that of the Fort McMurray samples, 18/35 had titers of at least 1:320, versus the Lethbridge group in which none of the positives had a titer greater than 1:160. This may be simply a result of the small number of samples from Lethbridge, however it has been shown that higher titers of ANA are more likely to occur in disease states.

Table 96: Distribution of Titer in Positive Samples

Titer	Fort McMurray, n (%)	Lethbridge, n (%)
1:80	8 (23)	2 (40)
1:160	9 (26)	3 (60)
1:320	6 (17)	0 (0)
1:640	8 (23)	0 (0)
1:1280	3 (9)	0 (0)
1:2560	0 (0)	0 (0)
1:5120	1(3)	0 (0)
Total	35 (100)	5 (100)

There were also some differences in the specificity of the ANA patterns between the two groups. The Fort McMurray group had more samples with antibodies to the nucleolus, and more samples with the ‘homogenous/speckled’ pattern that usually denotes antibodies to DNA or histones. Again, the size of the control group was much smaller and conclusions about the significance of these differences are hard to make.

10.2 Immunoglobulin gamma E

The study included several measures to account for health effects such as allergies unassociated with exposure to airborne chemicals. One of the best markers of genetically inherited allergies (atopy) is the excessive production of Immunoglobulin gamma E (IgE). High levels of IgE are associated with an increased incidence of diseases including bronchial asthma, allergic rhinitis, and eczema. A comparison of the total serum IgE level in the two sample populations with reference populations from previous studies can indicate whether there is evidence of increased allergic response in the sample population.

Serum IgEs are log normally distributed both in the general population and in populations of atopic individuals. However, a normal upper limit for IgE is difficult to define. For this reason, the results obtained were compared with two previous studies: 1) a population survey predominantly involving persons from Western Canada[98] and; 2) a study from Virginia, USA[99] that involved an asthmatic population and a population consisting of subjects routinely admitted to hospital. This latter group presumably more closely represents the general population.

A total of 242 samples were analyzed for total IgE serum levels, 214 from Fort McMurray and 28 from Lethbridge. The mean serum IgE of 98.03 kU/L for the Fort McMurray group was not significantly different from the mean serum IgE from the Lethbridge group of 100.31 kU/L. It is apparent from Table 97 that the distribution of IgE level in the Fort McMurray and Lethbridge populations is similar to the Virginia control group. The values of IgE are less than those reported by Salkie and Weimer[100] for serum samples from a similar region of Western Canada (Table 98); however, their group was selected on the basis that serum had been sent for IgE analysis and presumably come from patients with a history of atopy.

Table 97: Serum IgE by Point of Origin Using Charlottesville, Virginia Study[101]*

IgE (kU/L)	Fort McMurray (%)	Lethbridge (%)	Charlottesville, Virginia	
			Control (%)	Asthma (%)
> 400	1.4	7.1	3	27
100-399	19.2	14.3	23	16
20-99	43.9	60.7	27	37
< 20	35.5	17.9	47	20

* Age range 31-50 years

Table 98: Serum IgE by Point of Origin Using Western Canada Study[102]*

IgE (kU/L)	Fort McMurray (%)	Lethbridge (%)	Western Canada (%)
> 500	1.4	3.6	10.81
120-500	16.8	17.9	22.16
< 120	81.8	78.6	67.02

* The serum analyzed was from samples sent for analysis of IgE to the University of Alberta Hospital, Edmonton, prior to 1984.

The Phadiatop test, a screening test for IgE to specific common inhalant allergens, was also completed. A positive result means that one or more antibodies were present to the following allergens: Timothy grass, dandelion, silver birch, cat dander, dog epithelium, horse dander, rye, alternaria tenuis, house dust and

dermatophagoides pteronyssinus. A high proportion of subjects in Fort McMurray (43%) and Lethbridge (53.6%) had a positive screen for one or more inhalant allergens, which would indicate a high level of atopy, or genetically inherited allergies, in these two Alberta populations.

10.3 Lung Function

Spirometry measures were collected for the five consecutive days during which the exposure measurement was conducted. Each evening that the field monitoring team members visited the participants, the spirometry testing took place. The field teams attempted to obtain five completed spirometric sessions and during the initial interview at the study office, the field coordinator administered the respiratory health survey. Table 99 provides a summary of the data obtained for participants in Fort McMurray and Lethbridge who completed both the lung function component and questionnaire component of the respiratory health assessment. As expressed by the table, 104 of 148 (70.3%) Fort McMurray participants completed at least three of the spirometric sessions, comparatively higher than Lethbridge's 15 of 34 (44.1%), due to equipment malfunctions during the data collection process.

Table 99: Summary of Completeness of Data

Study Components Completed	Proportion of Participants, n (%)
Questionnaire and 5 complete spirometric test sessions	Fort McMurray: 45 (30) Lethbridge: 7 (21)%
Questionnaire and 4 complete spirometric test sessions	Fort McMurray: 30 (20) Lethbridge: 3 (8.8)
Questionnaire and 3 complete spirometric test sessions	Fort McMurray: 29 (20) Lethbridge: 5 (15)
Questionnaire and 2 complete spirometric test sessions	Fort McMurray: 13 (8.8) Lethbridge: 5 (15)
Questionnaire and 1 complete spirometric test session	Fort McMurray: 9 (6) Lethbridge: 1 (3)
Questionnaire only	Fort McMurray: 22 (15) Lethbridge: 13 (38)

10.3.1 Spirometry Test Results

When spirometry is performed, the results are compared with a set of normal or predicted values based upon a participant's age, height, and gender.[103] Reference values are calculated using prediction equations derived from previous epidemiologic studies involving healthy, non-smoking adult populations without a history of disease that could compromise their ventilatory function. Reference values come from studies that are conducted using both equipment and methods compatible with present standards.[104]

Two diagnostically important spirometric test measurements are forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1). Specifically, FVC refers to the maximal amount of air that can be forcefully exhaled after a full inhalation. FEV_1 is the volume of air exhaled during the first second of the FVC maneuver. The normal range for both FVC and FEV_1 is 80-120% of predicted values.

For participants involved in the spirometry component of the Adult Lung Health Study, the average baseline FVC and FEV_1 values were determined by applying the prediction equations of Crapo et al. (1982).[105] Table 100 provides a summary of the findings.

Table 100: Summary of Spirometry Data

Lung Function Measurement	Percent of Predicted Value (%)	Standard Deviation
FVC	111.07	14.58
FEV_1	100.51	14.26

Note: These average values reflect normal lung function.

10.3.2 Respiratory Health Survey

Participants also completed the standardized, interviewer-administered European Community Respiratory Health Survey Questionnaire.[106] This questionnaire collected information on respiratory symptoms, smoking status, and past history of respiratory conditions and related medication use.

The percent of respondents in each community who responded "Yes" or "No" to specific questions were compared. Results for the 149 Fort McMurray participants and 33 Lethbridge participants who completed the survey are summarized in Table 101.

Table 101: Differences in the Prevalence of Reported Respiratory Symptoms between Fort McMurray and Lethbridge

Respiratory Symptom	Fort McMurray n (%)	Lethbridge n (%)
Wheeze within the last 12 months	43 (28.9)	16 (48.5)
Wheeze in the absence of a cold	27 (18.2)	10 (30.3)
Waking with chest tightness in the last 12 months	27 (18.1)	8 (24.2)
Shortness of breath		
while at rest	21 (14.1)	6 (18.2)
while hurrying on level ground or walking up a slight hill	21 (14.1)	3 (11.5)
Woken by shortness of breath	10 (6.7)	5 (15.2)
Cough in the morning during winter	19 (12.8)	2 (6.3)
Phlegm in the morning during winter	25 (16.8)	6 (18.2)
Ever seen by a doctor for a breathing problem	41 (27.5)	13 (39.4)
Ever diagnosed by a physician as having asthma Physician	20 (13.4)	10 (30.3)
Nasal allergies (e.g. hay fever)	59 (39.6)	15 (45.5)
Eczema/skin allergies	48 (32.2)	11 (33.3)
Parental asthma/allergy history		
Mother:		
Asthma	12 (8.3)	0 (0.0)
Skin allergies	30 (21.1)	8 (24.2)
Father:		
Asthma	7 (4.9)	0 (0.0)
Skin allergies	29 (20.9)	3 (9.4)
Serious respiratory infection before the age of 5	19 (13.3)	7 (21.2)
Hospitalized over night for breathing problem	9 (6.0)	2 (6.1)
Total Number of Participants	149	33

Apart from "wheeze within the last 12 months" and "diagnosis of asthma by a physician", the prevalence of each respiratory symptom reported in the two study populations was similar. It is important to note that "wheeze in the absence of a cold" is more suggestive of respiratory problems (e.g., asthma) than is "wheeze within the last 12 months". With respect to the prevalence of asthma, respondents in Lethbridge were approximately twice as likely to indicate wheezing in the last twelve months and almost three times as likely to report having received a physician's diagnosis of asthma.

10.4 Neurocognitive Functioning

Neuropsychological assessment explores another method of investigating toxic exposure. Within the discipline of occupational neuro-epidemiology, tests such as the NES2, NIS, and Verbal Digit Span provide a non-invasive means of evaluating associations between exposure and effects on measures of neurocognitive functioning. Comparisons were made between control groups of previous studies that have employed versions of the NES to that of the current study.

10.4.1 Neurobehavioral Evaluation System (NES2)

In order to determine whether the scores obtained from the sample population were any different than other unexposed populations, the sample population was compared to control populations obtained for a variety of other studies. Demographic data along with the description of the measures and control groups for each study is shown in Table 102. Fort McMurray and Lethbridge both had a higher average level of education than the reference populations of the other studies, with the exception of the studies by White (1996) and Broadwell (1995).

Table 102: Comparison between Study Sample and Other Study Populations

Study / Author	Study Objectives	Source of Controls	N	Age Mean (SD)	Gender (% Male)	N	Education Mean (SD)
Fort McMurray	Fort McMurray community exposure to oil sands industry	Community of Lethbridge	300	39.96 (10.05)	135 (45%)	274	14.53 (2.19)
Lethbridge			33	43.67 (14.14)	15 (45%)	29	14.90 (2.18)
Kilburn et al., 1998[107]	Population-based prediction equations for neurobehavioral tests	Randomly, from different areas of the United States	264	44.2 (19.7)	121 (46%)	264	12.8 (2.2)
Colvin et al., 1993[108]	Neurobehavioral effects of chronic solvent exposure on workers in a paint manufacturing plant	Unexposed internal group	24	43.52 (10.04)	24 (100%)	24	6.43 (3.87)
Tsai et al., 1997[109]	Neurobehavioral effects of exposure to low-level organic solvents among Taiwanese workers in paint factories	Unexposed internal group	47	37.9 (14.8)	38 (81%)	47	10.46 (2.54)
Laire et al., 1997[110]	Assessment of nocturnal oxygen desaturation in long-term solvent-exposed workers	Army personnel	21	38.1 (11)	20 (95%)	21	11 (2)

(cont'd)

Study / Author	Study Objectives	Source of Controls	N	Age Mean (SD)	Gender (% Male)	N	Education Mean (SD)
Tsai et al., 1996[111]	Neurobehavioral effects of occupational exposure to low-level styrene	Unexposed internal group	45	35.9 (9.6)	31 (69%)	45	10.6 (2.2)
White et al., 1996[112]	Validation of NES2 in patients with neurologic disorders	Spouses, friends and family of patients	67	56.5 (12.2)	28 (42.4%)	67	14.5 (2.5)
Muijser et al., 1996[113]	Behavioral effects of exposure to organic solvents in carpet layers	Cement floor layers	71	37.6 (9.6)	71 (100%)		
Broadwell et al., 1995[114]	Clinical and neurobehavioral assessment of solvent-exposed microelectronic workers	Unexposed internal group	32	47.6 (9.0)	15 (47%)	32	13.9 (2.2)
Altmann et al., 1995[115]	Outcome of chronic low-level tetrachloroethene exposure of dry cleaning shops	Unexposed personnel of Public Health Office and Medical Institute	23	37.2 (10.1)	9 (39%)		
Hooisma et al., 1993[116]	Behavioral effects of exposure to organic solvents in Dutch painters	Carpenters and brick-layers	53	36.9 (3.2)	53 (100%)	53	9.4 (1.6)

The following graphs compare the performance of the Fort McMurray and Lethbridge cohort to the other controls. Overall, there were no significant differences observed between the current study's participants and the other controls. However, the Fort McMurray group did perform better in the dominant hand subtest of Finger Tapping.

Figure 111: NES2 Finger Tapping Test

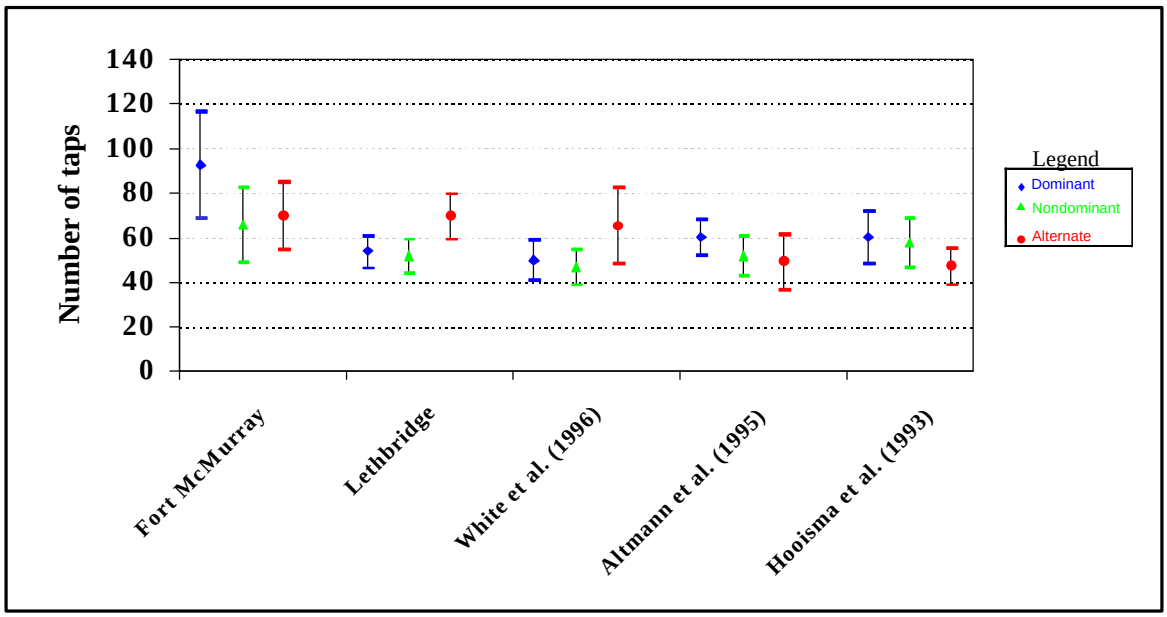


Figure 112: NES2 Associate Learning Test

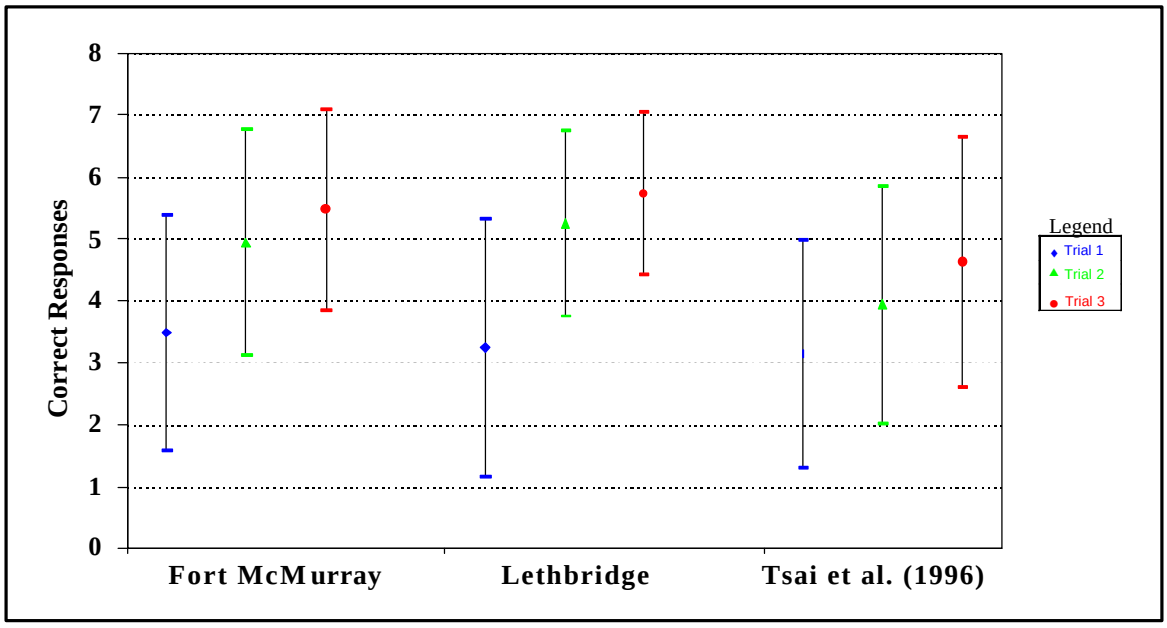


Figure 113: NES2 Switching Attention Test

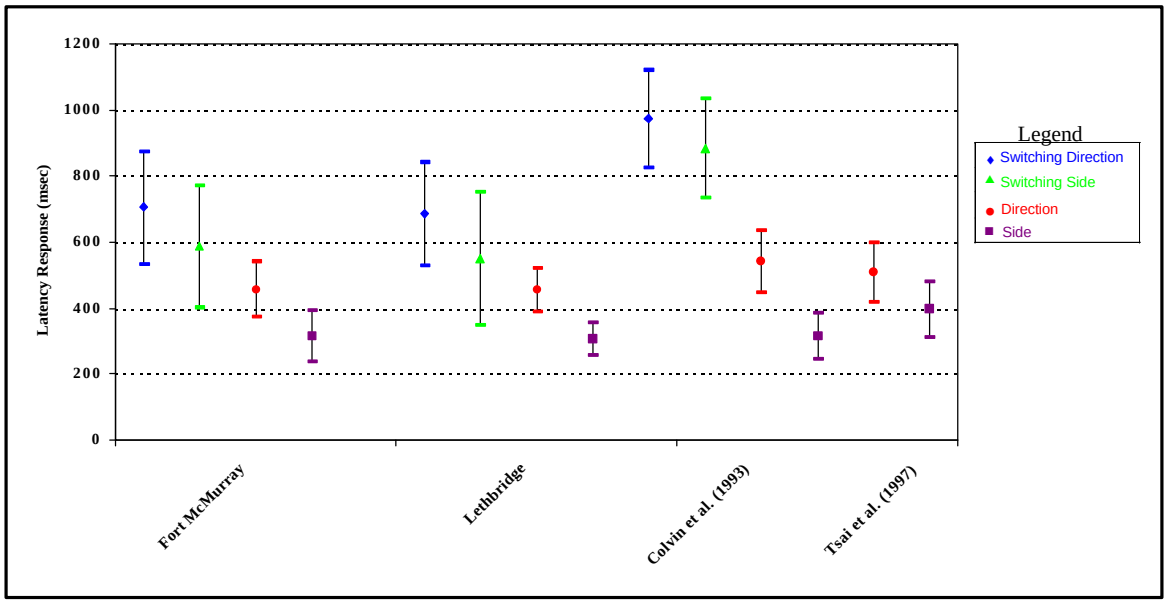


Figure 114: NES2 Mood Scales

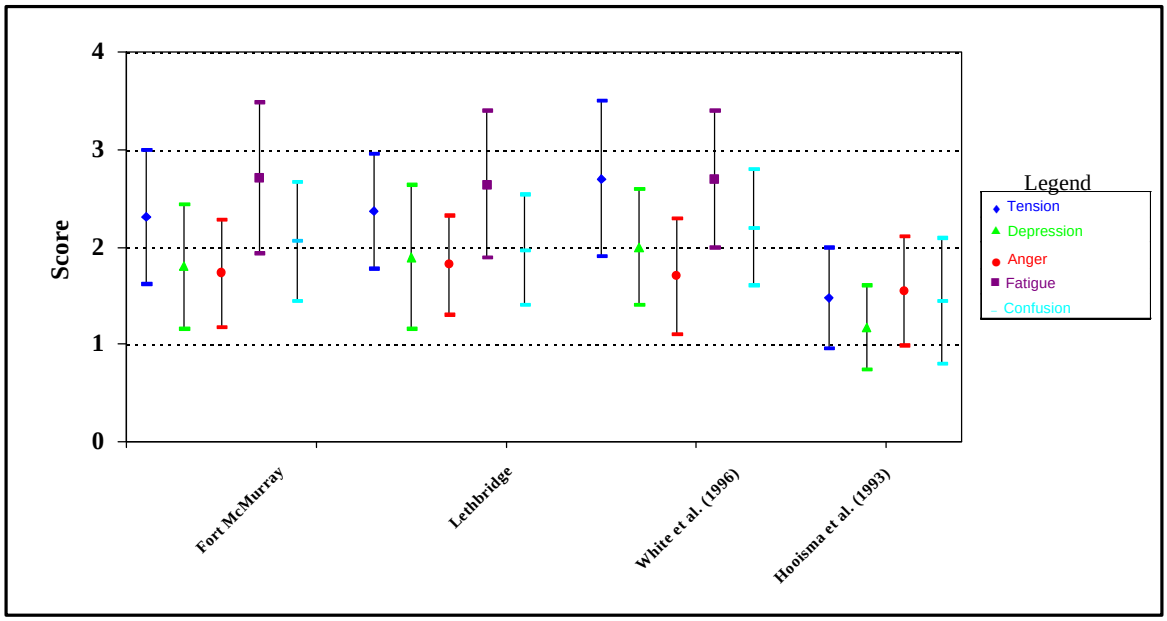


Figure 115: NES2 Continuous Performance Test

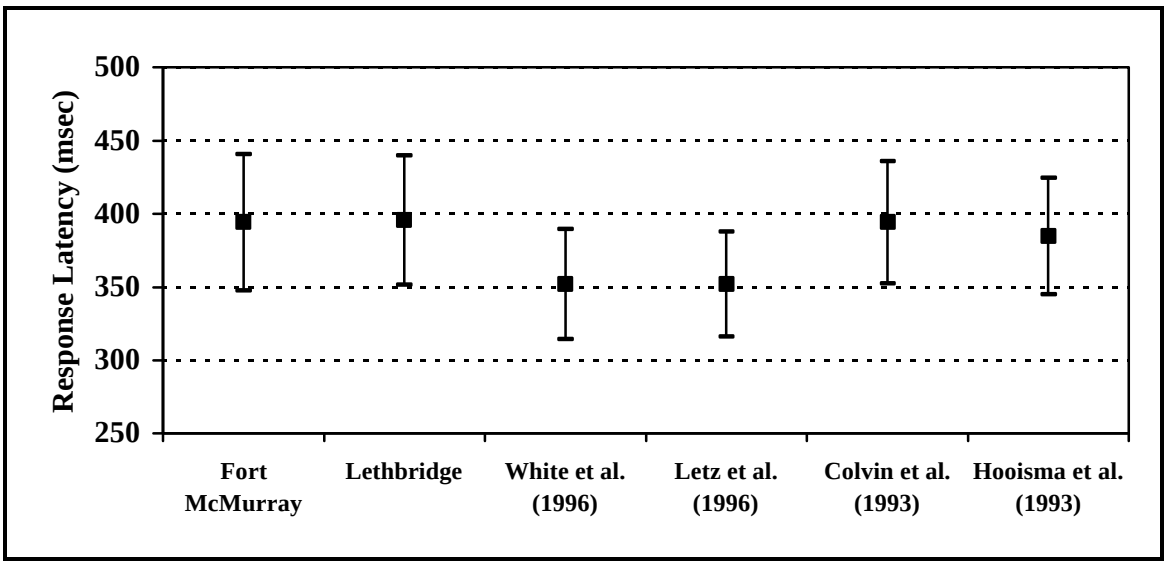


Figure 116: NES2 Hand-Eye Co-ordination Test

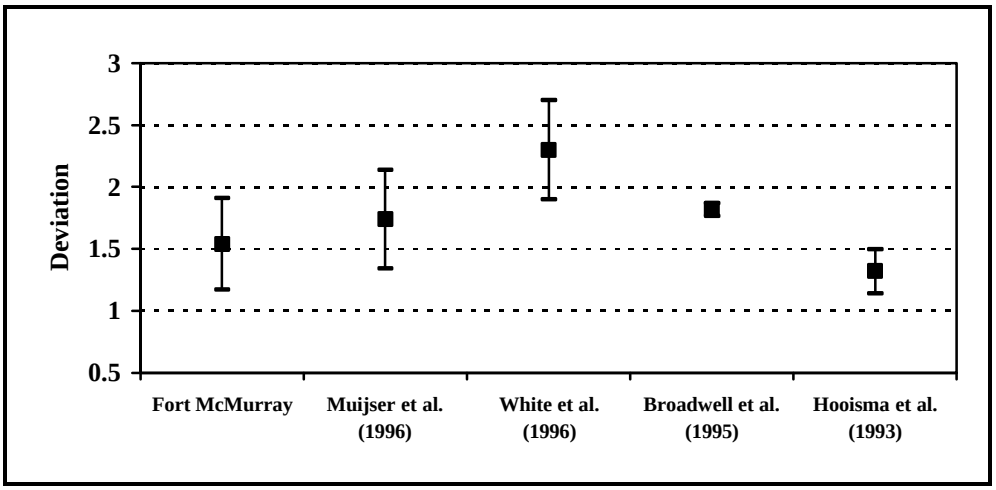


Figure 117: NES2 Simple Reaction Time Test

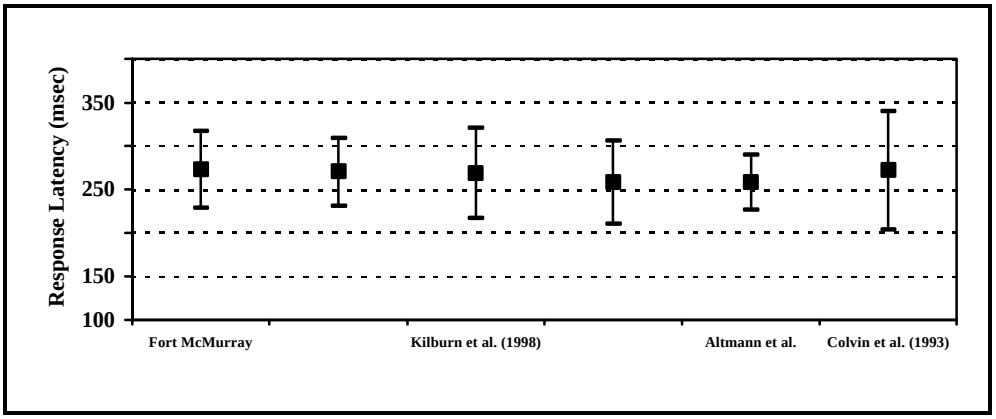


Figure 118: NES2 Symbol-Digit Test

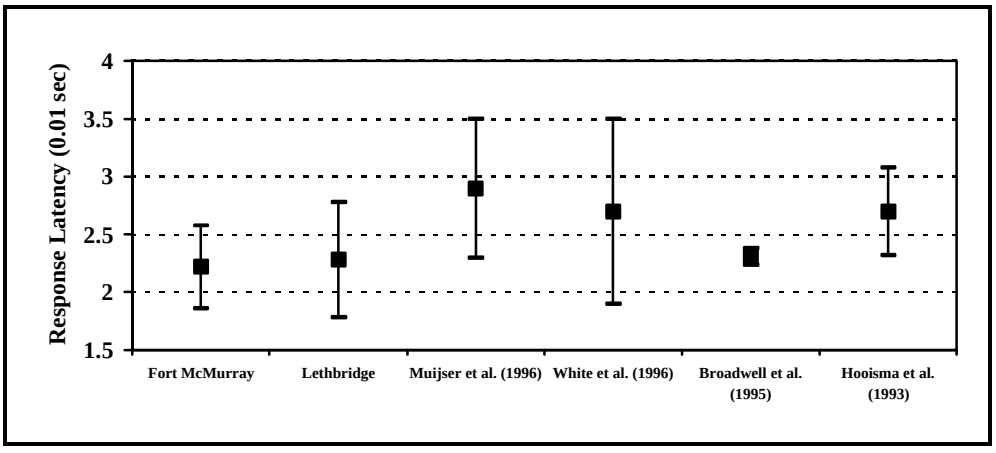


Figure 119

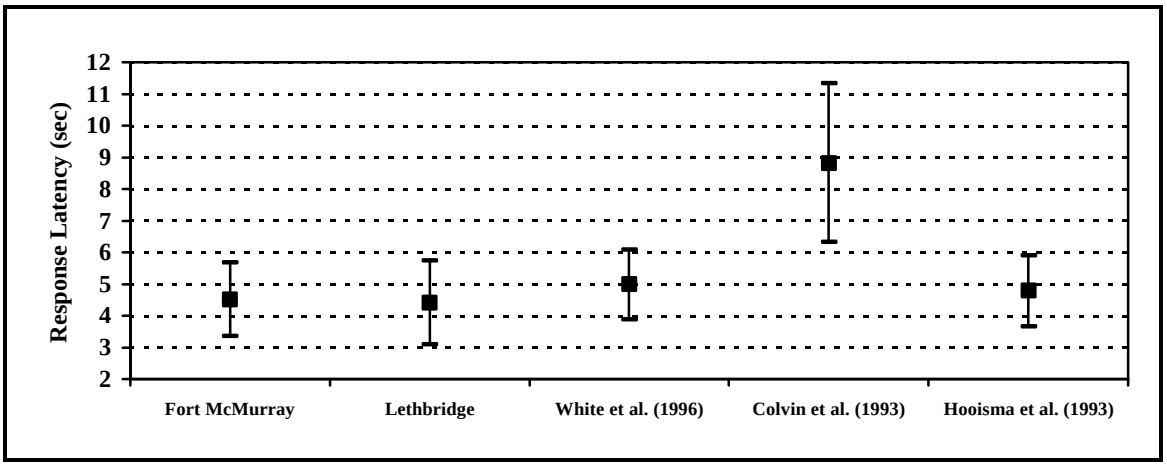


Figure 120: NES2 Pattern Memory Test

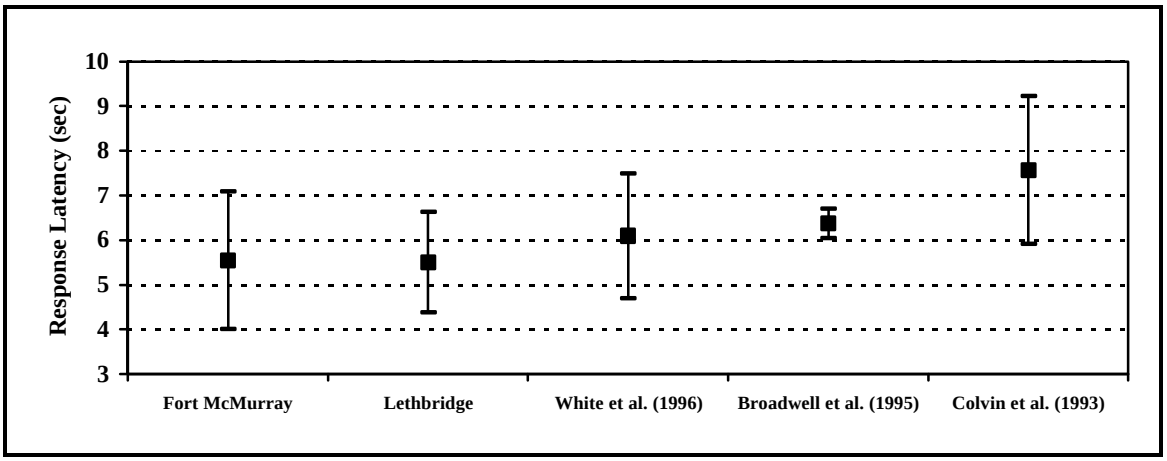


Figure 121: NES2 Serial Digit Learning Test

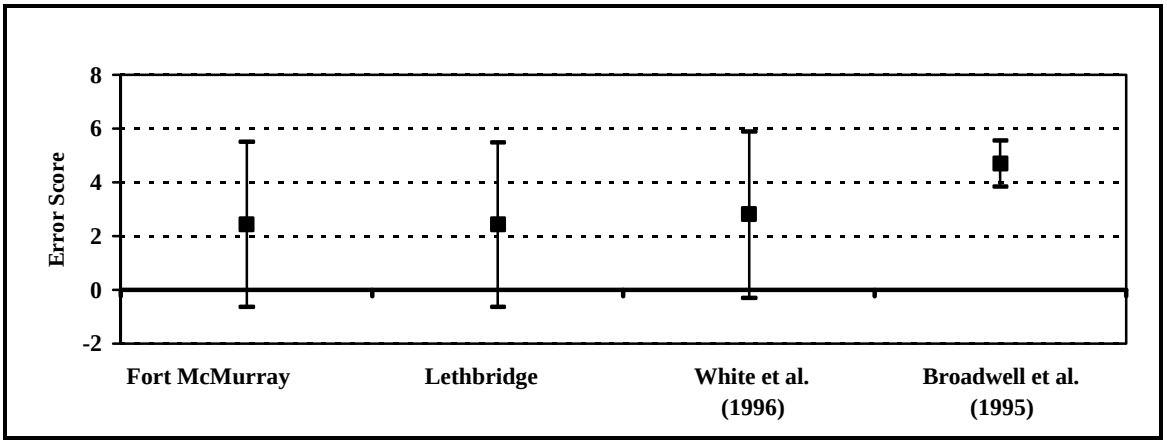


Figure 122: NES2 Color-Word Test

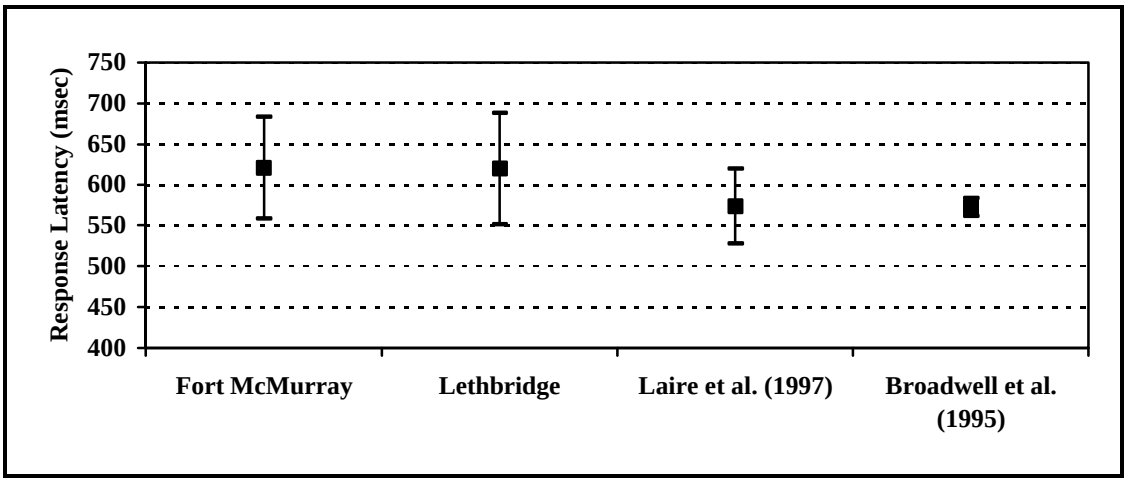


Figure 123: NES2 Vocabulary Test

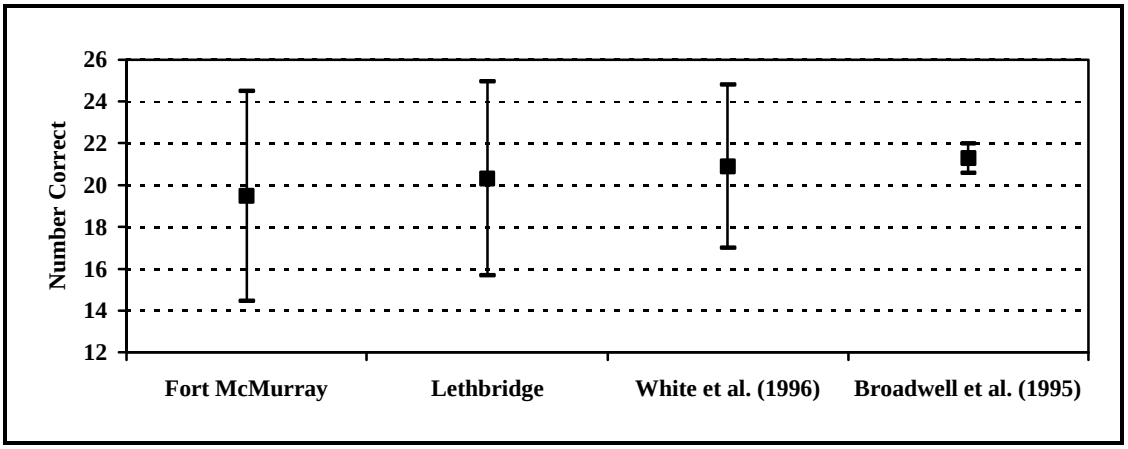
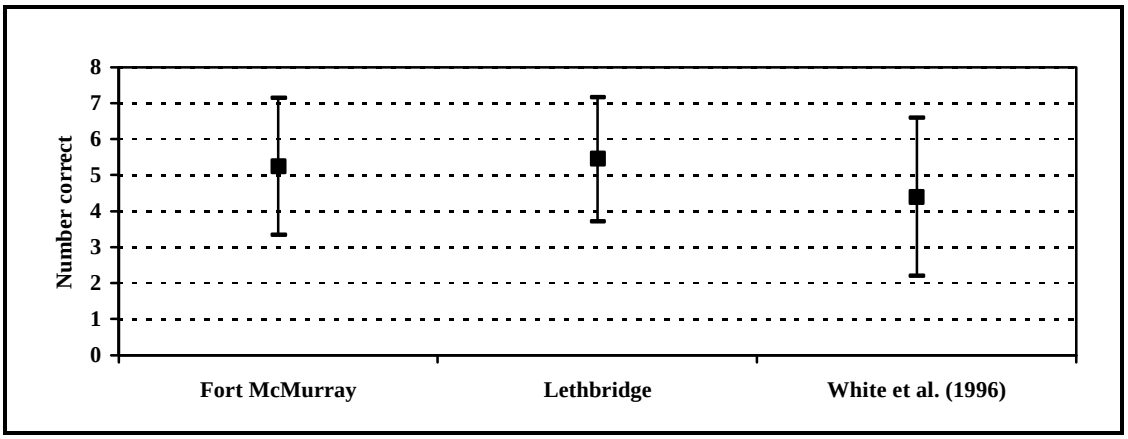


Figure 124: NES2 Delayed Associate Recognition Test



A symptoms questionnaire was also included in the NES2 program to collect information on symptoms that are often associated with exposure to neurotoxic agents. The questionnaire requires participants to indicate how often they experienced each of the symptoms in the past month. The results of this questionnaire are displayed in Table 103. The majority of the participants indicated they had not experienced most of the symptoms listed. A small percentage of Fort McMurray participants indicated frequently experienced symptoms: feeling tired (14.9%), having to make notes to remember things (10.2%), lack of sexual drive (6.8%), having difficulty falling asleep (6.1%), and dry skin (5.4%). Lethbridge participants indicated that they frequently experienced: lack of sexual drive (15.2%), feeling tired (15.2%), dry skin (9.1%), having to make notes to remember (9.1%), and indigestion (6.1%).

Table 103: Frequency of Experiencing Symptoms (NES2)

Symptoms	Fort McMurray (%, N=295)				Lethbridge (%, N=33)			
	Not at all	A little	Fair	A lot	Not at all	A little	Fair	A lot
Feeling tired	6.8	47.8	30.5	14.9	6.1	51.5	27.3	15.2
Difficulty concentrating	34.9	51.2	11.2	2.7	30.3	60.6	9.1	0.0
Difficulty remembering things	24.1	62.0	10.8	3.1	21.2	60.6	15.2	3.0
Seizures	99.3	0.7	0.0	0.0	100	0.0	0.0	0.0
Headaches	48.1	40.0	8.1	3.7	42.4	48.5	6.1	3.0
Difficulty falling asleep	48.1	35.3	10.5	6.1	45.5	48.5	3.0	3.0
Lack of sexual drive	46.4	33.6	13.2	6.8	42.4	33.3	9.1	15.2
Tingling in my fingers or toes	81.7	13.2	3.7	1.4	90.9	9.1	0.0	0.0
Loss of appetite	76.9	20.0	2.0	1.0	78.8	18.2	3.0	0.0
Diarrhea	71.5	25.1	1.7	1.7	63.6	21.2	15.2	0.0
Dry mouth	61.0	31.9	4.7	2.4	45.5	45.5	9.1	0.0
Feeling depressed for no reason	70.5	20.7	7.8	1.0	78.8	12.1	9.1	0.0
Confusion	60.0	35.9	3.7	0.3	54.5	39.4	6.1	0.0
Having to make notes to remember	25.1	45.1	19.7	10.2	21.2	39.4	30.3	9.1
Hallucinations	98.3	1.4	0.3	0.0	97.0	3.0	0.0	0.0
Heart palpitations	90.2	8.1	1.0	0.7	84.8	12.1	3.0	0.0
Lack of co-ordination	77.6	20.7	1.0	0.7	63.6	36.4	0.0	0.0
Sleeping more than usual	74.6	18.3	3.7	3.4	72.2	27.3	0.0	0.0
Perspiring for no reason	88.5	8.8	1.4	1.4	84.8	12.1	0.0	3.0
Skin Dryness	51.5	32.2	10.8	5.4	42.4	45.5	3.0	9.1
Unexplained weight loss	98.0	1.7	0.0	0.3	97.0	3.0	0.0	0.0
Indigestion	65.1	29.5	5.1	0.3	66.7	27.3	0.0	6.1
Excessive salivation	96.6	3.1	0.3	0.0	97.0	3.0	0.0	0.0
Feeling irritable	35.9	53.9	8.8	1.4	30.3	57.6	9.1	3.0
Feeling light-headed or “high”	80.0	16.6	3.4	0.0	75.8	21.2	3.0	0.0
Lack of muscle strength	66.4	26.8	5.1	1.7	57.6	39.4	3.0	0.0
Tightness in my chest	84.1	14.6	1.4	0.0	87.9	9.1	3.0	0.0
Feeling excitable	50.8	41.0	6.8	1.4	36.4	45.5	15.2	3.0
Nausea	81.0	16.3	2.0	0.7	81.8	15.2	3.0	0.0
Inflamed gums	90.5	8.1	1.0	0.3	81.8	15.2	0.0	3.0
Feeling anxious	41.4	49.8	7.1	1.7	36.4	54.5	6.1	3.0
Tremor in my fingers	89.8	7.8	1.4	1.0	90.9	6.1	3.0	0.0
Loose teeth	97.3	2.0	0.7	0.0	97.0	0.0	0.0	3.0
Trembling eyelids, lips or tongue	89.2	9.8	0.7	0.3	84.8	9.1	6.1	0.0
Difficulty buttoning clothes	95.9	3.1	0.3	0.7	93.9	6.1	0.0	0.0

The items of the symptoms questionnaire can be further combined to form seven scales, displayed in Table 104. The values reflect the average responses, based on the 4-point scale, of all the symptoms corresponding to their respective categories. These composite scales measure lassitude (weariness), neurasthenia (experience of physical symptoms such as tiredness or exhaustion with no physical justification), memory, confusion, co-ordination, neurological impairment ('neurologic'), and physical health ('physical'). The memory scale, the highest score, reflected "a little" experience with symptoms associated with a memory deficit.

Table 104: Symptom Composite Scales (NES2)

Scale	Fort McMurray Mean (SD)	Lethbridge Mean (SD)
Lassitude	1.98 (0.63)	1.98 (0.57)
Neurasthenia	1.53 (0.40)	1.55 (0.35)
Memory	2.04 (0.69)	2.14 (0.7)
Confusion	1.53 (0.49)	1.53 (0.47)
Co-ordination	1.15 (0.35)	1.21 (0.28)
Neurologic	1.20 (0.22)	1.19 (0.18)
Physical	1.28 (0.24)	1.35 (0.23)
Symptom mean intensity	1.41 (0.26)	1.45 (0.22)

10.4.2 Neuropsychological Impairment Scale (NIS)

The Neuropsychological Impairment Scale (NIS) was developed as a self-reported questionnaire consisting of 50 items which measure potential neuropsychological symptoms concerned with language usage, memory, sensory capacities, head injuries, motor capacities, frustration tolerance, and mental alertness. The NIS can be used to identify general neurocognitive deficits and as a useful research tool for evaluating neurocognitive impairments in the general population.

The NIS was developed to produce eight separate scores. A measure of test-taking attitude (LIE) is obtained from the answers to five independent items not included in any of the other scales. A raw score sum of the 45 items yields a Global Measure of Impairment (GMI) which indicates the patient's self-perceived adaptive deficiencies. The Total Items Checked (TIC) provides an additional index of symptom presence. The Symptom Intensity Measure (SIM) is a gauge of symptom severity calculated by dividing GMI by TIC. The General Scale (GEN) indicates general mental ability including mental efficiency, alertness and endurance. The Pathognomic Scale (PAT) identifies previous diagnosis of symptoms such as seizures, head injury, paralysis or other physical problems that may lead to possible neurocognitive deficits. The Learning-Verbal Scale (L-V) is a scale of verbal ability. The Frustration scale (FRU) identifies behavioral signs of anger, frustration, and resentment.

The NIS scores of Fort McMurray and Lethbridge were compared to norms used in previous studies.[117-115] The study by Errico et al. (1990) involved screening for neuropsychological impairment in alcoholics. His control group included subjects with no history of neurological disorders or alcohol abuse. O'Donnell et al. (1983) included thorough normative data from a heterogeneous population base. The results, shown in the following figures, indicate there are no significant differences between the Fort McMurray sample and Lethbridge sample as well as between control groups.

Figure 125: NIS General Measure of Impairment (GMI)

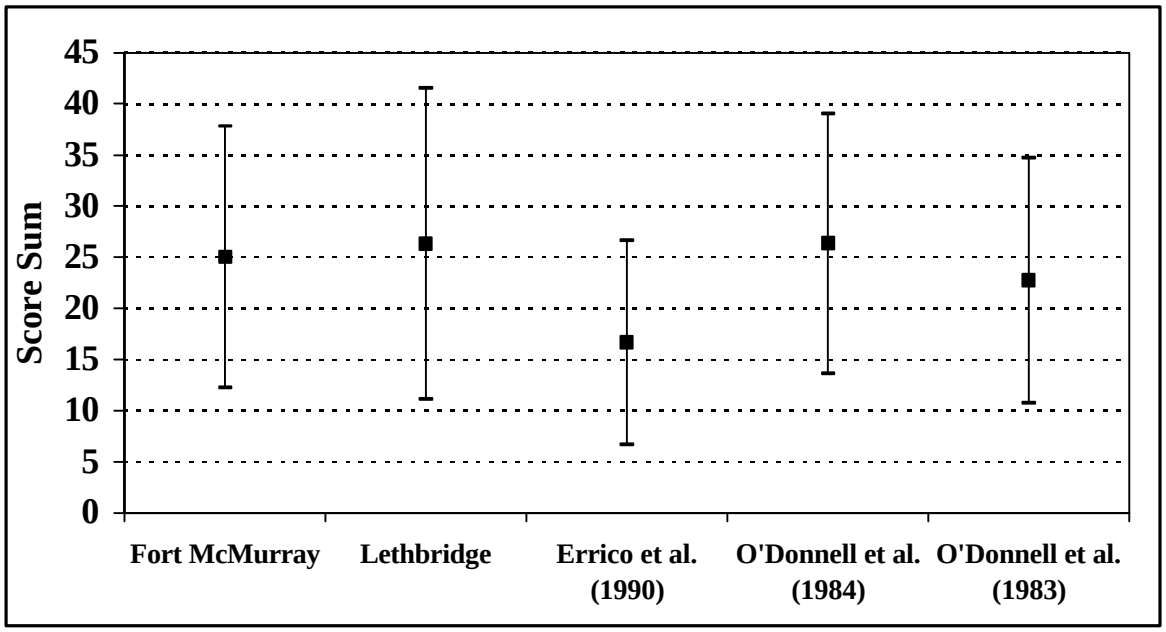


Figure 126: NIS Total Items Checked (TIC)

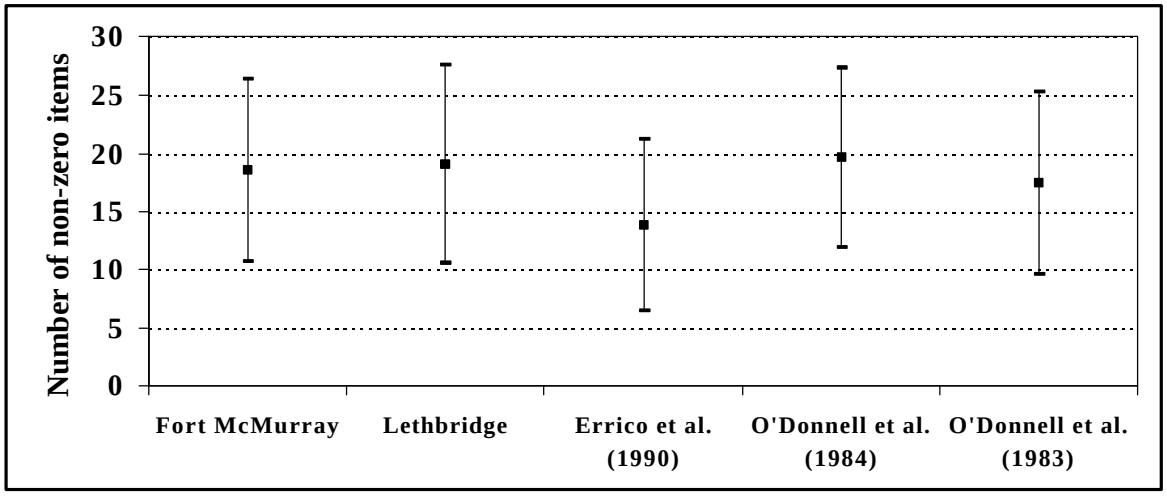


Figure 127: NIS Symptom Intensity Measure (SIM)

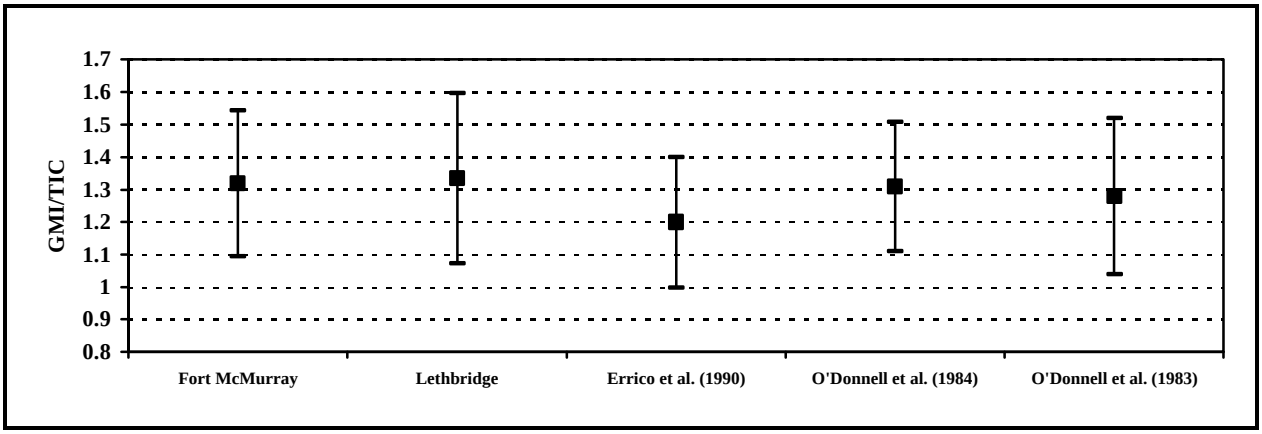


Figure 128: NIS General Scale (GEN)

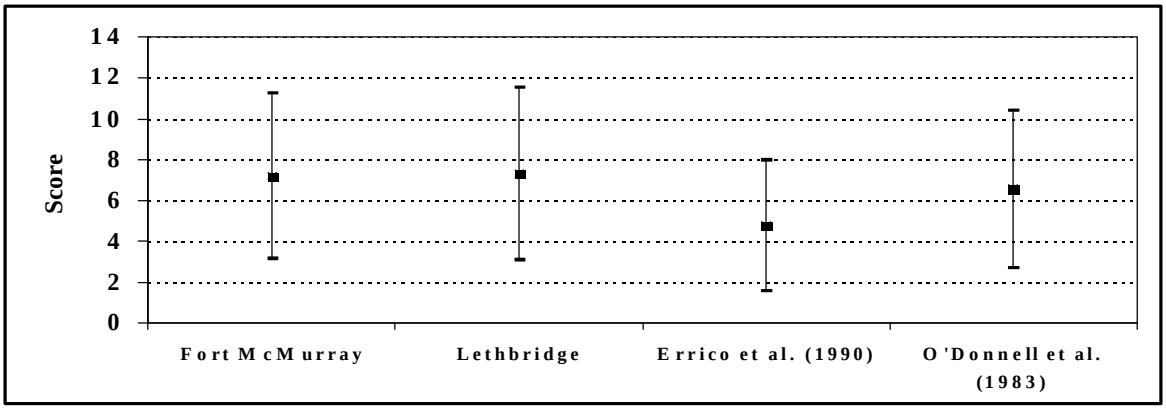


Figure 129: NIS Pathognomic Scale (PAT)

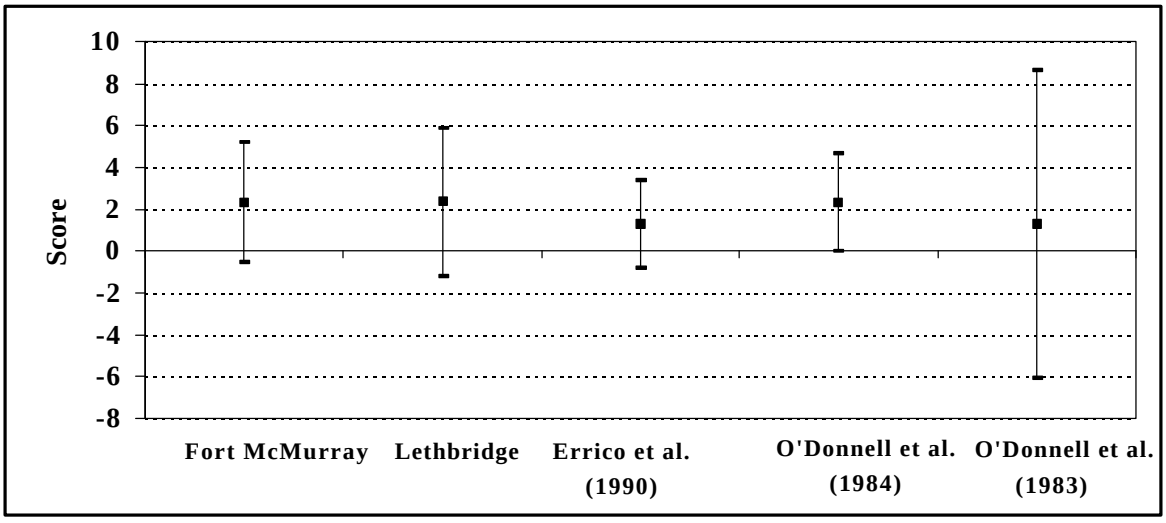


Figure 130: NIS Frustration Scale (FRU)

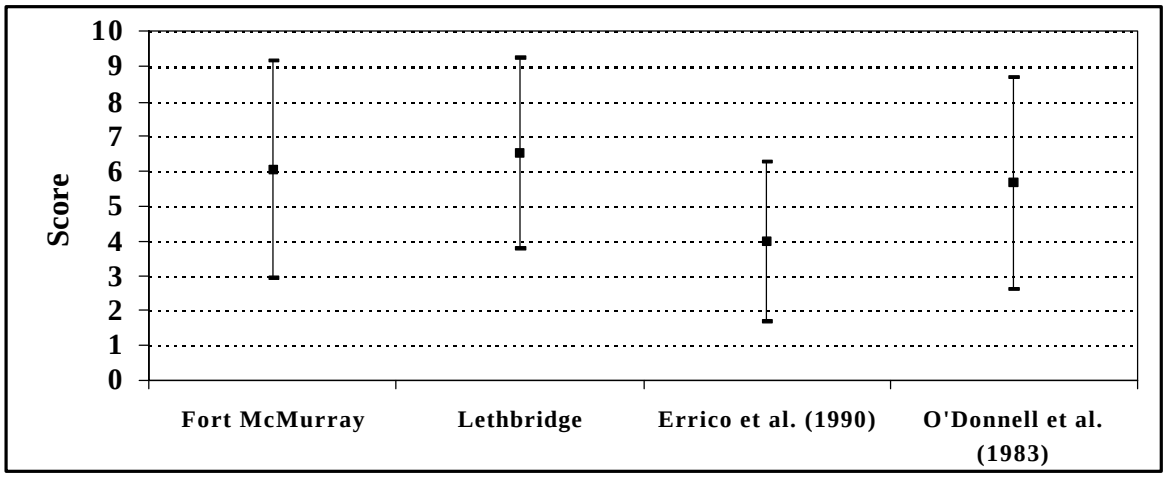


Figure 131: NIS Learning-Verbal Scale (L-V)

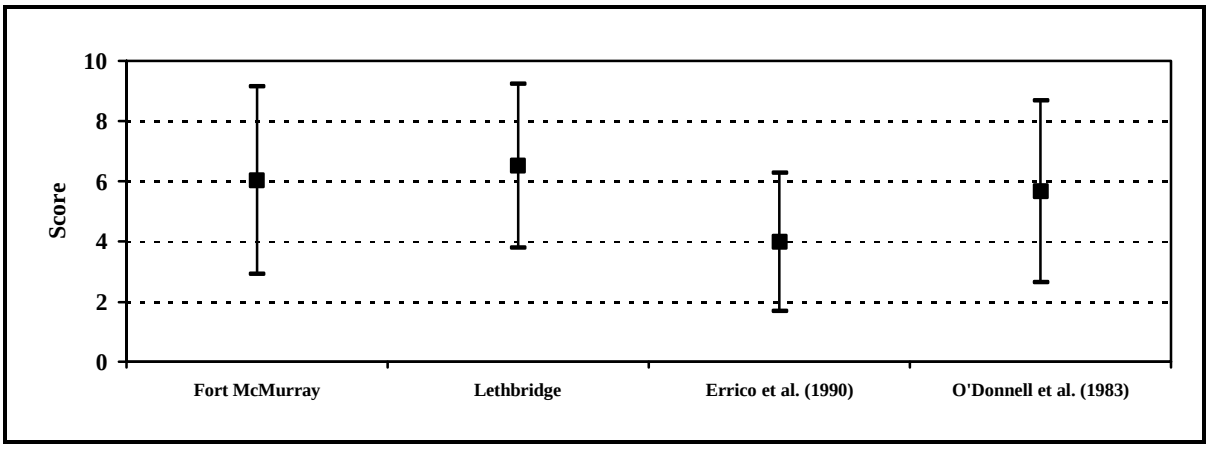
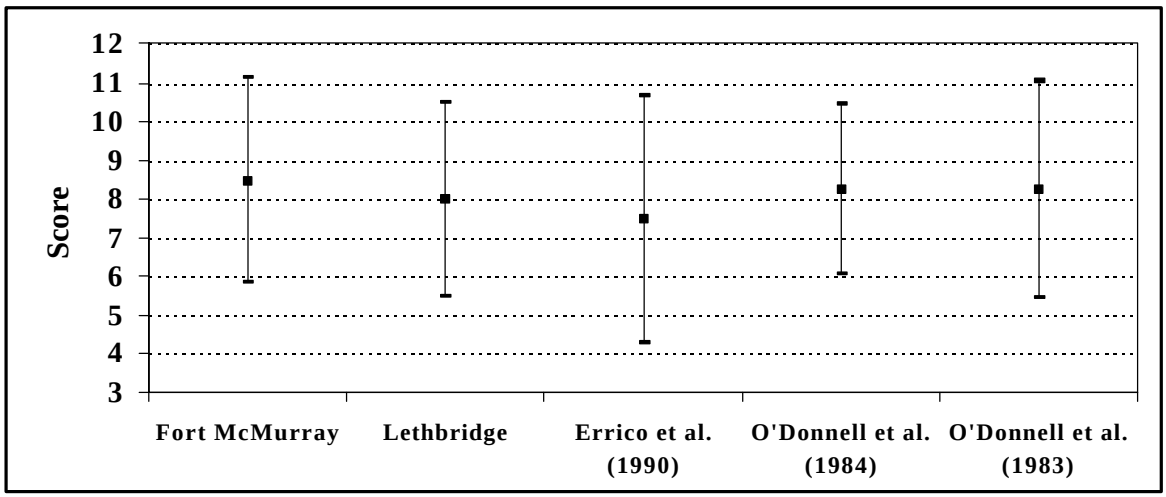


Figure 132: NIS Lie Scale (LIE)



10.4.3 Verbal Digit Span

The Verbal Digit Span from the Wechsler Memory Scale – Revised (WMS-R) was administered to each participant. There are two parts to the WMS-R version of the Digit Span (Digits Forward and Digits Backward), which are administered separately.[120]

Table 105 shows the Verbal Digit Span results for both Digits Forward and Digits Backward. As is shown, the means did not differ significantly between the Fort McMurray and Lethbridge samples. As well, the means for the two sample populations were very comparable to the results of other researchers. In a study conducted by Amitai (1988), control group participants were young (average age = 22.2 years), healthy university students.[121] Fastenau (1996) used a comparable group of healthy adults with a mean age of 43.5 years.[122]

Table 105: Verbal Digit Span Results

	Fort McMurray (N = 300)	Lethbridge (N = 34)	Amitai, et al. (1998) (N = 47)	Fastenau, et al. (1996) (N = 47)
Digits Forward	8.38 (1.99)	9.03 (1.66)	8.98 (1.80)	7.5 (2.1)
Digits Backward	6.63 (2.21)	6.91 (1.94)	7.83 (2.00)	N/A

11.0 Measures of Health

A variety of additional measures of health were obtained to supplement the lung function spirometry and neurocognitive assessment measures. This self-reported data is discussed below.

11.1 Occupational Health Questionnaire

A standard occupational health questionnaire, adapted by the Ontario Ministry of the Environment for the Windsor Winter '92 Personal Exposure Pilot (PEP) Study, was used to measure symptoms typically associated with the work environment.[123] The questionnaire uses a standard list of symptoms typically associated with indoor air quality, and requires the respondent to specify the location where the symptom is felt. Respondents were allowed to specify as multiple locations.

Table 106 shows the percentage of respondents from the Fort McMurray sample who reported experiencing the specified symptoms in the past year by location. There was no significant difference in reporting of symptoms or location between Fort McMurray residents and Lethbridge residents. The symptoms reported most frequently overall include headaches, cold and flu, dry skin, physical fatigue, back pain, eye irritation, and mental fatigue. Participants reported experiencing cold and flu, dry skin, headaches and physical fatigue as occurring most frequently at home, and strained eyes, mental fatigue, eye irritation, and difficulty concentration as occurring most frequently at work.

Table 106: Percentage Experiencing Symptom by Location

Symptom	None	Home	Work	Commuting	Combination
Eye irritation	47.4	10.1	11.9	1.5	29.1
Nose irritation	54.1	8.2	8.2	1.9	27.6
Throat irritation	57.1	8.6	6.7	1.5	26.1
Dry mucous membranes	66.4	10.1	3.4	0.0	20.1
Dry skin	39.9	16.0	4.1	0.0	39.9
Erythema	98.1	0.4	0.0	0.0	1.5
Mental fatigue	48.5	3.0	17.9	0.0	30.6
Physical fatigue	44.8	13.1	7.8	2.2	32.1
Headaches	34.7	13.8	9.0	1.1	41.4
Unspecified airway infections	93.3	1.1	1.1	0.0	4.5
Scratchy throats or coughs	53.0	9.3	5.2	1.1	31.3
Colds and flu	35.1	16.4	2.2	0.4	45.9
Nausea	79.1	7.5	1.1	0.7	11.6
Dizziness	81.3	6.3	1.9	0.4	10.1
Dry, itching or tearing eyes	59.0	9.0	5.2	0.7	26.1
Strained eyes or focusing difficulties	57.5	4.5	18.3	0.7	19.0
Chest tightness	80.6	6.3	1.9	0.7	10.4
Unspecified hyper-sensitivity	94.4	2.2	0.4	0.0	3.0
Feeling heavy-headed	86.2	3.7	3.0	0.7	6.3
Difficulty concentrating	63.8	4.5	10.4	0.4	20.9
Dry facial skin	64.6	11.2	2.6	0.0	21.6
Aching joints	59.3	8.2	2.6	0.0	29.9
Muscle twitching	75.7	8.2	1.1	0.0	14.9
Back pain	47.0	12.3	4.5	0.4	35.8

11.2 General Health Questionnaire (GHQ)

The General Health Questionnaire (GHQ) is a self-administered screening questionnaire designed to detect current, diagnosable psychiatric disorders.[124] The tool does not identify severe illness, but can identify individuals who feel they are unable to carry out their normal daily functions, focusing on changes in normal functioning rather than lifelong traits. Respondents who report 5 or more complaints are considered to have a psychosomatic disorder.[125]

There was no statistically significant difference in reporting between the Fort McMurray respondents and the Lethbridge respondents. The mean sum of reported symptoms was 4.0 for Fort McMurray respondents and 3.6 for Lethbridge respondents. Approximately 80% of the respondents in each location scored lower than 6 (see Table 107); 13% scored between 6 and 12; 6% of the Fort McMurray sample and 7% of the Lethbridge sample scored between 13 and 20; and 3% of the Fort McMurray sample scored over 20. Female respondents were somewhat more likely to report experiencing complaints or difficulties than the male respondents were.

Table 107: GHQ Score - Percentage of Respondents by Gender

Location	Score	Percentage		
		Males	Females	Total
Fort McMurray	0 - 6	82.9	75.3	78.8
	6 - 12	11.4	14.4	13.0
	13 - 20	4.1	6.8	5.6
	20 +	1.6	3.4	2.6
Lethbridge	0 - 6	92.9	68.8	80.0
	6 - 12	7.1	18.8	13.3
	13 - 20	0.0	12.5	6.7
	20 +	N/A	N/A	N/A

11.3 Medical Outcomes Study Short Form (SF-36)

The Medical Outcomes Study, conducted by the Rand Corporation in the 1970's, developed a standard questionnaire intended to provide a general indicator of health status for use in population health surveys referred to as the 36 item Short Form (SF-36). The SF-36 includes a variety of questions designed to assess limitations in usual role activities due to physical or emotional problems, limitations in physical activities, limitations in social activities, general mental health, vitality, bodily pain, and general health perceptions. The questionnaire has been used extensively and has been proven reliable and valid.

Table 108 compares the mean scale score for Fort McMurray respondents with the mean scale score for the Lethbridge respondents and with values from a reference population.[126] Differences in most cases are likely due to small sub-sample sizes. Differences between the two sample populations and the reference population were also not significant.

Table 108: Comparison between Participants and Reference Values, MOS SF-36 Limitations

	Age Category						
	18-24	**25-34**	**35-44**	**45-54**	**55-64**	**65+**	**Total**
Role Limitations, Emotional Health: Males							
Fort McMurray	80.0 (28.1)	80.7 (33.9)	87.3 (29.3)	92.8 (22.4)	95.2 (12.6)	0.0 (0.0)	87.8 (27.4)
Lethbridge	100.0 (0.0)	88.9 (19.2)	77.8 (38.5)	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)	92.9 (19.3)
Reference	82.9 (31.1)	87.1 (27.9)	86.0 (28.6)	87.5 (29.5)	85.8 (29.9)	N/A	N/A
Role Limitations, Emotional Health: Females							
Fort McMurray	81.5 (37.7)	87.8 (26.9)	81.4 (31.7)	80.0 (33.6)	96.3 (11.1)	0.0 (0.0)	83.2 (30.8)
Lethbridge	0.0 (0.0)	75.0 (50.0)	66.7 (38.5)	100.0 (0.0)	100.0 (0.0)	N/A	72.9 (40.8)
Reference	78.8 (33.0)	80.6 (34.0)	80.3 (33.6)	80.8 (33.6)	83.3 (32.5)	N/A	N/A
Role Limitations, Physical Health: Males							
Fort McMurray	82.5 (31.3)	86.8 (31.6)	94.1 (16.3)	90.5 (23.0)	82.1 (37.4)	0.0 (0.0)	90.3 (23.8)
Lethbridge	100.0 (0.0)	66.7 (28.9)	66.7 (57.7)	66.7 (28.9)	100.0 (0.0)	58.3 (38.2)	69.6 (34.2)
Reference	91.8 (22.6)	92.0 (23.2)	89.5 (25.5)	87.6 (28.3)	78.8 (36.1)	N/A	N/A
Role Limitations, Physical Health: Females							
Fort McMurray	86.1 (22.0)	83.3 (29.6)	82.1 (34.8)	80.6 (33.2)	83.3 (27.9)	0.0 (0.0)	82.3 (32.0)
Lethbridge	100.0 (0.0)	93.7 (12.5)	64.3 (40.5)	100.0 (0.0)	41.7 (52.0)	N/A	71.9 (38.6)
Reference	88.6 (25.5)	86.9 (29.2)	84.0 (32.0)	82.4 (32.0)	76.6 (36.9)	N/A	N/A
Physical Functioning: Males							
Fort McMurray	98.0 (3.5)	94.5 (9.7)	94.6 (8.8)	91.1 (9.7)	93.3 (7.5)	0.0 (0.0)	93.7 (9.0)
Lethbridge	100.0 (0.0)	91.7 (7.6)	78.3 (24.7)	100.0 (0.0)	100.0 (0.0)	78.3 (37.5)	88.1 (21.1)
Reference	92.8 (16.8)	93.9 (14.2)	91.9 (14.5)	87.9 (17.4)	80.0 (22.1)	N/A	N/A
Physical Functioning: Females							
Fort McMurray	93.9 (4.9)	89.3 (14.1)	90.9 (14.2)	85.8 (16.8)	76.9 (17.9)	85.0 (0.0)	88.6 (15.0)
Lethbridge	100.0 (0.0)	96.2 (2.5)	91.4 (14.1)	95.0 (0.0)	70.0 (10.0)	N/A	89.4 (13.9)
Reference	90.1 (16.4)	92.9 (13.3)	89.4 (16.1)	84.8 (18.3)	74.8 (23.5)	N/A	N/A
Social Functioning: Males							
Fort McMurray	55.0 (8.7)	52.8 (6.8)	49.5 (7.6)	50.3 (6.3)	50.0 (7.2)	N/A	50.7 (7.2)
Lethbridge	0.0 (0.0)	50.0 (12.5)	45.8 (7.2)	45.8 (7.2)	50.0 (0.0)	58.3 (14.4)	46.4 (16.6)
Reference	90.2 (16.4)	91.3 (16.3)	90.5 (17.0)	89.8 (18.7)	86.9 (22.6)	N/A	N/A
Social Functioning: Females							
Fort McMurray	47.2 (5.5)	48.6 (10.6)	49.8 (7.8)	49.7 (7.2)	51.4 (7.5)	50.0 (0.0)	49.7 (8.1)
Lethbridge	50.0 (0.0)	50.0 (0.0)	50.0 (7.2)	50.0 (0.0)	41.7 (14.4)	N/A	48.4 (7.7)
Reference	85.7 (19.7)	87.1 (18.9)	86.7 (20.5)	87.0 (20.8)	85.9 (22.6)	N/A	N/A
Mental Health: Males							
Fort McMurray	66.7 (11.3)	64.4 (6.5)	66.2 (7.4)	68.0 (7.8)	62.9 (4.4)	N/A	66.3 (7.6)
Lethbridge	60.0 (0.0)	66.7 (6.1)	65.3 (4.6)	69.3 (4.6)	60.0 (0.0)	69.3 (2.3)	66.6 (4.9)
Reference	74.8 (15.4)	75.8 (15.2)	75.0 (16.1)	76.0 (16.7)	78.0 (17.3)	N/A	N/A
Mental Health: Females							
Fort McMurray	63.6 (8.8)	63.9 (7.0)	65.6 (7.5)	64.3 (10.3)	60.0 (9.4)	80.0 (0.0)	64.5 (8.5)
Lethbridge	56.0 (0.0)	65.0 (5.0)	69.1 (6.8)	60.0 (0.0)	64.0 (4.0)	N/A	65.7 (6.4)
Reference	70.2 (17.4)	71.6 (15.2)	71.6 (17.8)	73.2 (18.2)	74.4 (18.5)	N/A	N/A

Table 109: Comparison between Participants and Reference Values, MOS SF-36 Vitality, Pain, and General Health Perceptions

	Age Category						
	18-24	**25-34**	**35-44**	**45-54**	**55-64**	**65+**	**Total**
Vitality – Males							
Fort McMurray Sample	53.5 (12.3)	54.7 (13.8)	56.2 (7.2)	58.0 (7.8)	52.8 (3.9)	N/A	56.1 (9.0)
Lethbridge Sample	30.0 (0.0)	48.3 (7.6)	56.7 (10.4)	60.0 (5.0)	45.0 (0.0)	56.7 (7.6)	52.9 (10.3)
Reference Norms	66.4 (17.1)	64.5 (17.3)	63.5 (18.6)	62.9 (19.9)	62.9 (20.3)	N/A	N/A
Vitality – Females							
Fort McMurray Sample	55.0 (14.1)	53.1 (8.7)	53.6 (9.6)	52.2 (10.8)	50.0 (6.6)	60.0 (0.0)	53.0 (9.8)
Lethbridge Sample	45.0 (0.0)	55.0 (10.8)	60.7 (5.3)	45.0 (0.0)	53.3 (7.6)	N/A	56.8 (8.3)
Reference Norms	59.8 (19.4)	58.3 (19.5)	58.2 (19.9)	59.4 (20.3)	59.0 (21.4)	N/A	N/A
Bodily Pain: Males							
Fort McMurray Sample	66.4 (14.6)	65.8 (13.4)	65.6 (15.2)	61.5 (19.2)	67.7 (16.7)	N/A	64.6 (16.2)
Lethbridge Sample	83.3 (0.0)	63.9 (5.4)	52.2 (30.8)	65.3 (20.8)	70.0 (0.0)	74.4 (7.7)	65.8 (17.7)
Reference Norms	86.6 (17.9)	87.5 (17.7)	85.6 (19.7)	81.8 (22.2)	78.8 (23.6)	N/A	N/A
Bodily Pain: Females							
Fort McMurray Sample	66.9 (13.4)	55.5 (20.6)	61.0 (19.6)	63.1 (16.0)	43.4 (18.0)	70.0 (0.0)	59.8 (18.9)
Lethbridge Sample	83.3 (0.0)	62.3 (20.8)	57.1 (22.7)	51.7 (0.0)	37.2 (13.2)	0.0 (0.0)	56.0 (21.2)
Reference Norms	81.7 (20.8)	82.1 (21.1)	79.4 (22.0)	77.4 (22.3)	75.0 (25.1)	N/A	N/A
General Health Perceptions: Males							
Fort McMurray Sample	48.8 (8.6)	49.3 (7.2)	49.5 (6.8)	50.1 (7.7)	50.6 (4.2)	N/A	49.6 (7.1)
Lethbridge Sample	51.8 (0.0)	44.2 (11.4)	45.7 (11.4)	51.8 (4.5)	56.4 (0.0)	52.7 (12.6)	49.4 (9.2)
Reference Norms	72.0 (20.1)	76.7 (17.7)	74.1 (18.5)	72.0 (20.1)	68.1 (22.9)	N/A	N/A
General Health Perceptions: Females							
Fort McMurray Sample	49.2 (5.1)	49.7 (7.0)	49.6 (7.8)	50.7 (8.2)	52.1 (5.3)	51.8 (0.0)	50.1 (7.4)
Lethbridge Sample	47.3 (0.0)	53.2 (1.6)	48.3 (8.8)	47.3 (0.0)	51.2 (15.2)	N/A	49.9 (8.2)
Reference Norms	72.1 (20.3)	77.3 (18.5)	74.1 (20.3)	73.1 (19.9)	68.0 (22.0)	N/A	N/A

11.4 Previous Diagnoses

Study participants were asked to indicate which of a series of chronic diseases they have had diagnosed by a physician. Table 110 shows the percentage of the sample population who have been diagnosed with each specified chronic condition.

The proportion of the sample population diagnosed with each chronic condition in Fort McMurray is very similar to the proportion of the Lethbridge population diagnosed with those conditions. Differences between the two populations are likely due to the small sample size in the control community. Allergies (46%) and back problems (22.3%) were diagnosed most frequently for Fort McMurray residents, and allergies (43.3%), arthritis (26.7%) and asthma (26.7%) were diagnosed most frequently for Lethbridge residents. None of the residents of either location had been diagnosed with Alzheimer's disease or other forms of dementia, and less than 1% of the respondents in Fort McMurray indicated that they had been diagnosed with cataracts, glaucoma, effects of stroke, or kidney failure. One percent of respondents in Fort McMurray indicated that they had been diagnosed with one of the following diagnoses: heart disease, alcoholism, nervous system disease, cancer, and urinary incontinence. None of the Lethbridge residents had been diagnosed with any of these diseases. Three percent of the Lethbridge sample indicated they had been diagnosed with cancer, and approximately the same proportion of the Fort McMurray sample indicated they had been diagnosed with some form of cancer. Compared to the Lethbridge sample (13%),

a larger proportion of the Fort McMurray sample (21.5%) indicated that they had not been diagnosed with any of the chronic conditions listed.

Table 110: Percentage of Participants with Diagnosed Condition

Diagnosis	Townsite	
	Fort McMurray	Lethbridge
Food Allergies	12.8	10.0
Other Allergies	33.2	33.3
Asthma	13.1	26.7
Bronchitis/Emphysema	3.6	3.3
Sinusitis	12.8	23.3
Arthritis	14.2	26.7
Back Problems	22.3	23.3
Diabetes	2.6	3.3
Epilepsy	2.2	0.0
High Blood Pressure	9.5	13.3
Heart Disease	1.1	0.0
Effects of Stroke	0.7	0.0
Cancer	1.8	3.3
Alcoholism	1.1	0.0
Urinary Incontinence	1.8	0.0
Kidney Failure/Disease	0.7	0.0
Acne requiring medication	5.5	13.3
Cataracts	0.4	0.0
Glaucoma	0.4	0.0
Migraine	10.9	16.7
Head Injury	5.8	3.3
Alzheimer's Disease	0.0	0.0
Dementia	0.0	0.0
Emotional Illness	4.0	3.3
Mental Health Condition	2.9	3.3
Nervous System Disease	1.5	0.0
None of the Diagnoses	21.5	13.3

12.0 Analysis of Health Records

Using data from Alberta Health and Wellness administrative databases, an analysis was conducted on the morbidity of selected respiratory disorders and mortality from selected causes (lung cancer, cardiovascular disease, ischemic heart disease, respiratory disorders, and COPD, etc.) for Fort McMurray residents and residents of Lethbridge.

Specifically, the number of physician visits, incidence and prevalence of asthma, COPD, and all respiratory disorders (combined) were estimated for the permanent residents of Fort McMurray and Lethbridge areas, focusing on comparisons between the two communities.

Health profiles of study participants and non-participants were also compared.

12.1 Population and Population Cohort Construction

The population of interest was all individuals resident in Fort McMurray or Lethbridge between April 1, 1995 and March 31, 1998. The population cohort was defined as the individuals who were registered with the Alberta Health Care Insurance Plan (AHCIP) between April 1, 1995 and March 31, 1998. To be included in analysis, each individual had to be an exclusive resident of Fort McMurray or Lethbridge during the 3-year study period. Overall, there were 42,356 individuals living in Fort McMurray during the analysis period and 90,289 individuals from Lethbridge.

12.2 Data and Data Sources

All data were obtained from the following data sources:

1. Alberta Health Care Insurance Plan (AHCIP) Stakeholder Registry: This database provides demographic, socioeconomic information, and residence history information.

2. Alberta Physician Claims File: This database has all health records of AHCIP registrants visiting a Fee-For-Service (FFS) health care practitioner. The diagnostic information is available in the database.

3. Alberta Hospital Morbidity File: This database contains information of all in-patient hospital records, including diagnostic information for each fiscal year.

4. Alberta Vital Statistics Mortality File: This database contains information on all deaths in Alberta.

Relevant information was linked across databases by individual or geographic area as appropriate.

The ninth version of the International Classification of Disease for Clinical Modification (ICD-9-CM) was used for the identification of cases and for causes of death from disease. In an attempt to capture all possible cases, primary, secondary, and tertiary diagnoses as recorded in the Alberta Physician Claims file were used.

Criteria were developed for data extraction, cleaning, grouping, and coding of study variables of interest.

12.3 Statistical Analysis

The goal of the analysis was to compare health outcome measures between Fort McMurray and Lethbridge, using Lethbridge as a control community. The potential confounding effects of demographic and socioeconomic information and mobility of the residents between the two communities were examined.

Proportions, ratios, means, and rates were estimated for overall illness and for specific disease categories. Measures for the entire population and for sub-populations defined by sex and age group were also estimated for each community. Three age categories were used: children (0-14 years), adults (15-64 years), and seniors (65+ or over).

Measures were adjusted to the age distribution of the combined population of both communities. Both stratified analysis and multivariate logistic regression was performed for all categorical variables. In the stratified analysis, the age-weighted relative risk was estimated for the male and female populations. In the multivariate logistic regression, effects of sex, age, treaty status, and socioeconomic status were used

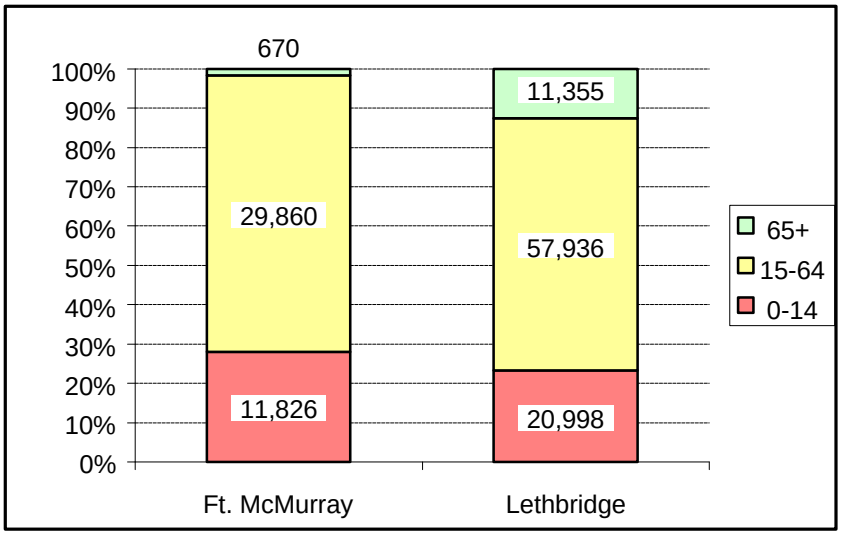
to adjust estimates of risk. Odds ratios and 95% confidence intervals were estimated for each specific measure of health outcomes. The conventional level (α= 0.05) was used to make judgements of statistical significance.

12.4 Population Characteristics

Age was found to be the most important confounder, followed by treaty status and socioeconomic status. These factors were associated with health outcomes and were unevenly distributed between the two communities.[127]

Of the 42,356 and 90,289 residents of Fort McMurray and Lethbridge, respectively, over three years, the age distribution varies between the two communities during the study period (Figure 133). Fort McMurray had more children (39.6% vs. 36.2%), but fewer seniors (2.2% vs. 19.6%).

Figure 133: Age Distribution of Study Population



The distribution of treaty status varies by study area during the study period. Overall, the proportion of people with treaty status in Fort McMurray (4.9%) is double that in Lethbridge (2.3%). The difference is largest in seniors (3.1% vs. 0.2%) and lowest in children (6.7% vs. 4.3%).

Socioeconomic status was defined according to the level of premium subsidy being received and the presence of social service assistance. During the 3-year period, the distribution of SES in the study population varied by study area. Overall, 9.0% of Fort McMurray residents fell into the lower SES category while the corresponding number in Lethbridge was 18.1%. A large proportion of senior residents fell into the lower SES category, 47.5% for Fort McMurray and 37.9% for Lethbridge.

There were 29,368 and 70,390 residents of Fort McMurray and Lethbridge, respectively, who remained in the community for the entire 3-year period. The mobility of this population varied by study area and age group (see Table 111). Overall, 26.4% and 21.8% of the population in Fort McMurray and Lethbridge, respectively, changed their residence address during the 3-year period. The residents of Fort McMurray were more mobile than residents of Lethbridge. Seniors were less mobile than children and adults.

Table 111: Mobility of the Population Cohort by Age Group, Change of Postal Code Area, Fort McMurray vs. Lethbridge, April 1, 1995 to March 31, 1998

Age Group (Year)	Residence Status	Fort McMurray		Lethbridge		p-value
		N	%	N	%	
0-14	Change	2,129	26.5	3,588	17.1	< 0.001
	No Change	5,914	73.5	11,778	76.6	
	Sub-total	**8,043**	**100.0**	**15,366**	**100.0**	
15-64	Change	5,550	26.6	23,092	23.1	< 0.001
	No Change	15,312	73.4	34,844	76.9	
	Sub-total	**20,862**	**100.0**	**57,936**	**100.0**	
65+	Change	80	17.2	1,244	12.7	< 0.001
	No Change	386	82.8	8,457	87.2	
	Sub-total	**466**	**100.0**	**9,701**	**100.0**	
All Ages	Change	7,759	26.4	15,311	21.8	< 0.001
	No Change	21,612	73.6	55,079	78.2	
	Total	**29,368**	**100.0**	**70,390**	**100.0**	

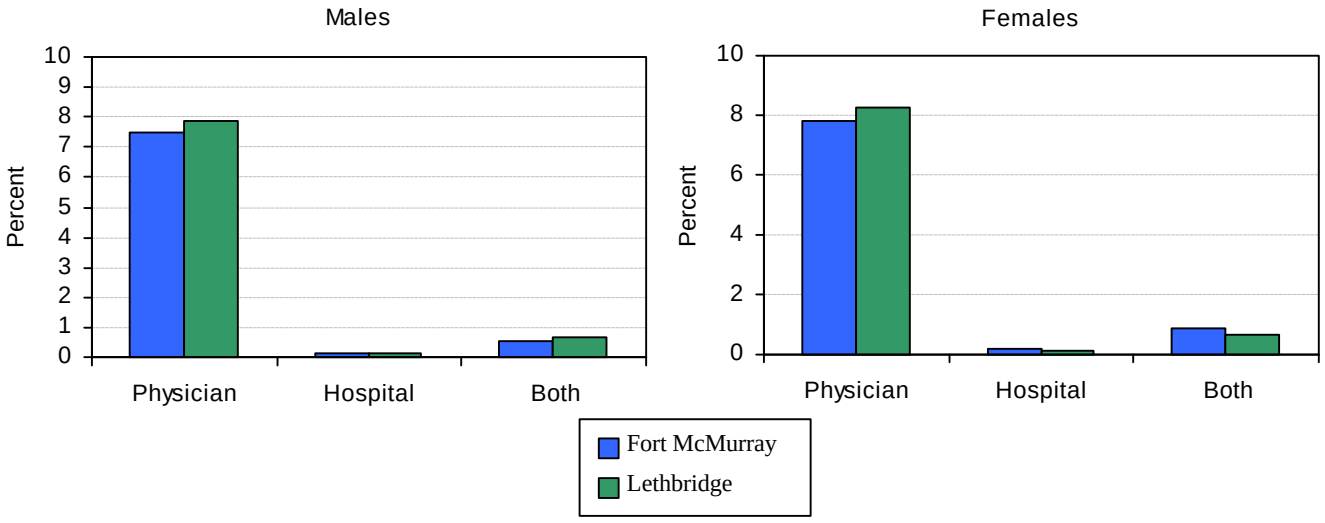
12.5 Results of Analysis of Health Records

Respiratory disorders, especially asthma, have received much attention in studies of potential health impact from ambient air quality. Several studies have reported a positive association between ambient air pollution and hospital admissions of asthma and other respiratory disorders.[128, 129] The proportion of individuals who visited a physician and/or were hospitalized for selected respiratory disorders were estimated for the permanent residents of Fort McMurray and Lethbridge during the 3-year period. The following examines a variety of measures of morbidity data on asthma, COPD, and all respiratory disorders.

12.5.1 Asthma

Overall, there was no significant difference in the proportion of people visiting a physician and/or being hospitalized for asthma between Fort McMurray and Lethbridge during the 3-year period (Figure 134).

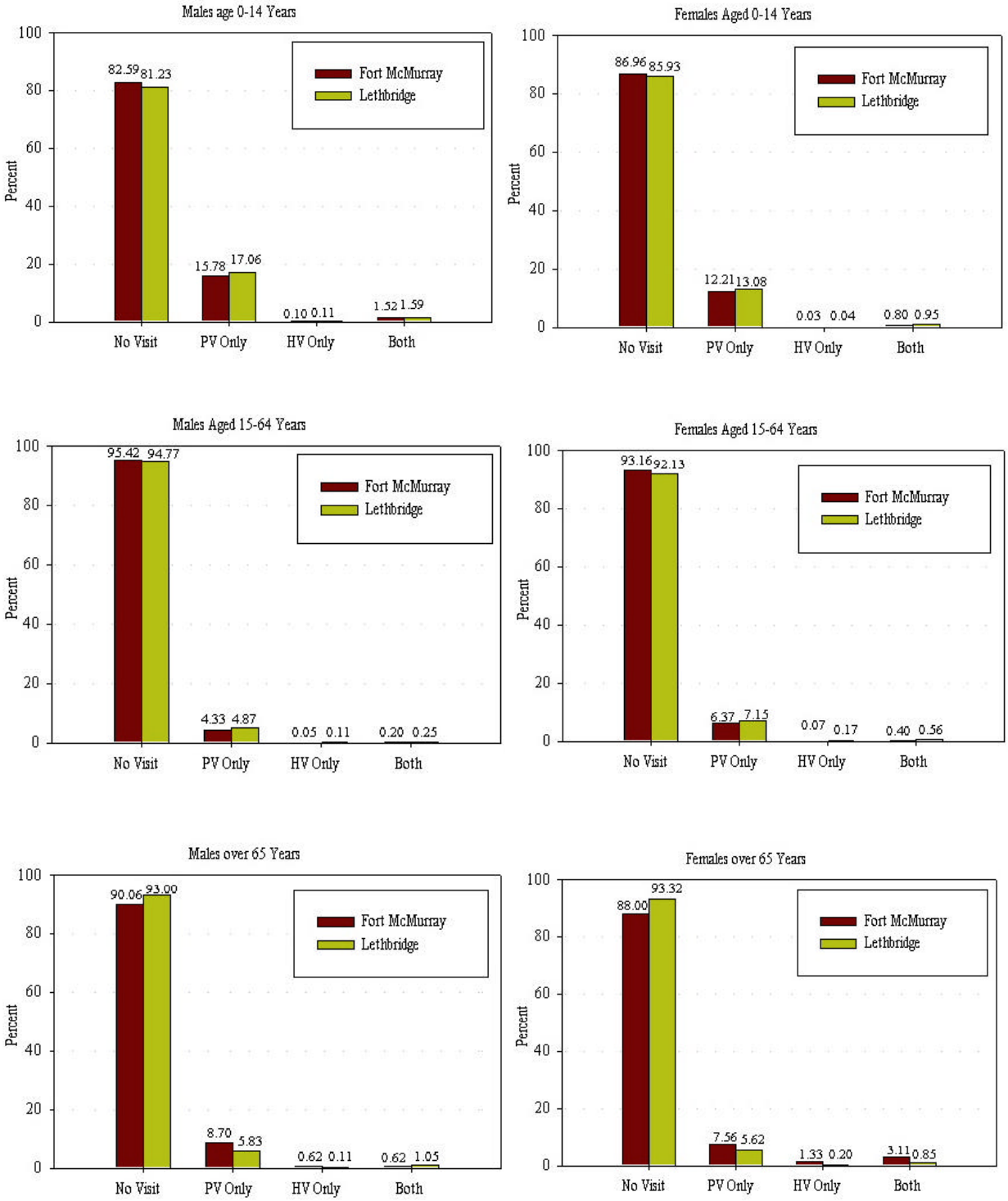
Figure 134: Physician Visits and Hospitalisation for Asthma



For females aged 15-64 years and 65 years or over, there were some differences between the two study areas (Figure 135). The proportion of physician visits and/or hospitalization for asthma was higher for residents of Lethbridge aged 15-64 years.

As shown in Figure 135, about 12-17% of children visited a physician for asthma at least once during the 3-year period, followed by seniors (6-9%) and adults (3-7%). Although only a small percentage of the population was hospitalized for asthma, about half of those admitted to a hospital had also visited a physician. Overall, less than 1% of the population was hospitalized for asthma. Seniors (0.1-1.3%) appeared more likely to be hospitalized than children (0.03-0.11%) and adults (0.05-0.17%). About 1-3% of the population either visited a physician or was hospitalized for asthma. The percentage was slightly higher for children and lower for adults. Women, aged 15-64 years, tended to have a higher proportion of physician visits for asthma (6.4-7.2%) than men aged 15-64 years (4.3-4.9%).

Figure 135: Age-Specific Proportions of Asthma, Fort McMurray vs. Lethbridge



12.5.2 Chronic Obstructive Pulmonary Disease (COPD)

The percent distribution of COPD varied by study area during the study period. Overall, the residents of Lethbridge were more likely to visit a physician for COPD (8.4-9.0%) than those of Fort McMurray (3.0-3.6%), but less likely to be admitted into a hospital (Figure 136). This pattern is consistent across sex/age groups, although it is not statistically significant for males less than 15 years and male residents 65 years of age and older (Figure 137). The small number of cases in these sex/age groups likely account for the non-significant associations. As expected, the proportion of physician visits and hospitalization for seniors is higher than the other two age groups, regardless of the study area (Figure 137).

Figure 136: Age-Standardized Proportions of COPD, Fort McMurray vs. Lethbridge

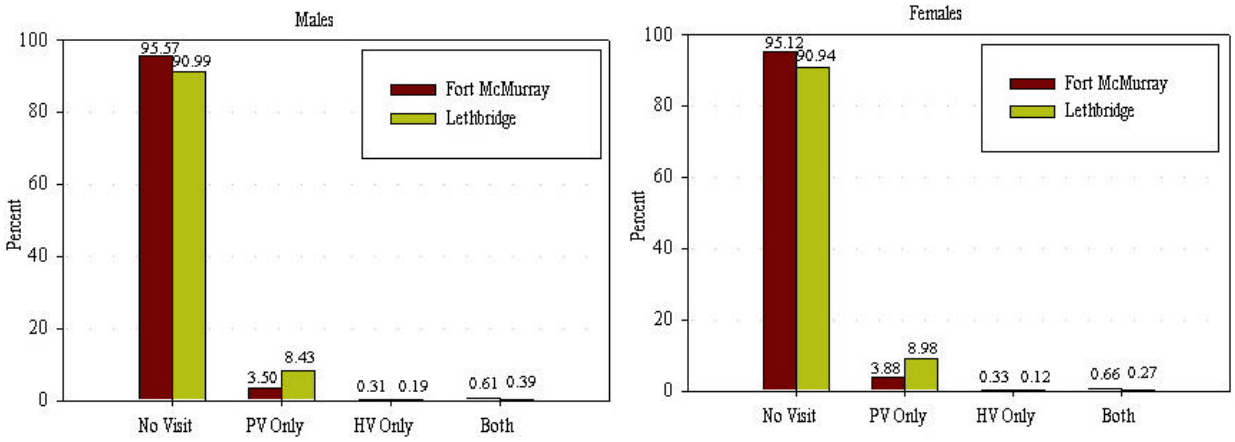
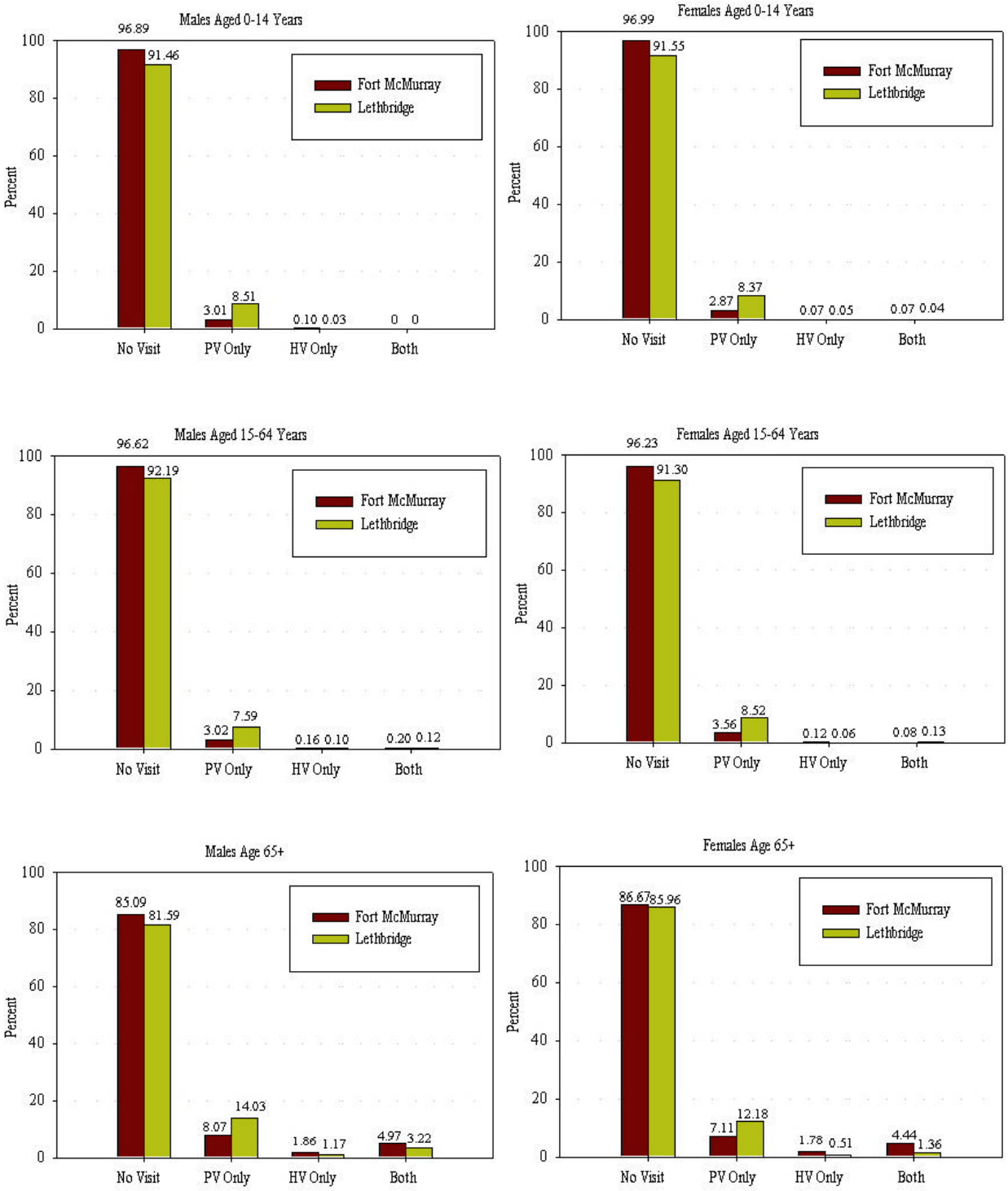


Figure 137: Age-Specific Proportions of COPD, Fort McMurray vs. Lethbridge



12.5.3 All Respiratory Disorders

The percent distribution of all respiratory disorders also varied by study area during the study period. Overall, the residents of Fort McMurray were more likely to visit a physician for a respiratory disorder (59.6-69.1%) compared to Lethbridge (53.5-62.0%; Figure 138). This pattern is consistent across sex/age groups, though it is not statistically significant for males 65 years of age and older (Figure 139). Contrary to the distribution found for COPD, the proportion of physician visits for children (70.2-76.2%) was higher than adults aged 15-64 years (48.7-70.0%) and residents aged 65 years of age and older (45.0-53.4%). This pattern is largely attributable to visits for upper respiratory infections, such as common cold and tonsillitis. As noted, women aged 15-64 years tend to be more likely to visit a physician for respiratory disorders (61.4-70.0%) than men in the same age group (48.7-55.0%).

Figure 138: Age-Standardized Proportions of All Respiratory Disorders, Fort McMurray vs. Lethbridge

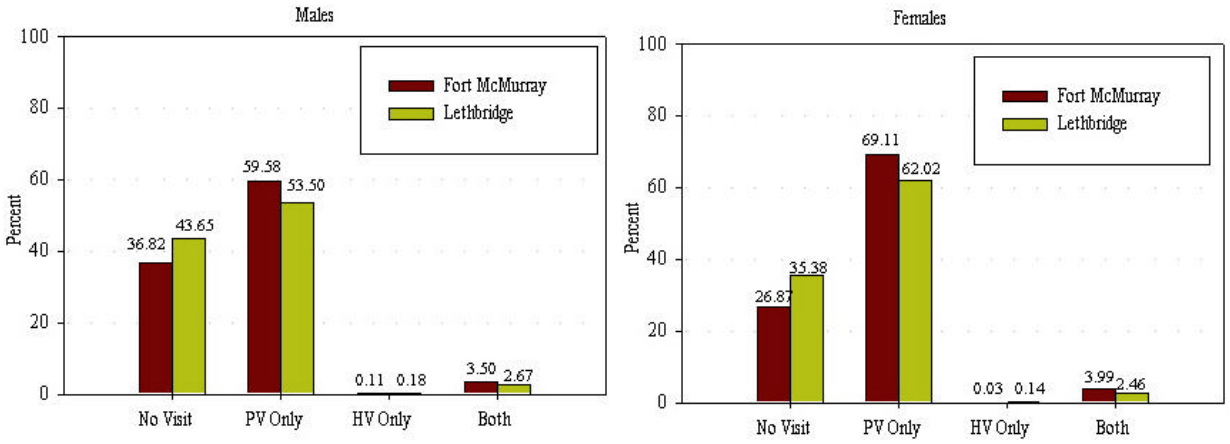
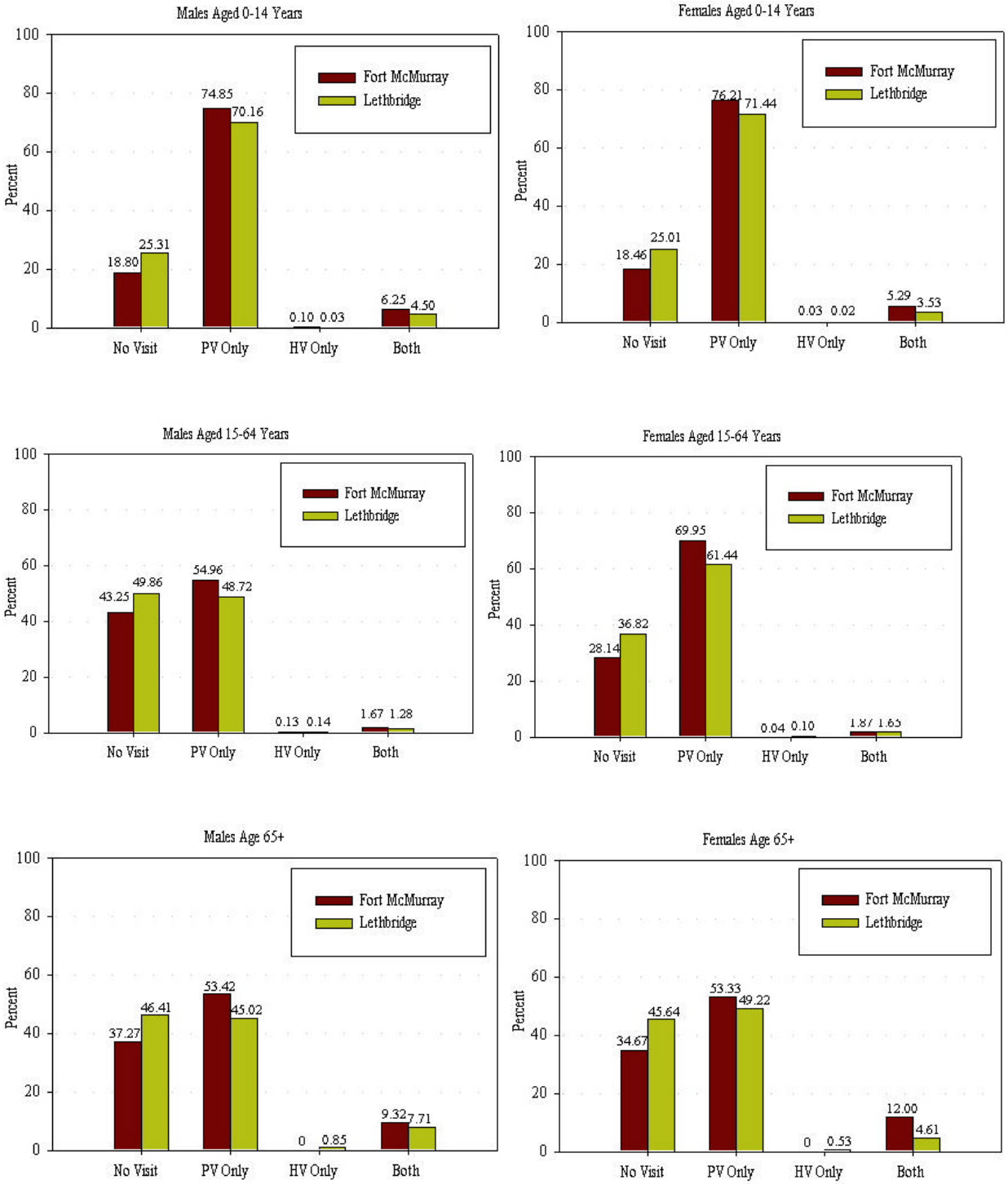


Figure 139: Age-Specific Proportions of All Respiratory Disorders, Fort McMurray vs. Lethbridge



12.6 Number of Visits per Case and per 100 person-years

The number of visits to a physician for asthma or COPD are sensitive measures of health outcomes from ambient air exposure. Several studies reported a positive association between ambient air pollution and daily hospital admissions for asthma.[130, 131] The patterns of the number of visits (physician visits and/or hospitalization) for asthma, COPD, and all respiratory disorders in permanent residents of Fort McMurray and Lethbridge during the 3-year study period are described below. Table 112 shows the number of visits for these respiratory disorders by sex and age group.

12.6.1 Asthma

The overall number of visits for asthma for residents of Fort McMurray was similar to residents of Lethbridge, with about 3 visits per individual over the 3-year period and 9 visits per 100 person-years. The frequency of visits varied by sex and age group. Males younger than 15 years tended to have more visits than females in the same age category and all children had more visits than the adults aged 15-64 years. Differences between Fort McMurray residents and Lethbridge residents were markedly higher in the oldest age groups. This is likely due to the small size of the senior population and a few residents with an extremely high frequency of visits in this area.

12.6.2 COPD

The frequency of visits for COPD was lower compared to visits for asthma, with about 2 visits per case in the 3-year period. The number of visits per 100 person-years for residents of Fort McMurray was very different than the number for Lethbridge residents. Overall, the number of visits to a physician for residents of Fort McMurray was lower than for Lethbridge residents. As would be expected for this diagnosis, the frequency of visits increases with age group. The seniors have more visits than children, regardless of sex and the study area.

Table 112: Number of Visits for Respiratory Disorders by Sex and Age Group, Fort McMurray vs. Lethbridge, April 1995 - March 1998

Diagnostic Category	Sex	Age Group (Year)	Fort McMurray			Lethbridge		
			Total Number of Visit	# Visit per Case	# Visit per 100 Person-Year	Total Number of Visit	# Visit per Case	# Visit per 100 Person-Year
Asthma	M	0-14	2,022	3.8	22.3	4,487	3.9	24.5
		15-64	1,050	2.9	4.4	2,451	2.7	4.7
		65+	68	4.3	14.1	870	3.5	8.3
		Sub-total	**3,140**	**3.5**	**9.4**	**7,808**	**3.4**	**9.7**
	F	0-14	1,243	3.3	14.3	2,423	3.0	14.3
		15-64	1,374	2.7	6.3	4,405	3.2	8.4
		65+	195	7.2	28.9	1,263	3.8	8.5
		Sub-total	**2,812**	**3.1**	**9.0**	**8,091**	**3.2**	**9.6**
COPD	M	0-14	123	1.3	1.4	740	1.4	4.0
		15-64	457	1.7	1.9	2,325	1.7	4.5
		65+	102	4.3	21.1	2,662	4.1	25.3
		Sub-total	**682**	**1.8**	**2.0**	**5,727**	**2.3**	**7.1**
	F	0-14	112	1.3	1.3	649	1.4	3.8
		15-64	416	1.5	1.9	2,397	1.6	4.6
		65+	146	4.9	21.6	2,029	2.9	13.7
		Sub-total	**674**	**1.7**	**2.2**	**5,075**	**1.9**	**6.0**
All Respiratory Disorders	M	0-14	14,595	6.0	161.0	22,395	4.9	122.1
		15-64	14,566	3.2	60.8	25,874	3.0	49.8
		65+	576	5.7	119.3	8,441	4.5	80.1
		Sub-total	**29,737**	**4.2**	**88.8**	**56,710**	**3.8**	**70.1**
	F	0-14	13,148	5.6	151.5	19,328	4.6	113.7
		15-64	21,106	4.0	96.0	40,291	3.6	76.7
		65+	957	6.5	141.8	10,216	3.8	68.9
		Sub-total	**35,211**	**4.5**	**112.4**	**69,835**	**3.9**	**82.8**

12.6.3 All Respiratory Disorders

The frequency of visits for all respiratory disorders was about 4 visits per individual over the 3-year period. Overall, the number of visits for residents of Fort McMurray was higher than for Lethbridge residents. Children had the most visits to a physician, with an average of about 6 visits each for residents of Fort McMurray, compared to an average of about 5 visits each for residents of Lethbridge.

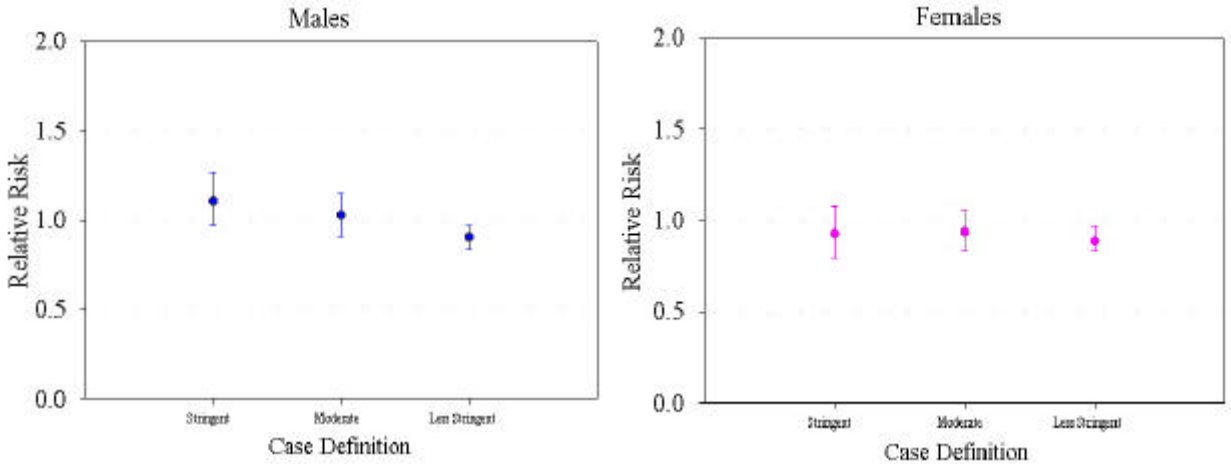
12.7 Prevalence of Asthma, COPD, and Respiratory Disorders

The prevalence of selected respiratory disorders was estimated for the permanent residents of Fort McMurray and Lethbridge. Cases were defined using three different sets of criteria. The effects of age, sex, treaty status, and SES were accounted for in multivariate logistic regression analysis. A detailed description of the methods of analysis can be found in the *Methods Report*.

12.7.1 Asthma

Figure 140 shows the relative risk (RR) for asthma prevalence by case definition for Fort McMurray residents by sex and age group. There were no differences in the prevalence of asthma between the two study areas, regardless of sex and case definition. This pattern is also true for all sex and age groups, except for the female senior population. The small number of senior residents in Fort McMurray is likely a contributing factor to the observed increase of prevalence in this area.

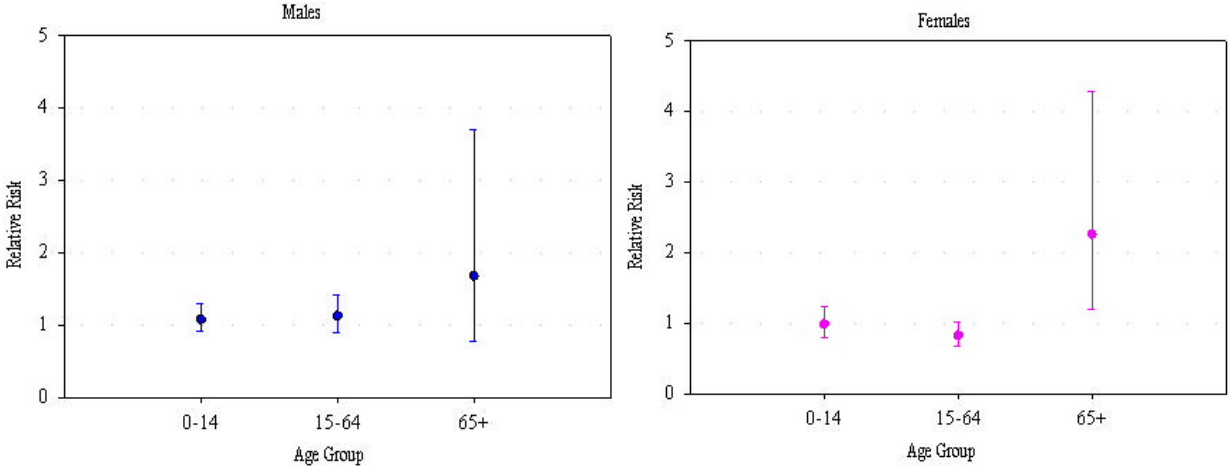
Figure 140: Relative Risk for Asthma Prevalence by Sex and Case Definition in Fort McMurray Residents



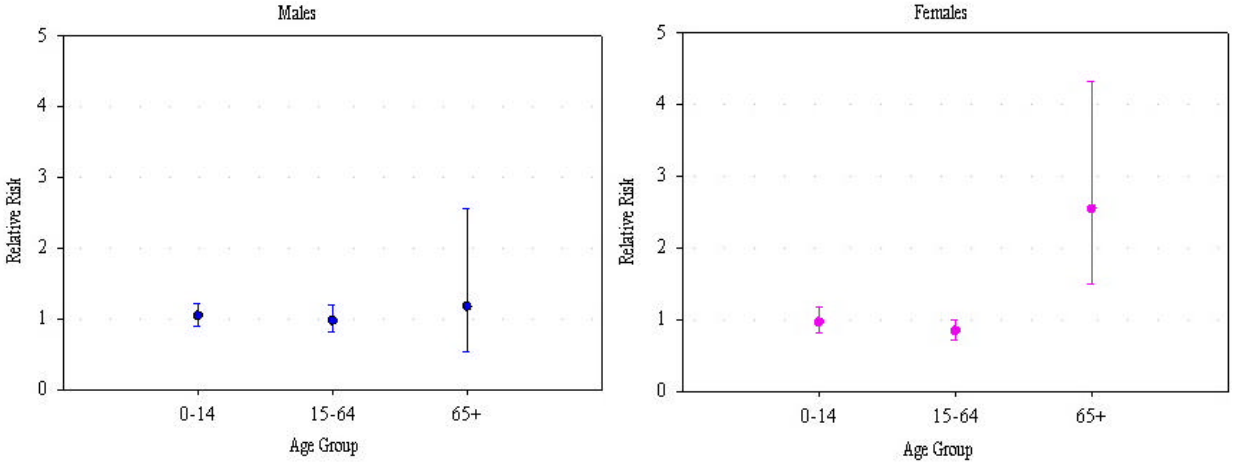
Similar to the number of visits for asthma, the prevalence of asthma varies by sex/age group and case definition. The prevalence of visits for asthma was higher for males younger than 15 years of age than for females in the same age group. Children have a higher prevalence (4.3-18.8%) than seniors (2.2-12.0%) and adults aged 15-64 years (1.3-7.9%). As expected, the prevalence is higher for the less stringent case definition and lower for the stringent case definition.

Figure 141: Relative Risk for Asthma Prevalence by Case Definition and Sex/Age Group in Fort McMurray Residents

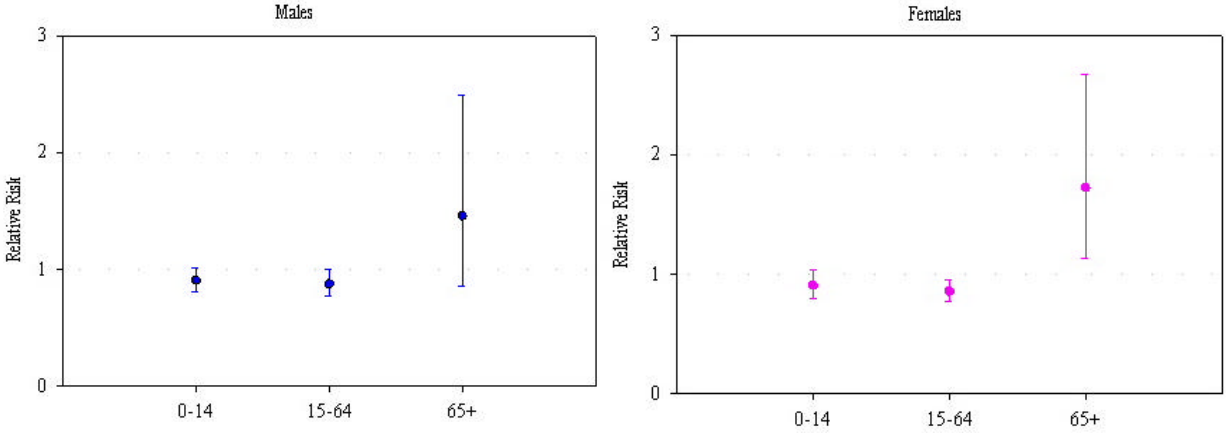
a. Stringent



b. Moderate



c. Less Stringent



12.7.2 COPD

The prevalence of COPD differed between Fort McMurray residents and Lethbridge residents during the study period. Overall, the prevalence of COPD was lower for both male and female residents of Fort McMurray, especially when the less stringent case definition was used. The adjusted risk of COPD prevalence in Fort McMurray was only about half that of Lethbridge, regardless of the case definition. The pattern of lower risk for Fort McMurray residents is consistent for all sex and age groups, except for the senior population.

Consistent with the patterns of physician visits for COPD, the prevalence of COPD also increases with age but decreases with the stringency of the case definition. Children have the lowest prevalence (0.1-8.5%), followed by adults aged 15-64 years (0.3-8.7%), and seniors (3.3-18.4%). As expected, the prevalence is higher when the less stringent case definition is used and lower when the more stringent case definition is used. Although the prevalence of COPD in males aged 15-64 years is similar to the prevalence for females in the same age group, there are differences in the senior population. Male seniors are more likely to have COPD than their counterparts. The difference is larger when the stringent case definition is used. This sex difference is probably, in part, due to the differences in smoking between men and women.

Figure 142: Relative Risk for COPD Prevalence by Sex and Case Definition in Fort McMurray Residents

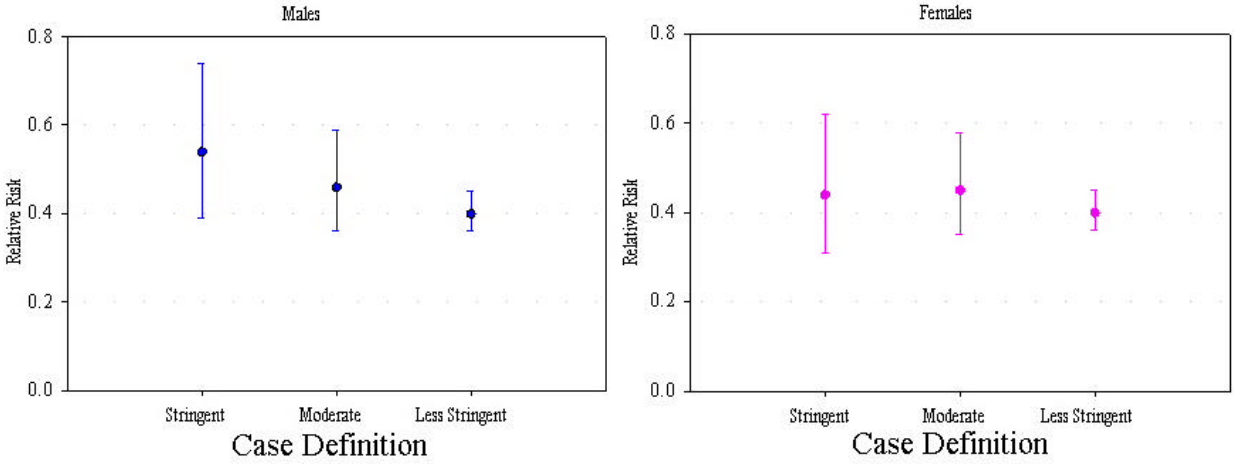
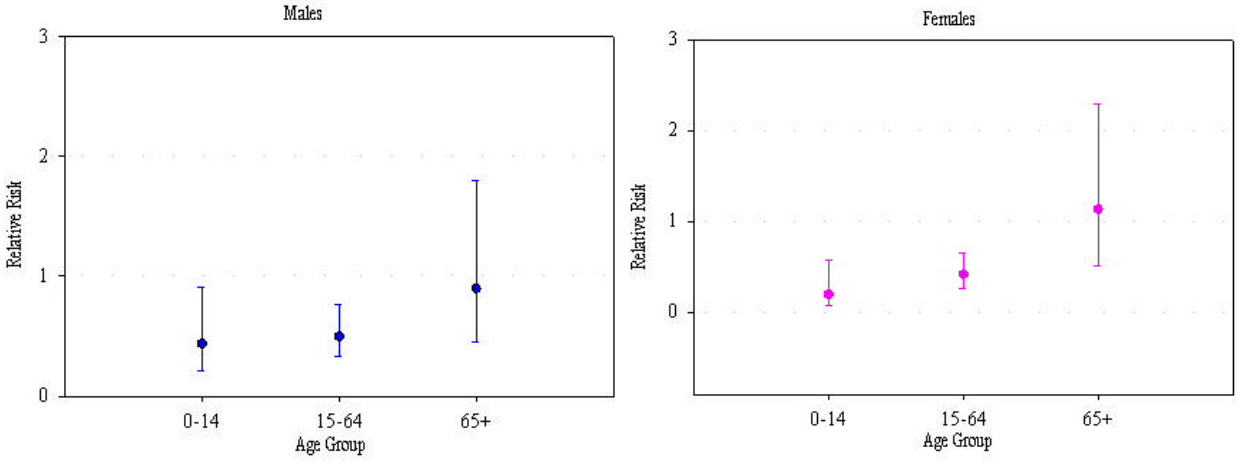
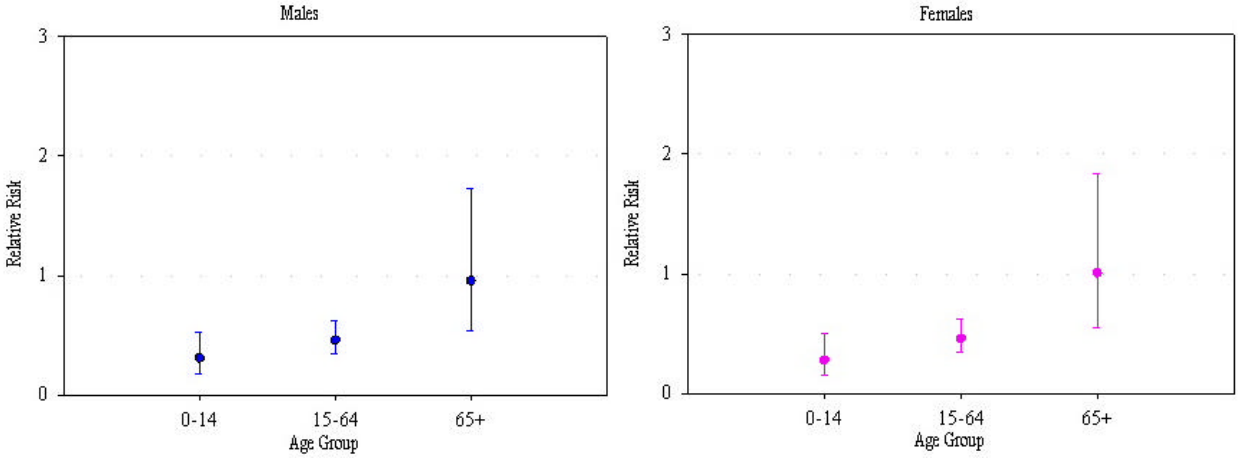


Figure 143: Relative Risk for COPD Prevalence by Case Definition and Sex/Age Group in Fort McMurray Residents

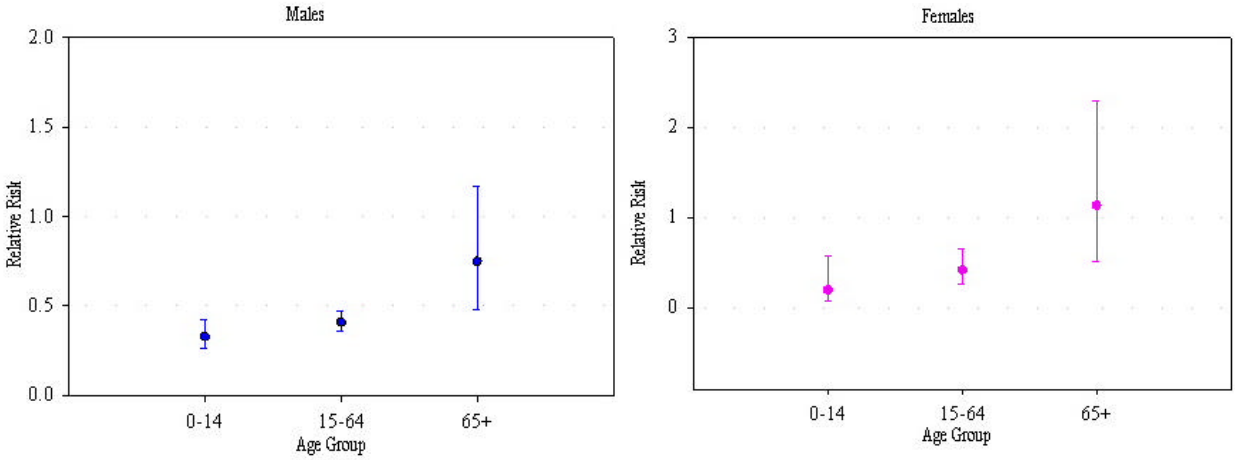
a. Stringent



b. Moderate



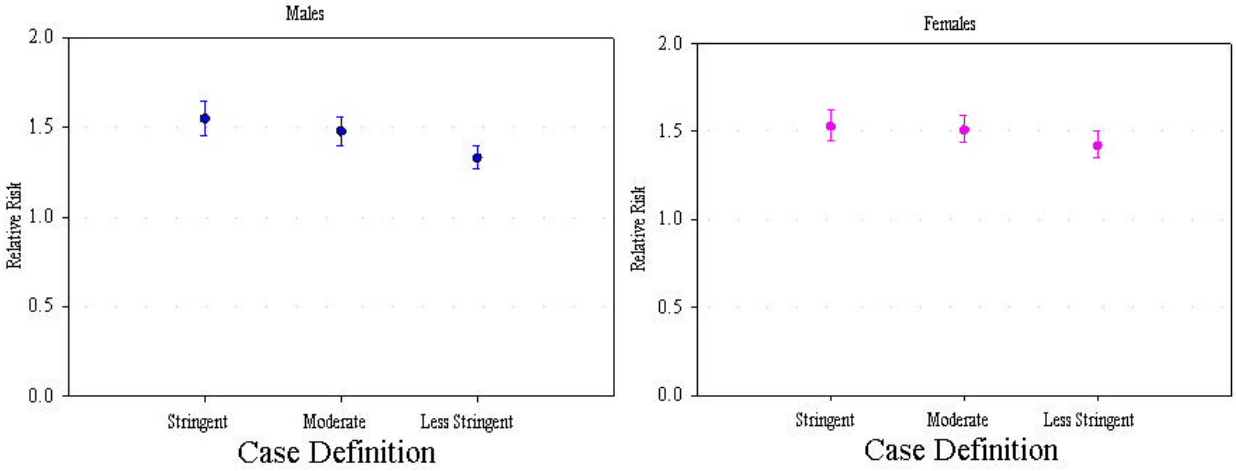
c. Less Stringent



12.7.3 All Respiratory Disorders

Contrary to the regional pattern of COPD, the prevalence of all respiratory disorders was higher in Fort McMurray than Lethbridge during the study period.

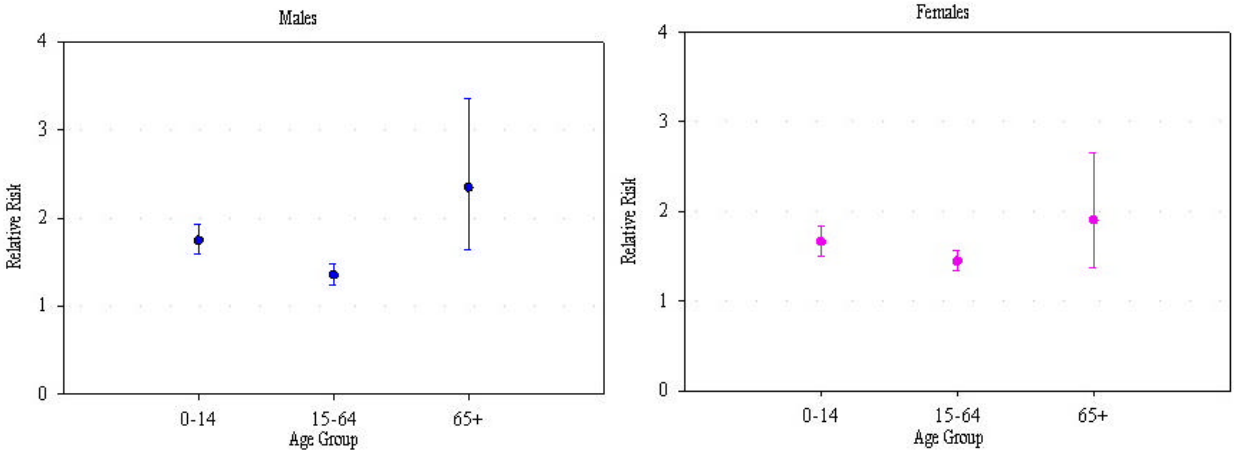
Figure 144: Relative Risk for All Respiratory Disorders by Sex and Case Definition in Fort McMurray Residents



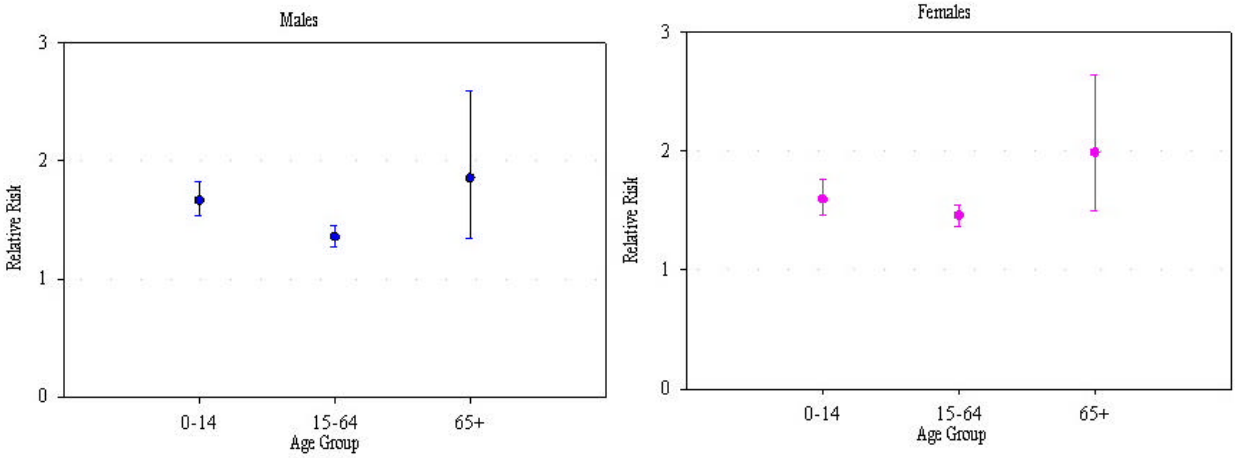
Compared to the residents in Lethbridge, the residents of Fort McMurray had a higher prevalence of respiratory disorders. The adjusted risk of respiratory disorders in Fort McMurray was 30 to 50% higher than that in Lethbridge. The larger difference in the stringent case definition scenario is due to more repeated visits by residents of the Fort McMurray area. The pattern of higher risk in Fort McMurray is true for all sex/age groups regardless of the case definition.

Figure 145: Relative Risk for All Respiratory Disorders by Case Definition and Sex/Age Group in Fort McMurray Residents

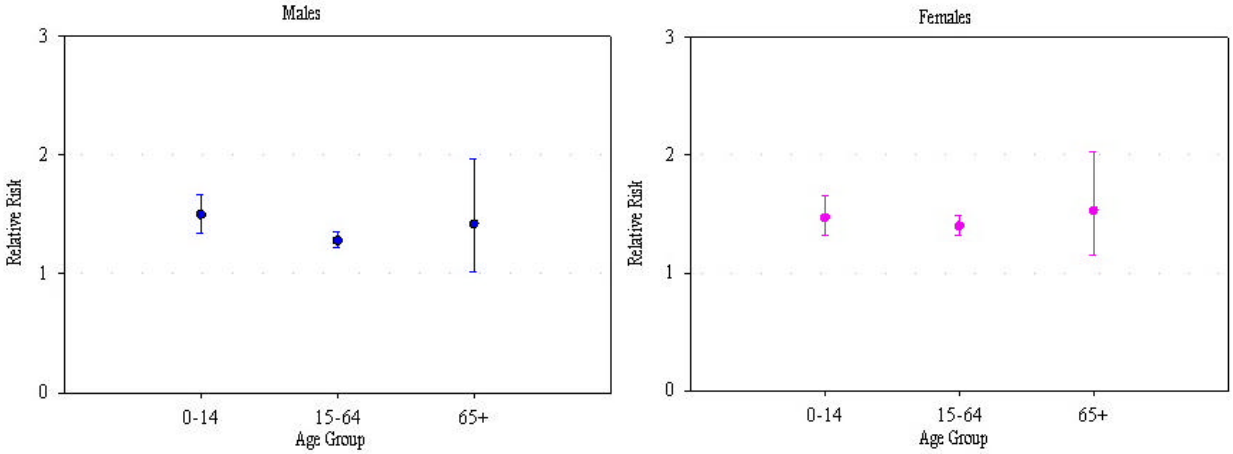
a. Stringent



b. Moderate



c. Less Stringent



The prevalence of all respiratory disorders varies by age group and case definition. Similar to the pattern of physician visits, children have a higher prevalence (25.3-81.5%) than seniors (12.1-65.3%) and adults aged 15-64 years (8.1-71.9%). The prevalence is higher when the less stringent case definition is used. No large difference in prevalence is found between males and females across age groups.

12.8 Selected Additional Findings

12.8.1 Validation of Asthma Prevalence Measure

The estimate of asthma prevalence identified using the methods defined above was compared to the 1996 National Population Health Survey (NPHS) results. The NPHS asked participants if a physician had ever diagnosed them with asthma in the past 12 months. In the current study, the age-specific and overall period of asthma prevalence by using three case definitions were estimated for residents aged 12 years and over for the Chinook and Northern Lights health regions, April 1995 - March 1998.

Table 113: Comparison of Asthma Prevalence between Present Study and NPHS

Region (RHA)	Age Group	NPHS	Present Study by Case Definition		
			Stringent	Moderate	Less Stringent
Chinook	12-19	16.2	2.8	4.3	10.1
	20-44	7.4	1.6	2.5	6.2
	45-64	5.0	1.6	2.5	5.9
	65+	4.2	2.3	3.3	7.0
	All	**7.7**	**1.9**	**2.9**	**6.9**
Northern Lights	12-19	9.5	2.5	4.2	9.4
	20-44	5.0	1.2	2.0	5.1
	45-64	4.1	2.1	2.8	5.9
	65+	9.5	4.6	6.3	11.6
	All	**5.9**	**1.7**	**2.7**	**6.3**

Note: 1) The analysis is limited to residents aged 12 year and over and under a complete 3-year observation.

2) Three case definitions were used for the prevalence estimation.

Source: 1) Alberta Health Care Insurance Plan (AHCIP) Stakeholder Registry, April 1995 - March 1998.
2) Alberta Physician Claims Database, Apr95-Dec.98.
3) Alberta Hospital Morbidity Database, April 1995 - March 1998.
4) Health Surveillance, 1999: The National Population Health Survey, 1996.

As shown in Table 113, the estimates of the prevalence of asthma are similar to those from the NPHS when the less stringent case definition is used. The asthma prevalence estimates are much lower when the stringent and moderate case definitions are used.

12.8.2 Incidence of Asthma in Children

Several studies reported a positive association between asthma incidence and long-term exposure to ambient air ozone concentration.[132, 133] The incidence rate of asthma in the children's cohort in Fort McMurray was compared to the rate for Lethbridge. The incidence rate was estimated for permanent

residents of each study area by case definition. The relative risk for asthma in Fort McMurray was also estimated, after controlling for sex, treaty status, and SES.

Overall, 135 males and 137 females from Fort McMurray and 336 males and 293 females from Lethbridge visited a health care service provider during the 3-year period were followed-up for three years. The incidence of asthma varied by sex and case definition but not by study area. In males, the incidence varied from 2.5 (for the stringent definition) to 7.9 (for the less stringent definition) per 100 person-years while the corresponding figures for females was from 1.2 to 4.8 (Table 114). No difference in the incidence rate was found between Fort McMurray and Lethbridge, regardless of sex and case definition. This finding was consistent in both the stratified analysis and the multivariate logistic regression.

Table 114: Incidence of Asthma by Case Definition and Sex in Children's Cohort, Fort McMurray vs. Lethbridge

Sex	Case Definition	Fort McMurray			Lethbridge			Relative Risk (RR)			p-value
		Case	Non-Case	Incidence	Case	Non-Case	Incidence	RR	Lower	Upper	
M	Stringent	10	125	2.5	26	310	2.6	0.96	0.47	1.93	0.903
	Moderate	17	118	4.2	41	295	4.1	1.03	0.61	1.75	0.907
	Less Stringent	32	103	7.9	78	258	7.7	1.02	0.71	1.46	0.910
F	Stringent	5	132	1.2	12	281	1.4	0.89	0.32	2.48	0.825
	Moderate	7	130	1.7	19	274	2.2	0.79	0.34	1.83	0.577
	Less Stringent	16	121	3.9	42	251	4.8	0.82	0.48	1.4	0.453

Note: 1) Analysis included all children born after March 31, 1995 of Fort McMurray and Lethbridge who did not change the address between April 1995 and March 1998.

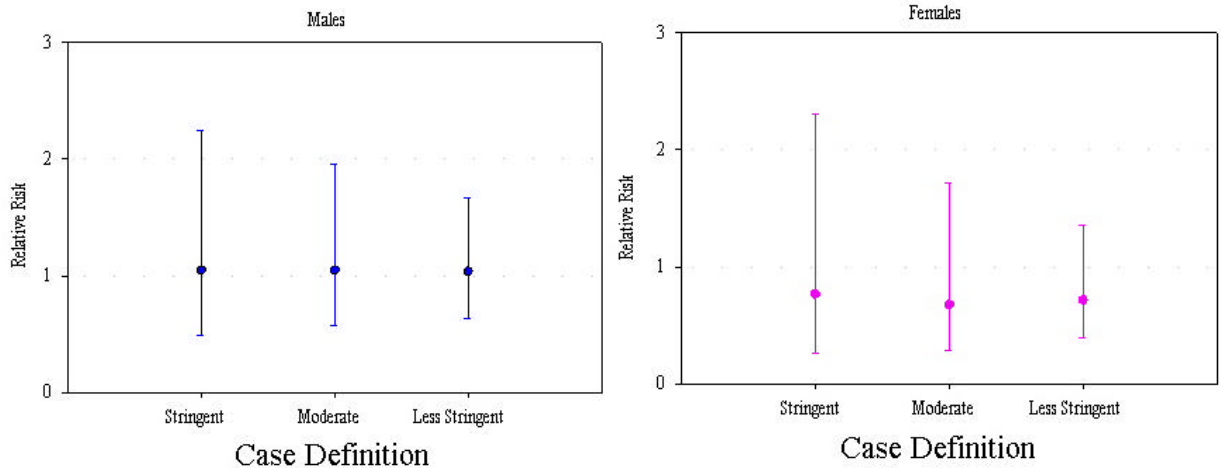
2) A case is defined by three criteria which is developed according to the statistical distribution and clinical likelyhood.

3) The Lower and Upper refer to the lower and upper 95% confidence limit of the relative risk.

4) Chi-Square test is performed for differences in the incidence between Fort McMurray and Lethbridge.

5) The multivariate logistic regression were performed for the estimation of the relative risk and the 95% confidence interval of the RR. The effects of sex, treaty status and SES were adjusted in the analysis.

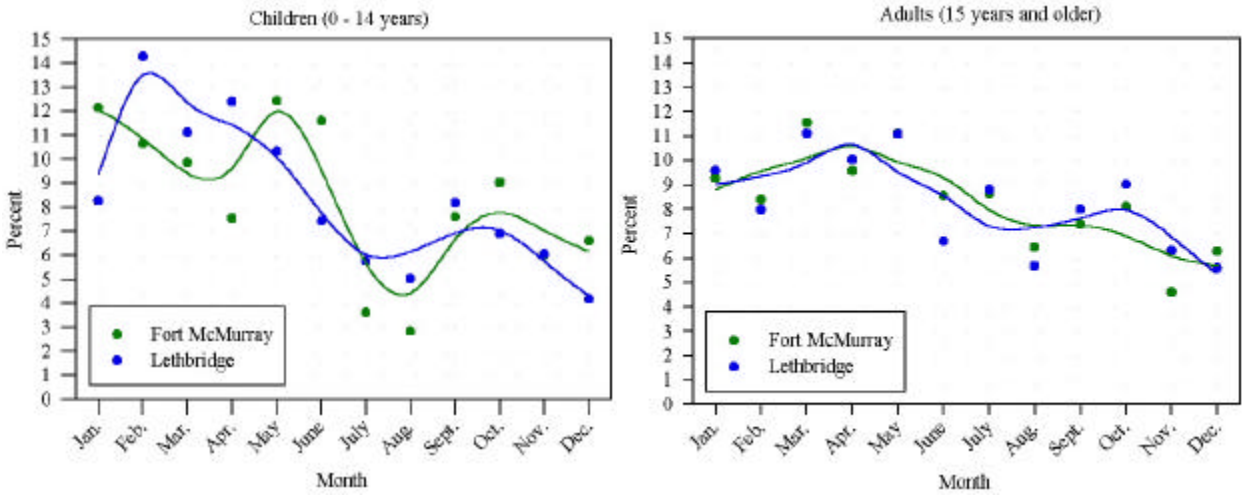
Figure 146: Relative Risk for Asthma Incidence by Sex and Case Definition in Fort McMurray Children's Cohort



12.8.3 Seasonal Patterns of Asthma in Children and Adults

Seasonal patterns of asthma have been reported in several studies.[134, 135] Examination of seasonal patterns may provide insights into factors that may trigger acute asthma episodes. Figure 147 shows the seasonal patterns of asthma visits (physician visits and hospitalization) for children and adults (15 years or over) of Fort McMurray and Lethbridge, 1996-1997. The pattern appears different for children and adults, and for children across study areas. For children, visits increased in spring, although the Fort McMurray area peaked later than the Lethbridge area. February was the highest and December the lowest in Lethbridge, while the corresponding months were May and August in Fort McMurray. For those aged 15 years and over, the seasonal variations were less pronounced, with March and May being the highest and November/December being the lowest for both areas. Regional differences in seasonal patterns only in children are likely due to the fact that children are more likely to have an allergic form of asthma and are thus more sensitive to the changes of environment by season.

Figure 147: Seasonal Variation of Asthma Morbidity, Fort McMurray vs. Lethbridge



Possible explanations of these patterns include:

- Seasonal covariation with cyclical patterns of acute respiratory infections;
- Variations in levels of environmental substances (pollen, dust, mite, particulate, airway irritants);
- Weather-related factors (temperature, wind, humidity);
- Agricultural activities (use of fertilizers, herbicides, pesticides, fungicides, crop, harvest); and
- Social activity patterns.[136-138]

12.8.4 Mortality of Selected Causes of Death

Mortality rate has been used as an outcome measure in many environmental epidemiological studies. Several studies examined the relationship between the ambient air quality and the mortality of cardiovascular disease,[139, 140] lung cancer,[141] and total death.[142-144] In this report, the mortality rate of selected causes of deaths was estimated for the residents of Fort McMurray and Lethbridge, between 1995 and 1997. The causes of death examined include all causes combined, lung cancer, cardiovascular disease, ischemic heart disease, respiratory disorders, and COPD. These specific causes of death were chosen due to their unique relationship with ambient air pollution. The rate of these causes in Fort McMurray were compared to that of Lethbridge. The age standardized mortality rate (SMR) was estimated according to the sex-specific age distribution of the two community's combined population. The effects of age and sex were adjusted in the stratified analysis.

During the 3-year period, a total of 218 and 1,635 deaths occurred in Fort McMurray and Lethbridge, respectively (Table 115). More males died than females, with a male/female ratio of 1.56 for Fort McMurray and 1.06 for Lethbridge. Overall, no difference in all causes of SMR was found between the two communities. The adjusted relative risk (RR) is 0.92 (95%CI=0.76-1.11) and 0.93 (95%CI=0.74-1.18) for males and females, respectively. This non-significant pattern is consistent across the three age groups. Similarly, significant differences were not found in the SMR of all specific causes examined between the two communities.

Table 115: Mortality Rate of All Causes of Death by Sex and Age Group, Fort McMurray vs. Lethbridge, 1995 to 1997

Sex	Age Group	Fort McMurray		Lethbridge		Relative Risk (RR) & 95%CI			p-value
	(Year)	# Death	Rate	# Death	Rate	RR	Lower	Upper	
M	0-14	11	60.9	11	33.8	1.80	0.73	4.46	0.239
	15-64	79	169.6	191	220.0	0.77	0.59	1.00	0.058
	65+	43	4,959.6	640	4,526.5	1.10	0.82	1.46	0.592
	Sub-total	**133**	**645.2**	**842**	**629.4**	**0.92**	**0.76**	**1.11**	**0.413**
F	0-14	4	23.0	7	23.0	1.00	0.29	3.41	0.754
	15-64	44	102.3	96	110.3	0.93	0.65	1.32	0.746
	65+	37	3,237.1	690	3,462.8	0.93	0.68	1.28	0.737
	Sub-total	**85**	**522.8**	**793**	**559.5**	**0.93**	**0.74**	**1.18**	**0.604**

Note: 1) The number of death for Fort McMurray and Lethbridge is based on the SGC code in Vital Statistics Database.

2) The rate was adjusted to the age distribution of two community combined population.

3) The Lower and Upper refer to the lower and upper 95% confidence limit of the RR of death in Fort McMurray.

4) Mantel-Haenszel weighted relative risk for death was estimated for the male and female population, separately.

5) chi-square test is performed for differences in the risk of the mortality between Fort McMurray and Lethbridge.

Figure 148: Relative Risk for All Causes of Deaths by Sex/Age Group in Fort McMurray Residents

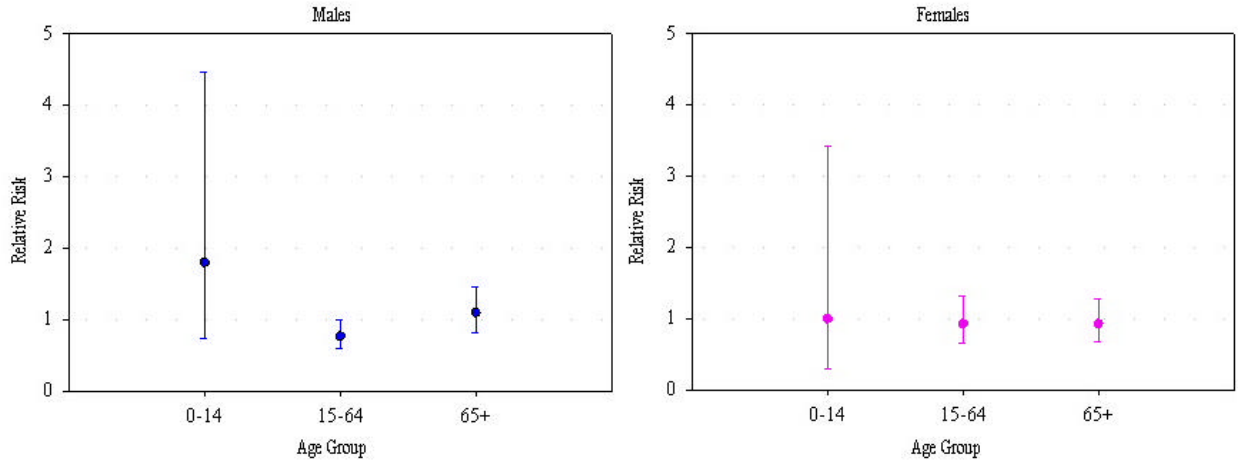
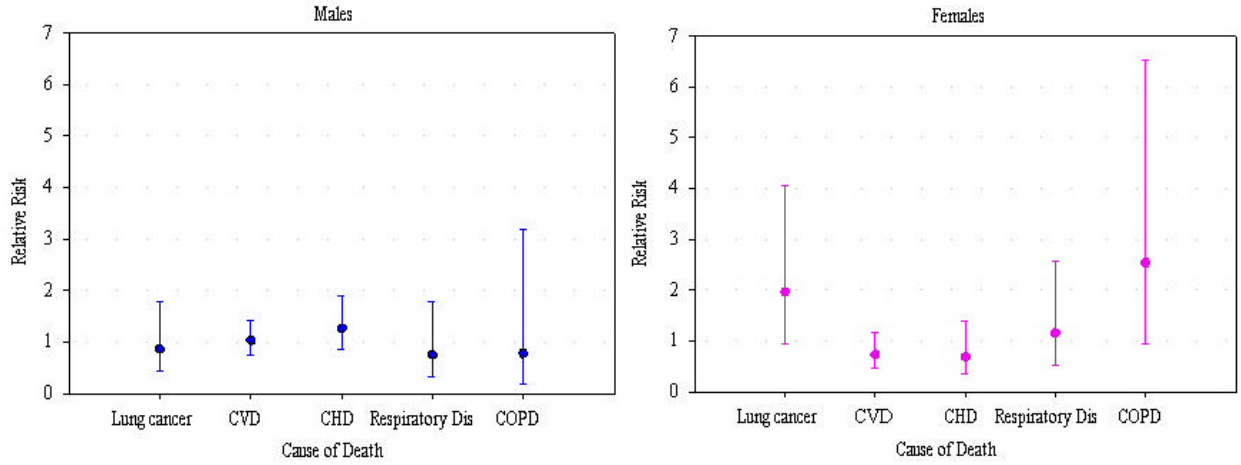


Figure 149: Relative Risk for Selected Causes of Deaths by Sex in Fort McMurray Residents



12.8.5 Comparison of Overall Illness: Participants vs. Non-Participants

A key question for the validity of inference in the current study as a whole is "Does the study sample represent the entire population for the variables of interest?" Specifically, the following analysis addressed the question, "Are the study samples more sick than the general population?" The health records for visits to a physician between January 1997 and December 1998 by study participants were compared to the visits for the rest of the population in the region.

Of the 320 study participants with complete information, 304 (95%) are matched to the Alberta Health Care Insurance Plan (AHCIP) Stakeholder Registry. Among those matched, 95% of them visited a Fee-For-Service (FFS) health care practitioner between January 1997 and December 1998. Records of all visits for any illness during the 2-year period are counted for participants and non-participants. The analysis is limited to those with a complete 2-year observation.

Figure 150: Number of Individuals and Visits For Any Illness Per 100 Person-Years, Participants vs. Non-Participants

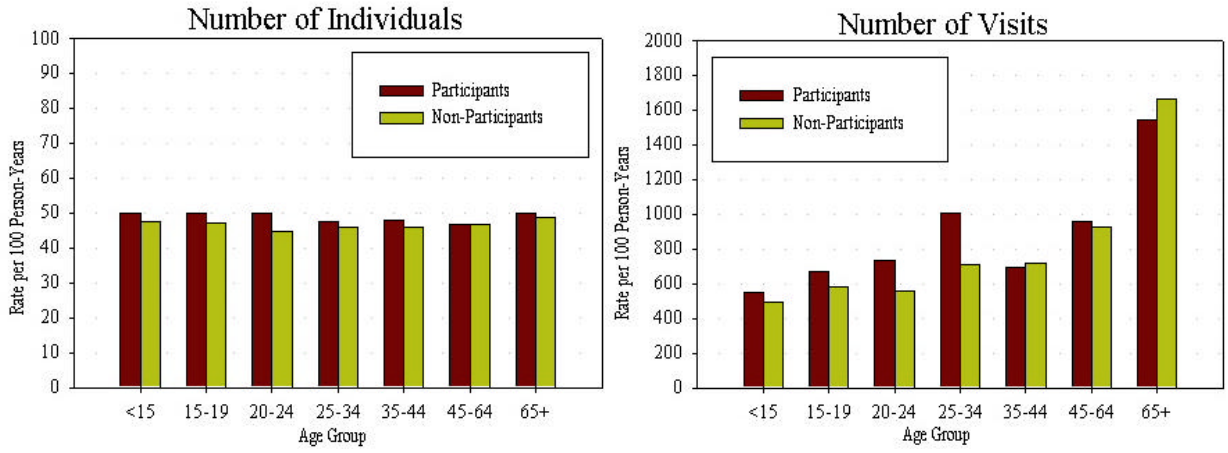


Figure 150 shows the number of individuals and visits for any illness per 100 person-years for the participants and non-participants. During the 2-year period, about 47% of the population visited a physician for any illness each year. The participants appear to have a small percentage increase in visits to a physician for all age groups, except those aged 45-64 years, although none of these differences are statistically significant ($p > 0.05$). Similarly, the frequency of visits also appears higher for participants, especially for those aged 25-34 years. The number of visits increases with age, from about 500 visits for children to 1,660 for the senior residents.

Findings from the above analysis do not provide any evidence suggesting a difference in the overall illness between the participants and non-participants of the study.

12.9 Summary of Analysis of Health Records

This section of analysis was designed to address primarily two concerns: (1) the impact of morbidity and mortality of selected diseases/causes of death on Fort McMurray residents, especially in comparison with the reference community of Lethbridge; and (2) representativeness of the study sample.

Findings from the analysis of health records suggest the following conclusions:

- There is no evidence of either a significantly higher morbidity (incidence, prevalence, number of visits) of asthma and COPD in Fort McMurray, nor an increased risk of death from all causes, lung cancer, cardiovascular disease, coronary heart disease, respiratory disorders, and COPD in this area.
- There is no statistically significant difference in the overall illness between the study participants and non-participants.
- Seasonal patterns in asthma morbidity (physician visit and hospitalization) are more pronounced in children and vary by study area. In Lethbridge, February is the highest and December is the lowest among children, while in Fort McMurray the corresponding months are May and August. No regional differences in seasonal patterns are found in the adult population.

13.0 Exposure Sources

An objective of this study was to quantify the relative contributions of various exposure sources and pathways to airborne chemicals. This section of the report will discuss sources of exposure by comparing the relative contributions of indoor vs. outdoor exposure sources. Further, outdoor sources will be categorized as local (emissions within the City of Fort McMurray), regional (oil sands and other industries outside the city), and background (levels not due to either regional industry or the city). A direct measure of the relative exposure sources was not possible with the data and information available however, indirect estimates were provided based on an analysis of meteorological and ambient air quality data and some findings of the other work in this study that addressed exposure pathways. The approach taken here provides a reasonable estimate of exposure sources but is qualitative in nature rather than quantitative.

13.1 Methods of Estimating Exposure Sources

13.1.1 Differentiating Between Indoor and Outdoor Sources

The comparison of the relative contributions of indoor vs. outdoor exposure sources will be assessed based on previous analysis of exposure relationships and pathways in Section 8.0. While the information and analysis available cannot provide conclusive quantification of indoor and outdoor sources, a qualitative assessment is possible. The assessment is based on the comparison of the indoor and outdoor levels measured and the statistical modeling of how these levels varied relative to each other (refer to Sections 7.1 and 7.2).

13.1.2 Characterising Outdoor Sources

The categorization of the outdoor sources as local, regional, and background was based on measures of meteorological conditions at the WBEA ambient station compared to contaminant levels at the station. In several studies, meteorological circumstances have been shown to characterize pollution levels in several communities around the world.[145-149] The approaches used to compare meteorological data to contaminant data varied somewhat between the studies, depending on the objective, but a common conclusion amongst most was that higher pollution levels were associated with weak surface movements of air masses (i.e., low winds or calm conditions). A study in Dublin Ireland of meteorological conditions and NO_X concluded that high concentrations of NO and NO_2 were probable whenever there was light winds and low temperatures that inhibited pollutant dispersal.[153] In Athens, researchers studying relationships between meteorological conditions and O_3, NO_2, SO_2, CO, and black smoke concluded that bad and severe conditions were mainly associated with weak air flows and almost calm conditions while good conditions were established under mainly strong northerly airflow.[154] Several studies have concluded that SO_2 levels decrease as wind speeds increase.[155-155] In some studies, other meteorological factors such as temperature and mixing height were shown to affect pollution levels.[159, 160]

This analysis compares wind speed and direction measures to contaminant concentrations to meet the objective of qualitatively characterizing local, regional, and background sources of the airborne contaminants in question.

13.1.3 Evaluation of Fort McMurray Data as an Indicator of Outdoor Sources

Data was obtained from the WBEA Athabasca air monitoring station for the time period spanning June 1997 to December 1998. The data included hourly measures of SO_2, NO_2, O_3, $PM_{2.5}$, wind speed, and

wind direction. The measures of wind speed and direction were compared with the contaminant measures in three-dimensional scatterplots. An example of the distribution of the NO_2 data with respect to the wind is shown in Figure 151. Figure 152 shows the data with the addition of a surface representing the average NO_2 levels that were estimated using a normal kernel with both bandwidth multipliers set at 0.1. The areas of the surface where there are many data points will represent a more accurate estimation of the average NO_2 levels compared with areas where there are fewer data points. The surface provides a clear comparison between NO_2 levels and the wind speed and direction. The data for O_3 and SO_2 with surfaces representing the average levels are shown in Figures 153 and 154, respectively.

In Figure 152 the surface describing average NO_2 levels reflects what has been reported in the other studies previously discussed. The figure shows that calm conditions coincide with the highest average NO_2 levels that decrease as wind speed increases. This relationship is fairly constant for all wind directions and is indicative of a build-up of NO_2 from local emission sources of during calm conditions. This figure shows that air moving into the community at high wind speeds and from any direction results in much lower levels of NO_2 than results from air over the community during low wind speeds. The contaminant measures at higher wind speeds reflect regional and background sources, which in the case of NO_2 were very low.

The surface describing the average O_3 levels in Figure 153 shows lower concentrations in calm conditions and increasing levels as wind speed increases. This is consistent with the conditions in many urban settings. O_3 is photochemically produced from reactions between NO_X and VOC in both natural and polluted atmospheres. The concentration of ground level O_3 is the result of a complex balance depending on the amount of sunlight, NO_2, NO, and VOCs present and accordingly there are diurnal and seasonal variations in the levels. While precise conclusions of local, regional, and background sources of O_3 are not possible given its complex nature, Figure 153 does seem to indicate that regional sources do not cause an increase of O_3 as evidenced by concentrations at higher wind speeds which were fairly constant in all directions. The lower levels at low wind speeds are an indication that local emissions have impacted the O_3 balance resulting in lower concentrations. This analysis indicates that O_3 is not increased due to local or regional sources and that the levels measured in the community are background levels reduced by local emissions.

Figure 154 shows the hourly SO_2 data and the average surface with little variation evident due to the expanded scale necessary to include all hourly readings. Figure 155 is the SO_2 surface without the hourly data and the scale adjusted to highlight the variations in the surface. This figure shows a very interesting relationship between average SO_2 levels and wind speed and direction. In the area of the figure showing winds from the southern directions the surface resembles the NO_2 surface with the highest concentrations of SO_2 at calm conditions and declining concentrations with increasing wind. This is indicative of local sources of SO_2. The area of the surface representing winds from the north shows similar levels for calm conditions as the southern directions but conversely the concentrations increase with increasing wind speed to a maximum concentration at speeds of around 10 km/hr. This is indicative of regional SO_2 sources north of the city. The lower SO_2 concentrations at higher wind speeds seem to indicate minimal background sources of SO_2.

The air contaminant concentrations and wind data were investigated further to ensure the relationships were stable throughout the seasons. Figures 156 to 158 show three-dimensional surfaces of NO_2, O_3, and SO_2 vs. wind speed vs. month of the year. For NO_2, Figure 156 shows that while the pattern was consistent throughout the year, there were higher concentrations during the winter months than the summer. Similarly for SO_2, Figure 158 shows that the pattern was fairly constant throughout the year but that the levels were higher in the winter. Figure 157 shows O_3 with a similar pattern of lower levels in

calm condition throughout the year, but indicates higher levels in the spring. These plots demonstrate that the characteristics of the wind diagrams were reasonably stable throughout the seasons.

Figure 151: Scatterplot of Hourly NO_2 Reading vs. Wind Speed and Wind Direction

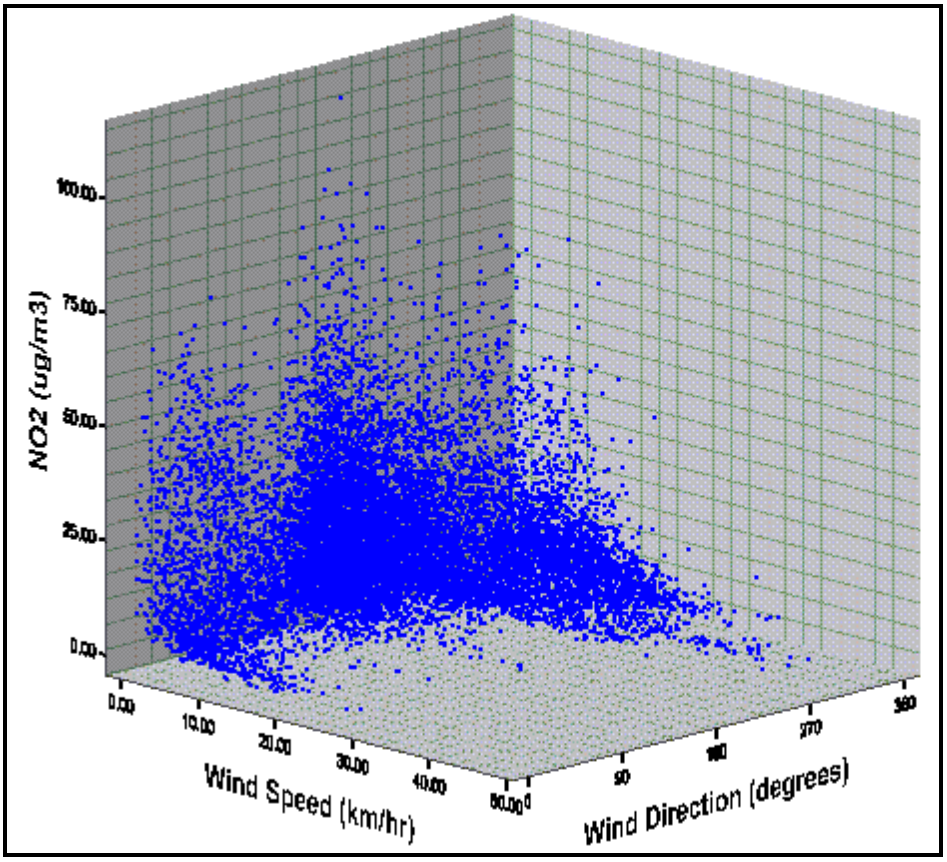


Figure 152: Hourly NO_2 Readings with Surface Representing the Average Levels of NO_2

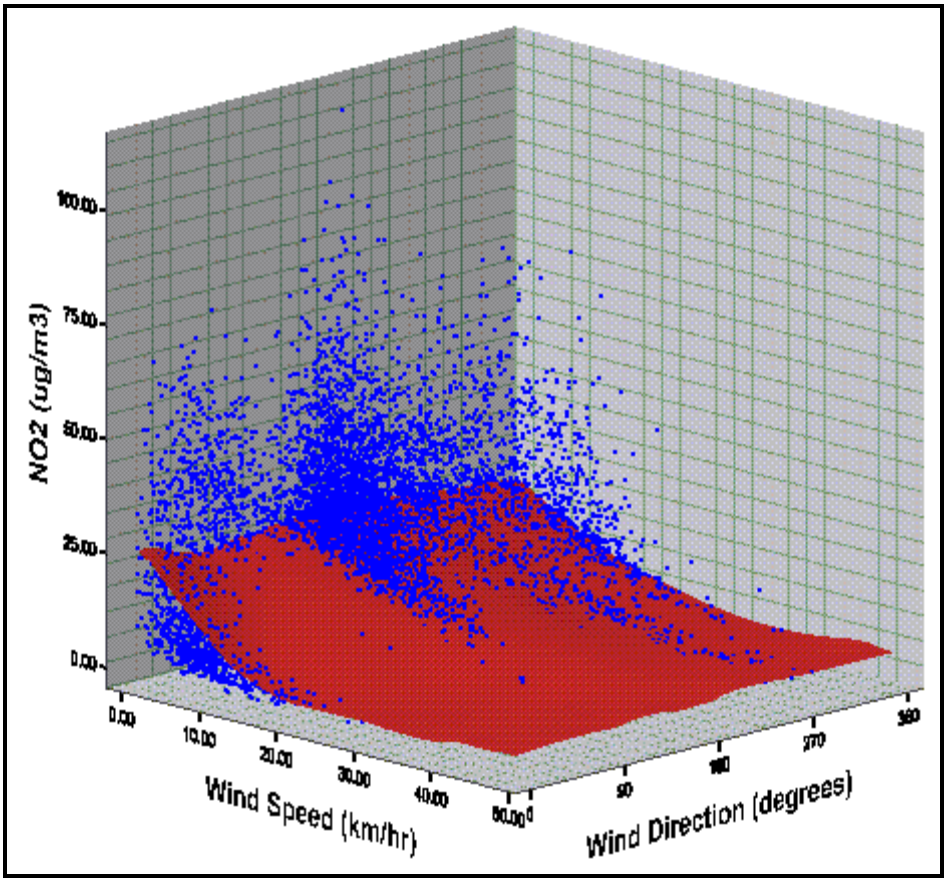


Figure 153: Hourly O_3 Readings with Surface Representing the Average Levels of O_3

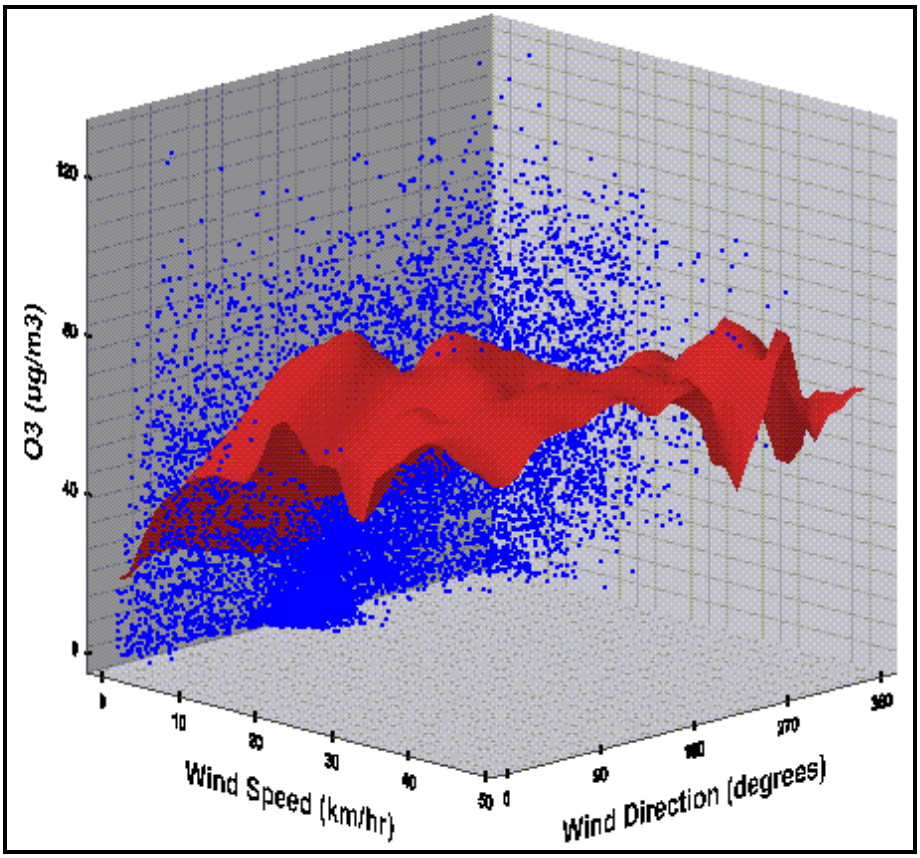


Figure 154: Hourly SO_2 Readings with Surface Representing the Average Levels of SO_2

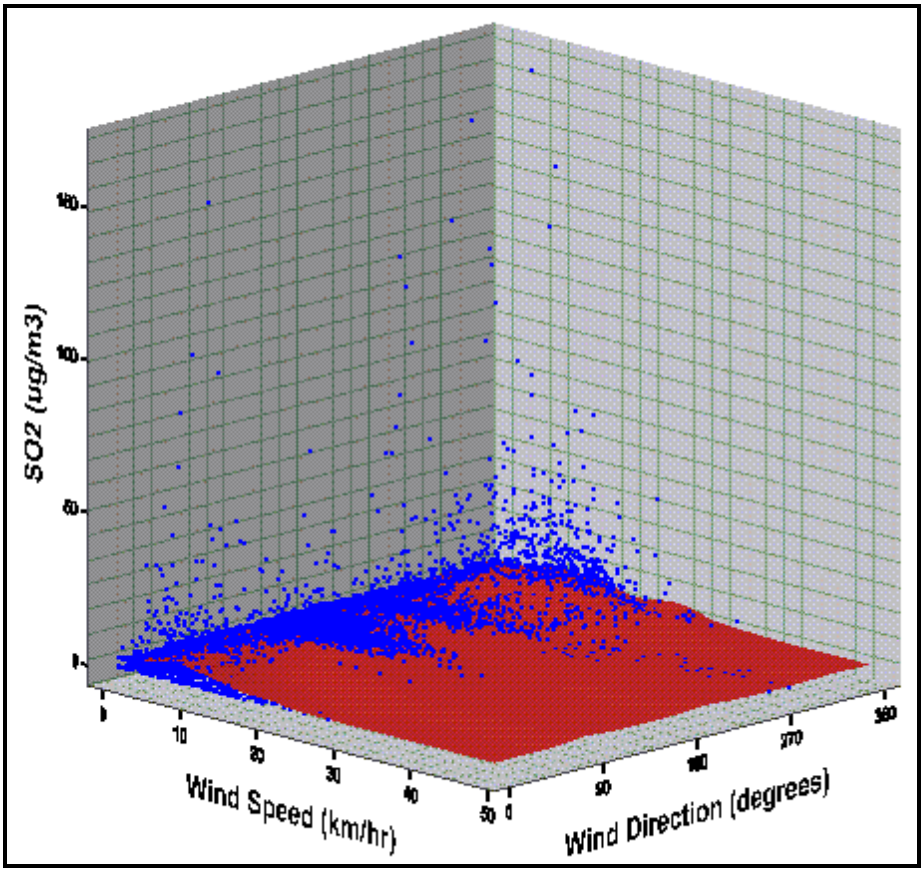


Figure 155: Average SO_2 Levels at Fort McMurray Measured by WBEA During Study (June 1997 to Dec. 1998) Plotted by Wind Speed and Wind Direction

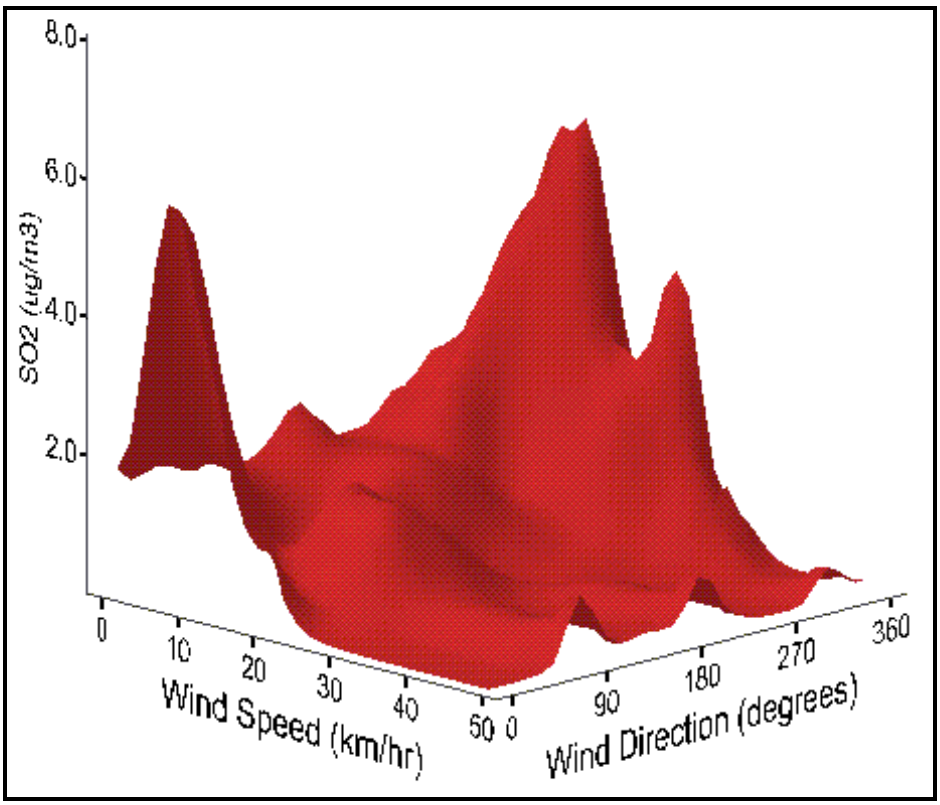


Figure 156: NO_2 vs. Wind Speed vs. Month of the Year

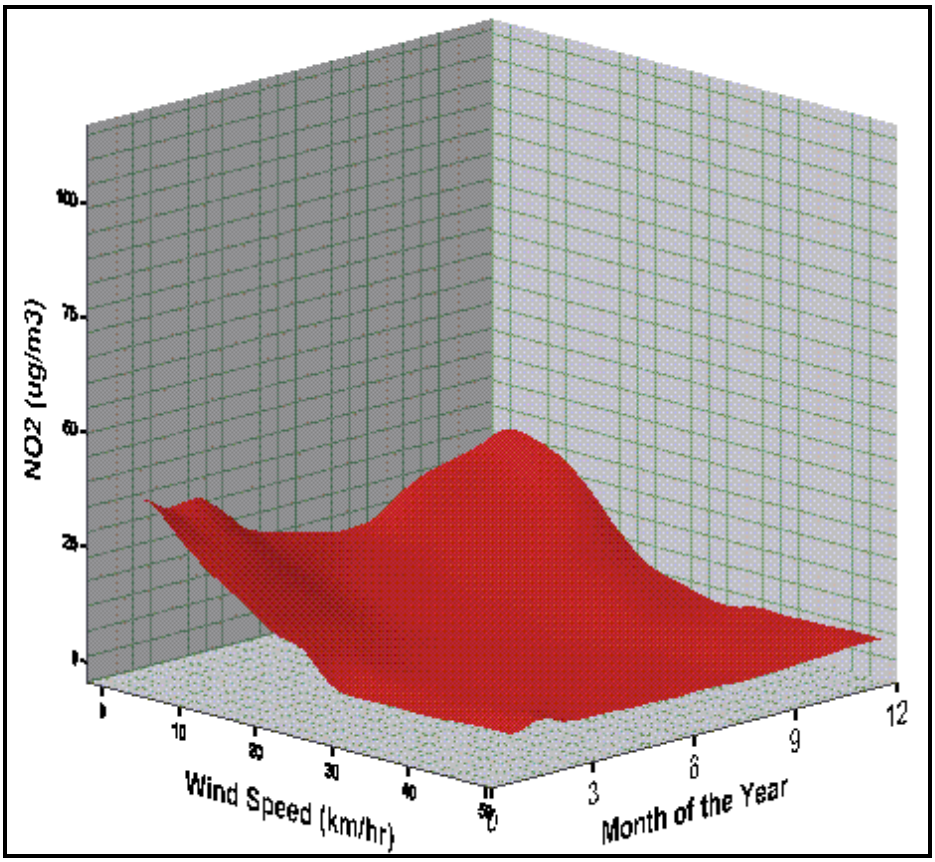


Figure 157: O_3 vs. Wind Speed vs. Month of the Year

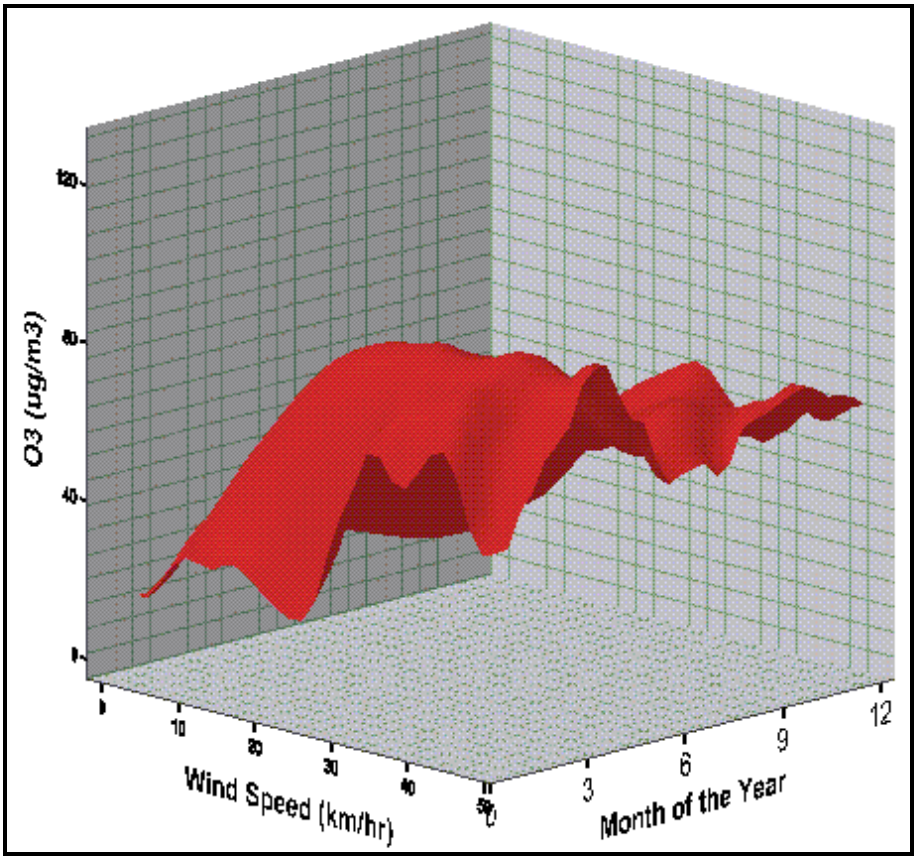
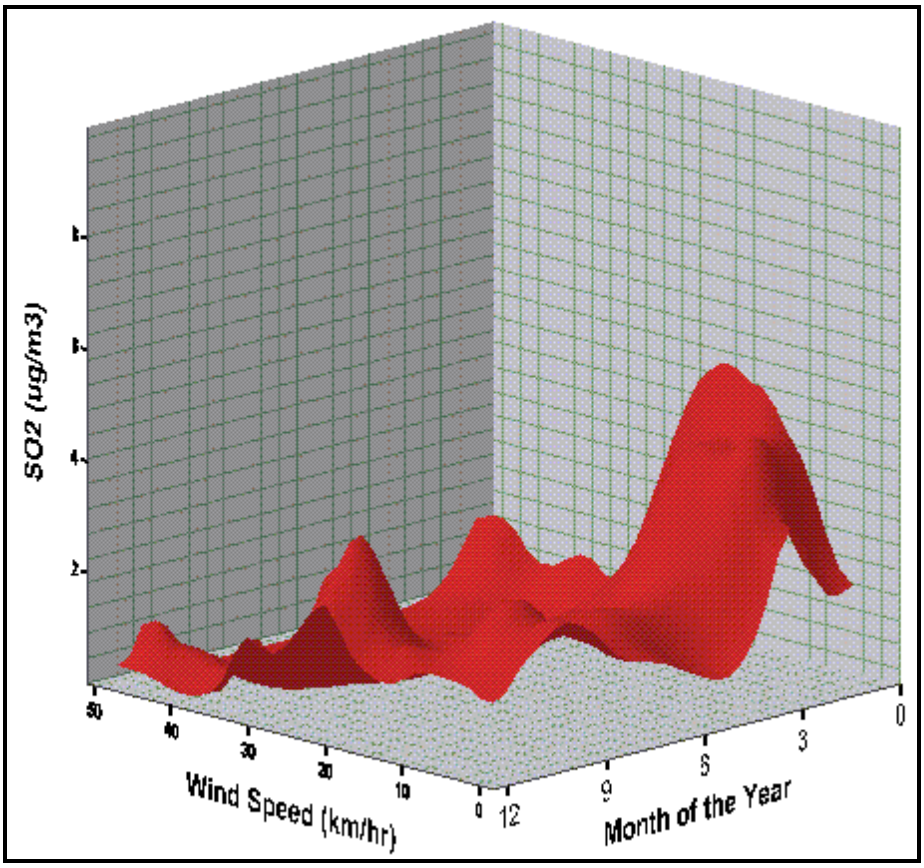


Figure 158: SO_2 vs. Wind Speed vs. Month of the Year

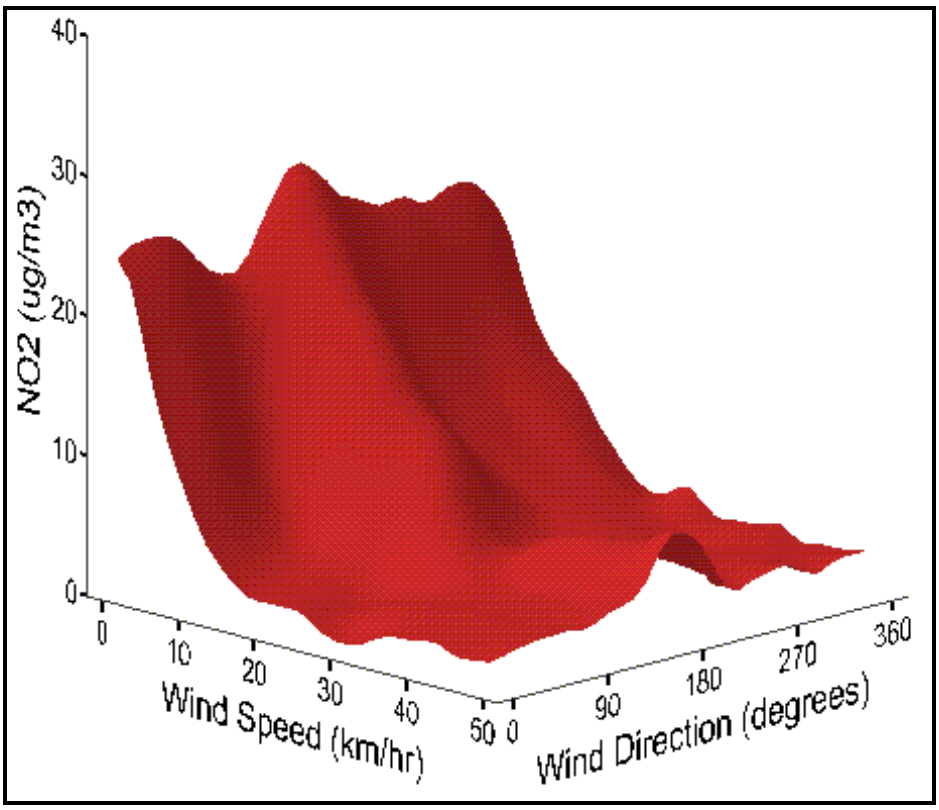


13.2 Qualification of the Relative Contributions of Exposure Sources on Personal Exposure

13.2.1 Nitrogen Dioxide (NO_2)

Figure 159 shows the average NO_2 surface alone without the hourly data points showing the highest concentration of NO_2 occurring at low wind speeds consistent for all directions. The NO_2 concentrations in the figure indicate that ambient NO_2 levels in Fort McMurray are dominated by local sources with little influence of regional or background sources being evident.

Figure 159: Average NO_2 Levels at Fort McMurray Measured by WBEA During Study (June 1997 to Dec. 1998) Plotted by Wind Speed and Wind Direction



The analysis of NO_2 exposure relationships and pathways (Section 8.4) showed both indoor and outdoor impacts on personal NO_2 exposures. The results identified outdoor levels of NO_2 as the more important driver and pathway of personal exposure. Based on these findings, local emissions of NO_2 were the largest exposure source identified while the influence of regional or background sources was not detected.

13.2.2 Sulfur Dioxide (SO_2)

Figure 155 shows a surface that represents the average of hourly SO_2 readings taken with the WBEA monitors at the Athabasca ambient station. As the figure shows, there were significantly higher average levels of SO_2 in the city of Fort McMurray when the wind was from the north (roughly 281 to 56 degrees) at moderate wind speeds. The increase in SO_2 levels in the city when winds are from the north is likely due to SO_2 emissions from the oil sands plants that are located north of the city. The significant impact of local emissions of SO_2 is illustrated through examination of the figure when the wind is from the south at low speeds. The impact of background levels was very low as is shown by the low concentration in the area of the figure with high wind speeds.

The impact of the regional SO_2 sources north of the city on the average SO_2 levels in Fort McMurray was estimated. The estimate is based on an overlay of the SO_2 surface in Figure 155 and the wind diagram in Figure 160. The wind diagram describes the percent of time the wind blows from various directions and

speeds. The wind diagram shows the predominant wind direction during the study was from south-southeast and the average wind speed was 7.5 km/hr.

A summary of the SO_2 data showing the average concentration for each condition of wind speed and direction is shown in Table 116. The wind data is summarized in Table 117 showing the number of hours each wind speed and direction conditions occurred during the study. The estimate of the relative contribution of a source of SO_2 (i.e., local, regional, or background) started with apportioning regions of the SO_2 surface in Figure 155 to the sources under consideration. For example, the SO_2 surface from between ESE and SSW (winds from the south) and all wind speeds was apportioned to local sources because of the characteristic pattern of decreasing concentrations with increasing wind speed. The surface for the other wind directions was apportioned to both local and regional sources due to the apparent combined effect. This combined local/ regional source impact was separated by assuming that the local affect seen when winds were from the south were constant for all wind directions and then subtracting the assumed local affect from the total to determine the regional source affect. The background sources impact was assumed to be zero based on the low SO_2 concentrations at high wind speeds. The magnitude of the impact of the sources on the city's average SO_2 concentrations were estimated by time weighting the apportioned SO_2 levels.

The impact of local sources was assumed constant for all wind directions and estimated from the levels shown when the wind is from the ESE to SSW. The sum of the time-weighted SO_2 concentrations due to local sources (i.e., sum of (local source attributed [SO_2] multiplied by the number of hours)) for all wind speed and direction conditions was calculated as 15,577 ($\mu g/m^3$ hr).

The SO_2 concentrations attributable to regional sources were assumed to be the difference between the average SO_2 levels measured (i.e., Figure 155 and Table 116) and the levels assigned to local sources. The sum of the time weighted SO_2 concentrations due to regional sources (i.e., sum of (regional source attributed [SO_2] multiplied by the number of hours)) for all wind speed and direction conditions was calculated as 9,191 ($\mu g/m^3$ hr).

The overall sum of the time-weighted SO_2 concentrations for all conditions of wind speed and direction (i.e., sum of ([SO_2] multiplied by the number of hours)) for all wind speed and direction conditions was calculated as 24,765 ($\mu g/m^3$ hr).

The SO_2 levels attributed to background sources was assumed to be zero. Estimates of the relative contribution of local and regional sources were as follows:

- Portion of SO_2 levels due to regional sources = 37% = (time-weighted SO_2 levels due to northern sources, 9191) / (time-weighted total SO_2 levels, 24765).
- Portion of SO_2 levels due to local or non-northern sources = 63% = (time-weighted SO_2 levels due to non-northern sources, 15577) / (time-weighted total SO_2 levels, 24765).

Figure 160: Wind Diagram Showing Frequencies of Wind Speed and Direction Combinations

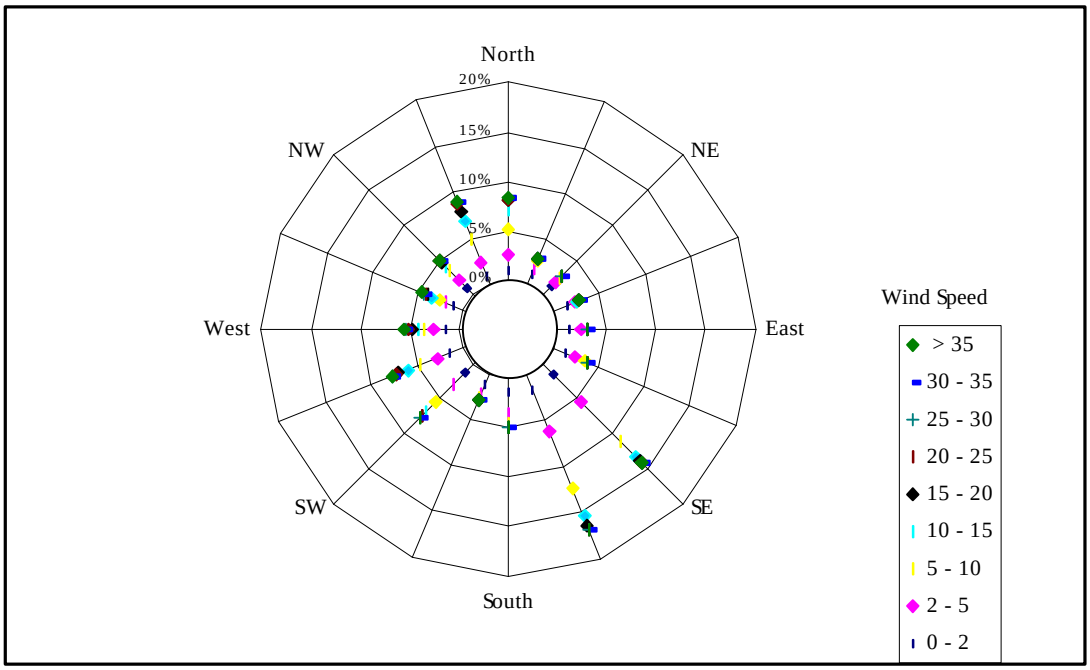


Table 116: Average SO_2 Concentration ($\mu g/m^3$) each Wind Speed and Direction Condition

Wind Direction	Wind Speed (km/hr)								
	0 - 3	3 – 5	5 - 10	10 – 15	15 - 20	20 – 25	25 30	30 - 35	> 35
North	1.80	2.68	4.82	4.83	1.77	2.62	0.00	0.00	
NNE	1.61	2.44	6.12	2.17	0.00	0.00			
NE	1.59	1.01	2.24	0.26	0.00				
ENE	1.03	1.53	1.67	0.52	0.00				
East	1.91	1.66	0.62	0.00	3.49	1.75			
ESE	1.07	1.11	1.08	0.07	0.00				
SE	1.23	1.11	0.84	0.64	1.28	0.55	1.31	0.00	
SSE	1.37	1.21	1.13	1.10	1.58	0.95	0.00		
South	2.03	1.68	1.48	1.55	0.95				
SSW	1.05	0.95	1.09	1.69					
SW	1.21	1.24	1.24	1.37	0.68	0.46	0.00		
WSW	1.71	2.40	0.83	0.72	0.58	0.39	0.24	0.33	
West	1.64	1.71	3.24	1.68	0.30	0.41	0.17	0.00	0.00
WNW	2.09	1.72	2.29	0.39	0.32	0.21	0.00	0.00	0.00
NW	2.19	2.57	4.60	1.71	2.69	1.84	0.29		
NNW	2.31	3.04	5.17	6.16	3.21	1.88	2.22	2.62	

Table 117: Number of Hours each Wind Speed and Direction Condition Occurred During the Study

Wind Direction	Wind Speed (km/hr)									Total
	0 - 3	3 - 5	5 - 10	10 - 15	15 - 20	20 - 25	25 30	30 – 35	> 35	
North	122	212	371	270	126	18	5	2		1126
NNE	120	124	91	31	13	3				382
NE	153	98	73	10	1					335
ENE	180	128	48	5	1					362
East	164	162	66	12	7	3				414
ESE	144	172	130	39	4					489
SE	183	564	733	323	84	25	4	3		1919
SSE	216	609	859	440	132	38	1			2295
South	186	286	160	35	11	3				681
SSW	140	151	59	17	2					369
SW	154	257	336	177	66	17	8			1015
WSW	187	193	238	194	127	62	46	10		1057
West	180	163	129	97	71	47	49	14	14	764
WNW	132	131	92	88	83	51	21	5	4	607
NW	120	183	141	101	69	37	10			661
NNW	108	210	353	260	160	87	27	3		1208
Total	2489	3643	3879	2099	957	391	171	37	18	13684

The SO_2 levels in Fort McMurray are significantly higher when influenced by northern regional sources. Based on wind speed and direction data, 37% of the average SO_2 concentrations in Fort McMurray were attributable to these regional sources. This result is sensitive to wind direction. During this study, the wind blew from the north roughly 25% of the time. If wind from the north increases in the future, it would be expected that the oil sands plants influence on the SO_2 levels would also increase. It should be reiterated that these SO_2 levels are considered low compared to current guidelines.

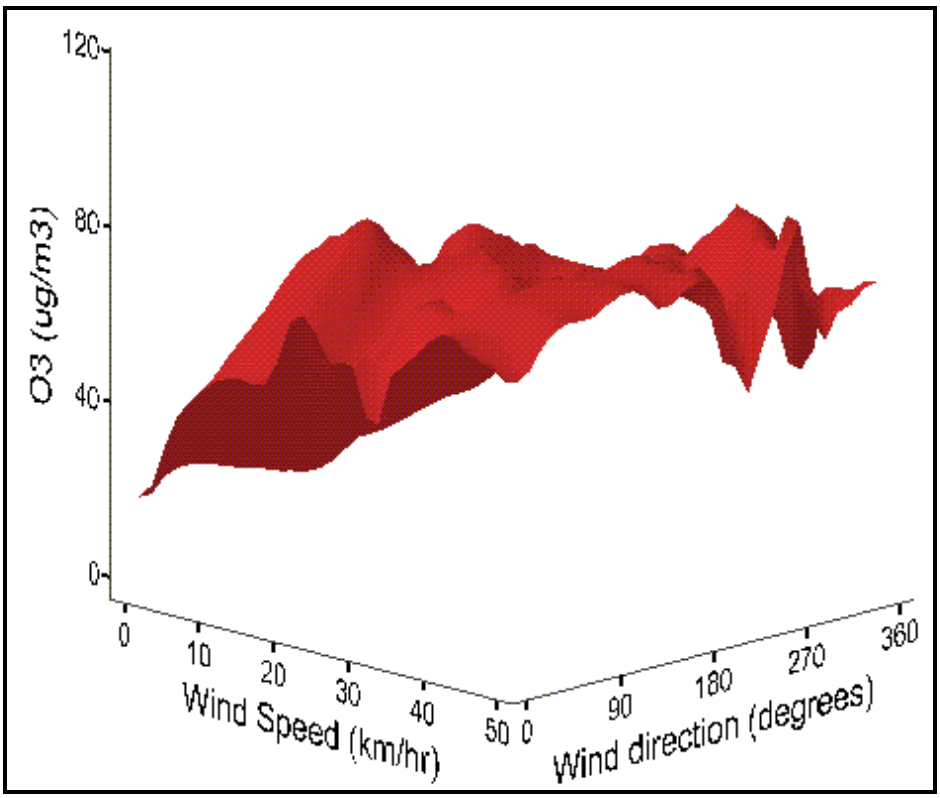
Section 8.5 identified outdoor levels of SO_2 as an important driver of personal exposure both directly and through indoor air. This analysis indicates that local urban emissions and oil sands plant emissions have a significant impact on the ambient SO_2 levels in Fort McMurray. Based on these findings, the most important exposure source identified during this study was local sources followed by regional sources while background influences could not be identified.

13.2.3 Ozone

Figure 161 shows the surface representing the average ozone levels during the study. As shown, the highest levels of ozone occurred during higher wind speeds. These ambient levels did not predict personal exposures well (refer to Sections 7.1.3 and 8.6). This figure demonstrates the classic characteristics of ozone in many urban areas, namely, lower concentrations of ozone due to interactions with urban pollutants during low wind speeds (low winds coincide with higher pollutant concentrations); and, higher concentrations of ozone coincidental with lower urban pollution during high wind speeds. The figure does not demonstrate that the levels of ozone in Fort McMurray are significantly impacted by regional pollution sources, but it does suggest that local urban pollution was an important influence on the ozone levels.

The behavior of ozone in the environment is very complex, making it difficult to draw succinct conclusions as to important exposure sources. This analysis indicates that outdoor air is the source of ozone in personal exposure and that background sources are the most important relative source with regional and local sources not increasing personal exposure to ozone.

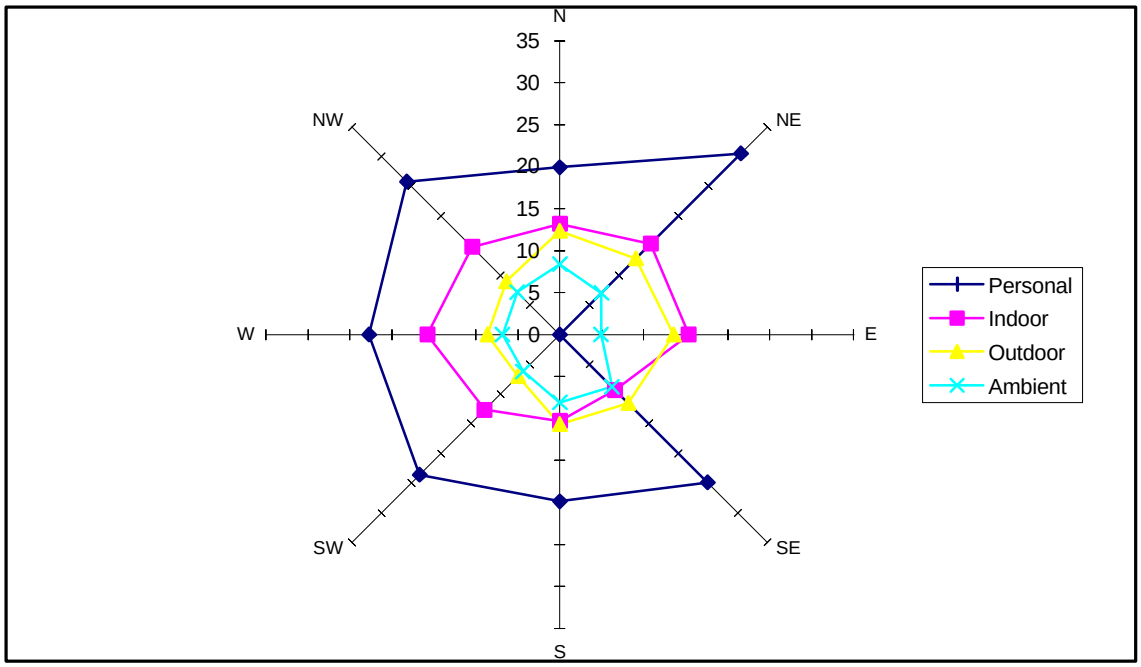
Figure 161: Average O_3 Levels at Fort McMurray Measured by WBEA During Study (June 1997 to Dec. 1998) Plotted by Wind Speed and Wind Direction



13.2.4 Particulate Matter ($PM_{2.5}$)

The analysis of exposure pathways for $PM_{2.5}$ demonstrated that outdoor concentrations were not a significant pathway for $PM_{2.5}$ exposures and that personal activities and indoor air were most important (refer to Section 8.8). The personal activity that was most important was time spent outdoors at the oil sands plants, which indicates higher levels of $PM_{2.5}$ in that environment. An analysis of the effect of wind direction on the mass concentration of $PM_{2.5}$ in samples collected for this study concluded that these higher $PM_{2.5}$ levels were not detectable in the Fort McMurray samples (Figure 162). Based on these findings, indoor air and personal activities) is the most important exposure source while the influence of outdoor air (local, regional, and background sources) was not detectable.

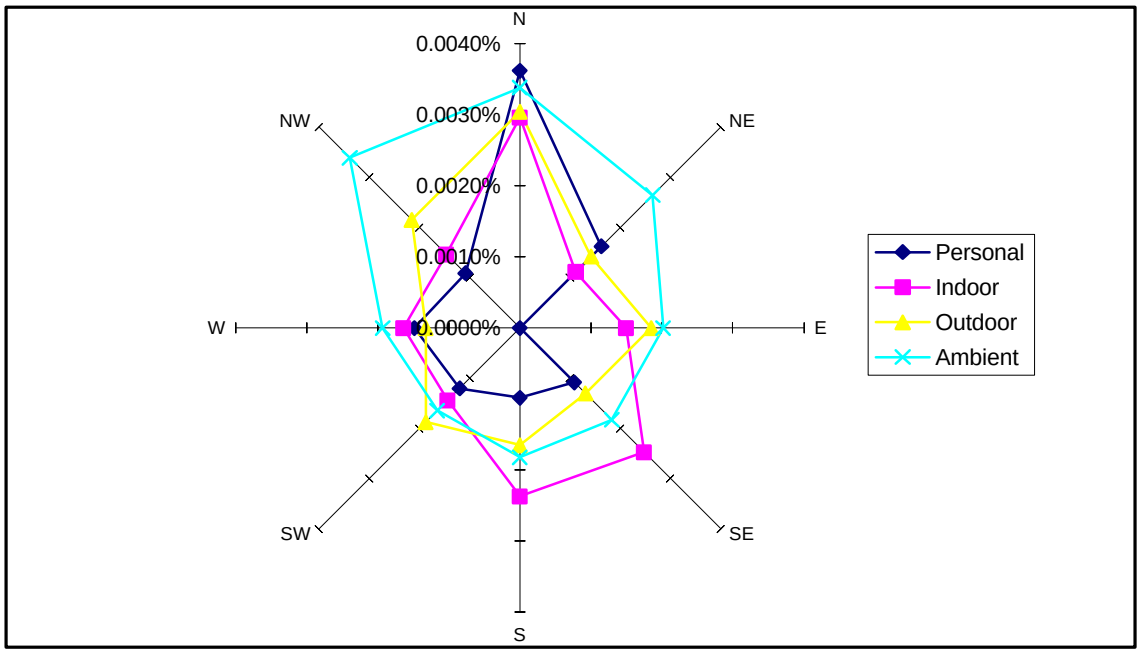
Figure 162: Average $PM_{2.5}$ Mass Concentration ($\mu g/m^3$) by Average Wind Direction during Sampling



To further investigate the exposure sources of $PM_{2.5}$, an analysis was undertaken focusing on the composition of the $PM_{2.5}$. The analysis identified that the percent of vanadium in $PM_{2.5}$ may be an indicator of oil sands industry sources. This was based on significantly higher $PM_{2.5}$-bound vanadium exposures for participants spending time at the plants and significant increases in the vanadium concentration when the wind was from the north in the $PM_{2.5}$ collected at the ambient air station in Fort McMurray. Figure 163 shows that the higher vanadium fractions of the $PM_{2.5}$ occur when the wind is from the north in personal, indoor, outdoor, and ambient station samples, though only the ambient samples were statistically significant. The data suggests that levels of $PM_{2.5}$-bound vanadium on personal, indoor, and outdoor samples in Fort McMurray were also impacted from the oil sands plants, although there were not enough samples to show statistical significance. The results also suggested increased levels on non-plant workers through ambient air, however there was insufficient data to conclude this with confidence. There is no indication that the levels of vanadium measured are a concern to human health.

In summary, the impacts of regional sources on the mass concentration of $PM_{2.5}$ in personal exposures were indistinguishable from other sources and background levels. Using $PM_{2.5}$-bound vanadium as an indicator of oil sands industry emissions of $PM_{2.5}$ enabled the identification of oil sands activity on the character of $PM_{2.5}$ in the ambient air in Fort McMurray and personal exposures of plant employees and suggested impacts on indoor air and exposure for all residents. This may be a useful indicator in future assessments as it may distinguish between local sources of particulate matter and industrial sources.

Figure 163: Percent Vanadium in $PM_{2.5}$ Compared to Average Wind Direction during Sampling



14.0 End Notes

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Management Committee

The Management Committee was responsible for providing overall direction to the program to ensure that the objectives and intent of the program were carried out. The participating organizations are currently represented by:

Alberta Health and Wellness	Alexander MacKenzie
Community of Fort McMurray (member at large)	Debbie White
Fort McKay First Nation	Ken Shipley
Fort McMurray Environmental Association	Ann Dort-McLean
Northern Lights Regional Health Services	Dalton Russell
Suncor Energy	Tim Gondek
Syncrude Canada	Dr. Ken Nickerson

Operations Committee

The Operations Committee was responsible for managing the affairs of the program between meetings of the Management Committee. The Operations Committee included representatives from the following organizations:

Alberta Health and Wellness	Alexander MacKenzie
Community of Fort McMurray (member at large)	Debbie White
Northern Lights Regional Health Services	Patricia Pelton

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Appendix A

Fine Aerosol Chemistry at Dissimilar Non-urban Sites

Previously Presented at the International Global Atmospheric Chemistry Conference in Seattle, Washington from August 19-25, 1998, by
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Fine Aerosol Chemistry at Dissimilar Non-urban Sites

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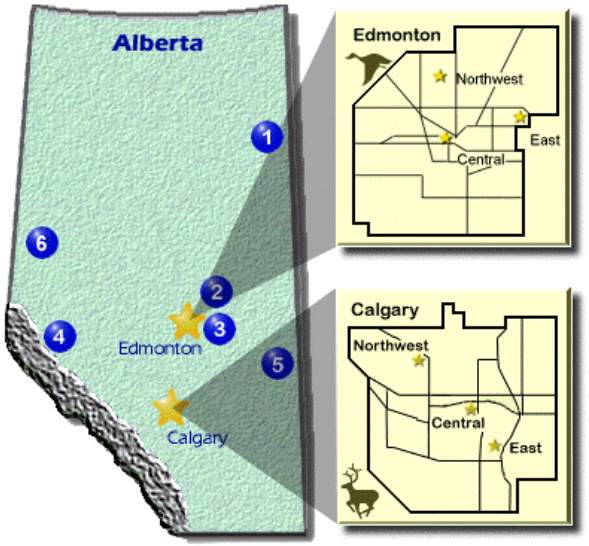
Introduction:

Particulate Matter (PM) sampling for chemical analysis was performed at two sites in Alberta, Canada. One site, Esther, is an extremely clean background site with no nearby sources. It does tend to be impacted by localized dust events leading to elevated coarse PM concentrations [Bailey, 1994] but the fine PM levels are near background. The other site, Fort McMurray, is a small community with heavy industry (including mining and oil sands upgrading) about 40 km distant. Although both are non-urban sites and have similar levels of fine PM in the atmosphere, the chemistry of that fine PM is dramatically different. The concern is that simply measuring PM mass to monitor the impact of the industrial operations will not sufficiently describe the potential risk to human health in the nearby communities.



Map showing air quality monitoring stations in Alberta, Canada. Position #1 is Fort McMurray and position #5 is Esther. The major urban centres are located at the stars.

Experiments:

(1) Analysis of Airborne Particulate Matter at Esther, Alberta

The sampler is installed on an existing CAPMoN (Canadian Air and Precipitation Monitoring Network) site in the southeastern part of Alberta about 13.7 km west of the Saskatchewan border. Both the filter module and the pump house are on a roof of a trailer. Module inlet stack is about 5.5 m above ground. Esther is sited at 51°40′ north latitude and 110°12′ west longitude at an elevation of 616 m above sea level. This is an extremely clean site used as a continental background station for acid precipitation and photochemistry.

The University of Guelph has installed a sampler which is compatible with Module A ($PM_{2.5}$ at 22.9 L/min) of the IMPROVE (Interagency Monitoring of Protected Visual Environments) protocol. This includes analytical measurements of fine PM mass and elemental composition (Na-Pb).

Gravimetric Mass Analysis

The measured variable is $PM_{2.5}$ mass. A computer controlled Mettler MT5 microbalance is used to weigh the Teflon filters (total mass around 40mg) with 1µg precision and about 2µg reproducibility. The average particulate loading is around 200µg.

Particle Induced X-Ray Emission (PIXE)

Measured variables include air concentrations of elements with atomic number from Z=11 to 83 (sodium to bismuth). X-ray emission occurs when an electron is removed from one of the inner electron shells of an atom (during collision with a projectile) and the vacancy is subsequently filled by another electron falling from a higher shell. The characteristic x-ray photons are then collected. The minimum detection limit of PIXE analysis of environmental samples is in the range of ng/m^3, depending on the trace element and sample composition. The new Guelph target chamber simultaneously utilizes two x- ray detectors, one for light elements (sodium to chlorine) and another for heavy elements (potassium to bismuth). This setup increases sensitivity for elements with low atomic number (sodium,

silicon) and provides a crosscheck on the analysis. The chamber allows fully automatic analysis of aerosol filters mounted in slide frames.

For more information, please see:

http://www.physics.uoguelph.ca/PIXE/airq/airq.html

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Robert A. Eldred, IMPROVE Sampler Manual, version 2, January 1988, Air Quality Group, Crocker Nuclear Laboratory, University of California, Davis, CA 95616.

(2) Analysis of Airborne Particulate Matter at Fort McMurray, Alberta

Environment Canada's eight-stage cascade impactor was installed in the Alberta Environmental Protection air quality monitoring compound in Fort McMurray, Alberta. This is situated in a small community with developments to extract bitumen from oil sands which are situated about 40 km north of the monitoring station. Alberta Heath operated the sampler collecting 6-day integrated samples of particulate matter (PM) between August and October, 1997. Each filter stage in the sampler was analyzed for the total PM mass concentration as well as chemical components at the Alberta Research Council (ARC) environmental laboratories in Vegreville, Alberta.

Mass of Particulate Matter

An analytical microbalance with the sensitivity of 10 µg is used to determine the mass of PM gravimetrically at a temperature of 23 ±3 C. For the Teflon membrane filter (80 mm in diameter), the instrumental detection limit (3s) is 30 µg (n=10). The average particle loading per filter is 340 µg.

Chemical Composition of Particulate Matter

An automated ion chromatography system located in a "clean" room is dedicated to the analysis of anions and cations from dry and wet deposition of air samples. The anions include sulphate, nitrate, chloride and phosphate. The cations include ammonium, calcium, sodium, magnesium and potassium. A clean room facility equipped with a class-100 fume hood is dedicated to sample preparation and/or digestion for the elemental determination of PM at ultra-trace levels. An ICP-MS (inductively couple plasma - mass spectrometer) system equipped with either a pneumatic or an ultrasonic nebulizer is dedicated to elemental analysis at trace and ultra-trace levels. Methods have been developed for the determination of the elemental composition of PM (with mass of 0.02 - 2 mg collected on Teflon filters). The elements determined are shown with green in the periodic table. For the majority of elements, the detection limits of the ICP-MS method are comparable to or better than those obtained by XRF (x-ray fluorescence spectrometry) and INAA (instrument neutron activation analysis).

For more information, please see:

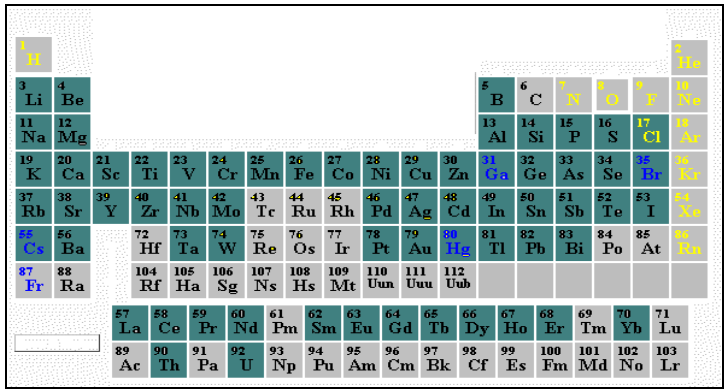
http://www.arc.ab.ca/

L.M. Jalkanen and E.K. Hasanen (1996) *J. Analytical Atomic Spectrometry*, 11, 365-369.

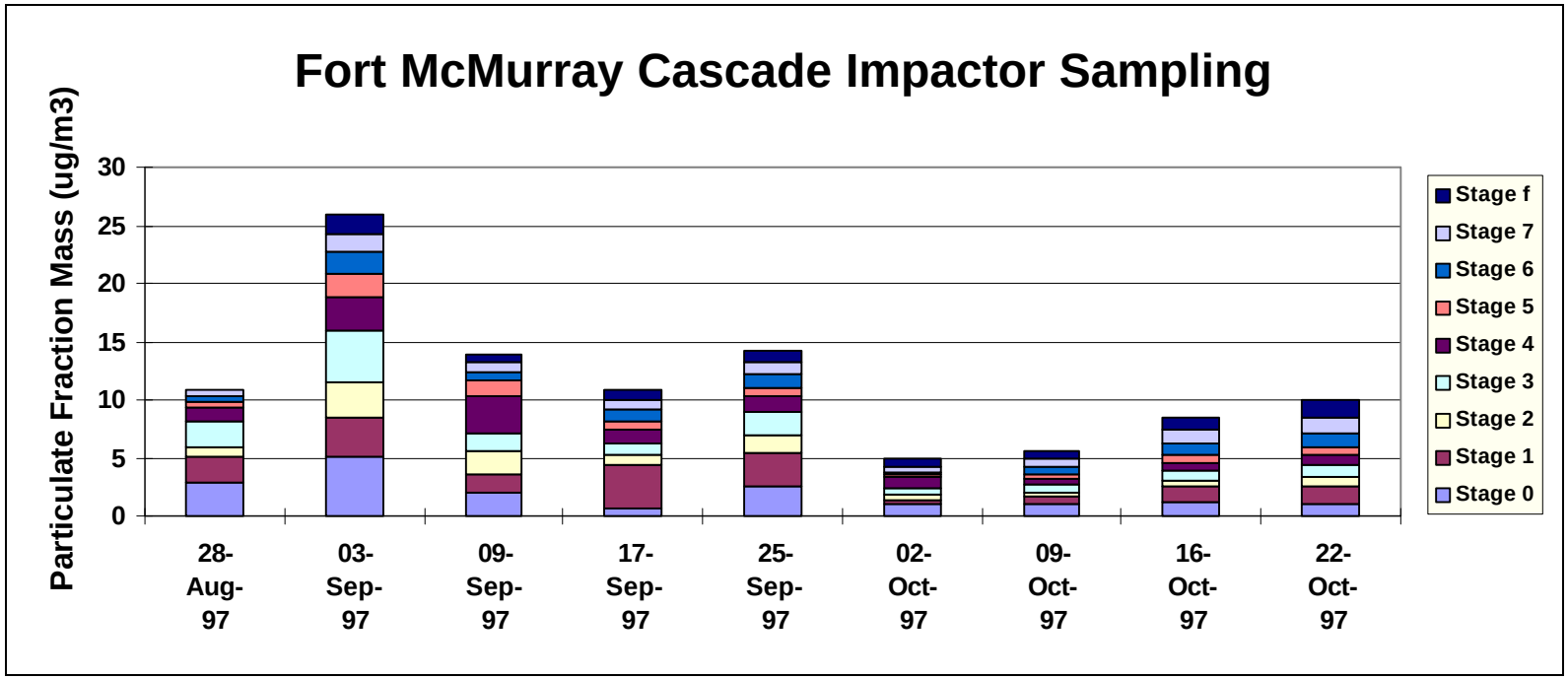
Results:

One: Fort McMurray eight-stage cascade impactor comparison of the size fractions and cumulative percent average mass showing definitions of fine particulate matter (FPM) and coarse particulate matter (CPM) as used in this comparison. The mass collected and chemistry of each stage is determined separately.

	Stage	Size Fraction (microns)	% Mass of Fraction	Cumulative % Mass
	0	9.0 to 10.0	0.166	0.166
CPM	1	5.8 to 9.0	0.164	0.330
	2	4.7 to 5.8	0.092	0.422
	3	3.3 to 4.7	0.130	0.552
	4	2.1 to 3.3	0.122	0.673
	5	1.1 to 2.1	0.065	0.738
FPM	6	0.65 to 1.1	0.083	0.821
	7	0.43 to 0.65	0.093	0.913
	f	0 to 0.43	0.087	1.000

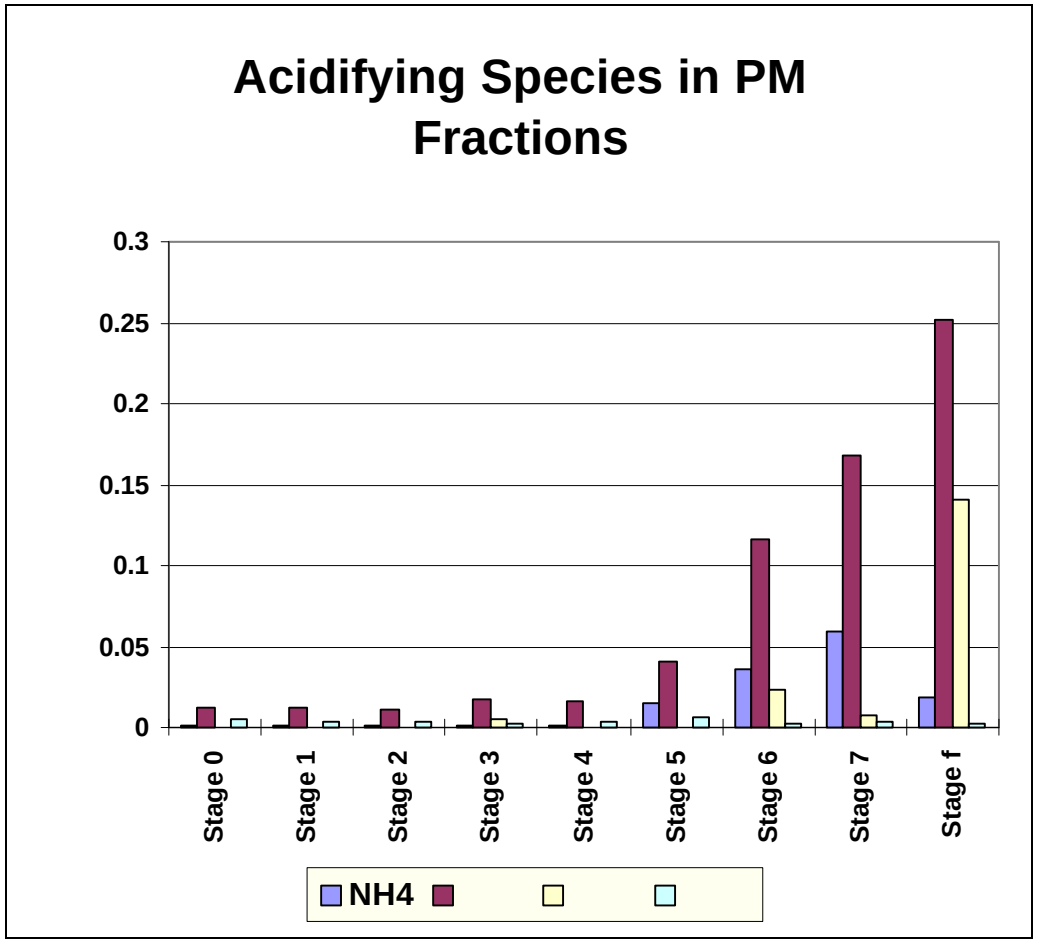


Two: Integrated PM mass concentration averaged over the six-day sampling periods starting on the date is shown separated according to the stages described. The average meteorological conditions for each period are listed for comparison.



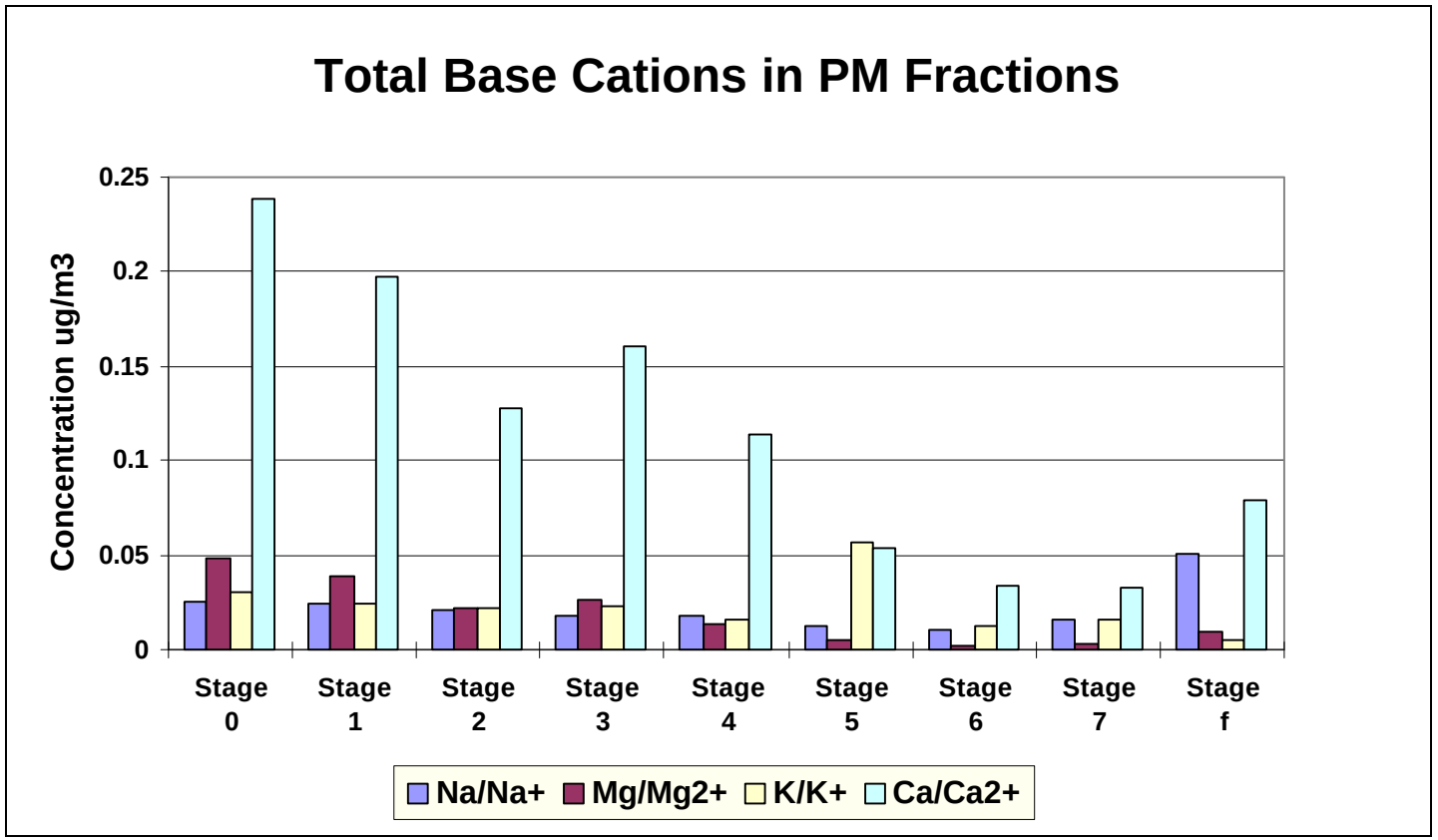
	Start date	Aug 28	Sep 3	Sep 9	Sep 17	Sep 25	Oct 2	Oct 9	Oct 16	Oct 22
	End date	**Sep 3**	**Sep 9**	**Sep 15**	**Sep 23**	**Oct 1**	**Oct 8**	**Oct 16**	**Oct 22**	**Oct 28**
Wind Speed	avg km/h	8.8	7.0	9.7	10.4	11.6	11.6	10.2	8.5	10.7
Wind Direction	avg deg CW from N	150.0	172.8	158.6	202.9	174.8	207.2	182.4	153.3	145.4
Temperature	avg deg C	13.3	13.5	9.0	9.5	11.0	2.9	-0.2	0.7	0.4
Relative Humidity	avg %	73.6	84.6	90.5	75.5	83.3	78.8	88.0	84.5	86.2
Precipitation	total mm	3.8	12.4	96.6	2.4	37.0	12.0	14.0	1.6	7.6

Three: The acidifying species are contained primarily in the fine size fractions. This implies that the source for these compounds is likely combustion and corroborates the significant daily SO_2 and NO_x emissions from the oil sands operations [Suncor, 1998].

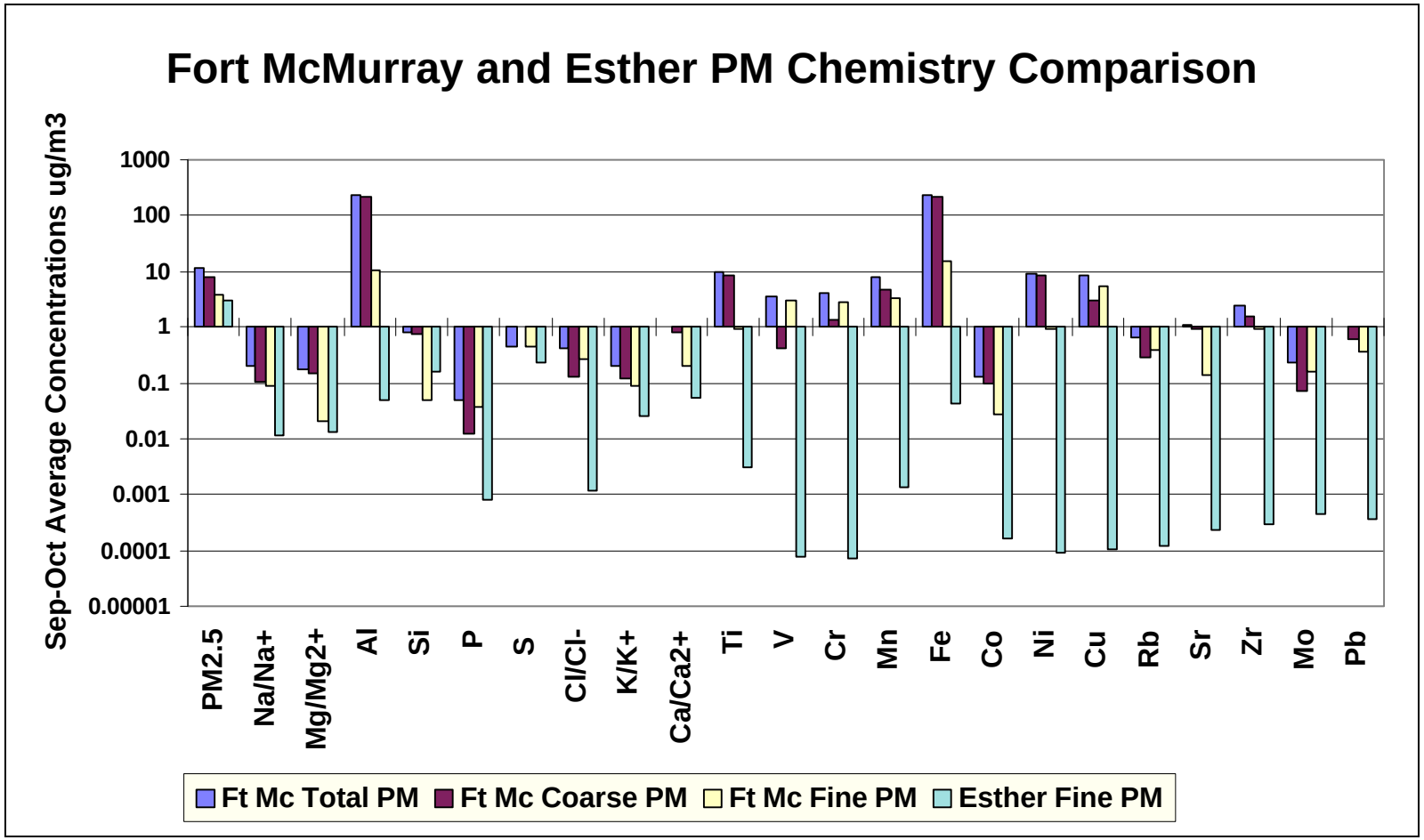


Emissions in T/d	SO_2	NO_x	Primary PM_{10}
Suncor	65.3	47.7	1.7
Syncrude	209.0	44.4	5.4
Others	3.9	8.7	0.9
Residents	0.2	1.4	1.5
Total	278.4	102.2	9.5

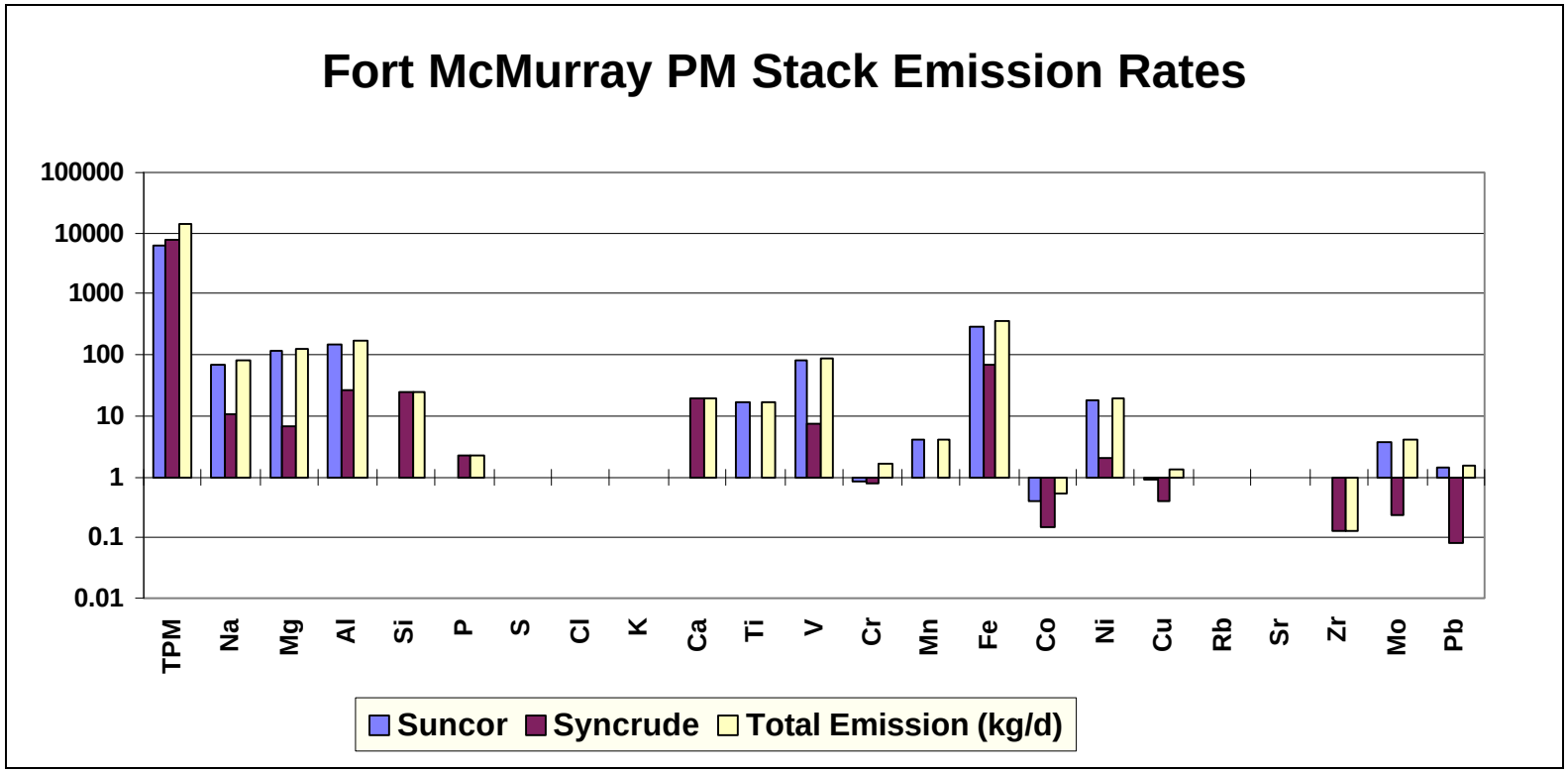
Four: Base cations especially calcium are found for the most part in the coarser components. This is not surprising since road dust and other soil breakdown sources are responsible for the coarse fraction. The operational mining activity in the industrial area likely contributes to these concentrations as well as natural background sources. Note that there is substantial sodium and calcium found in the very finest fraction.



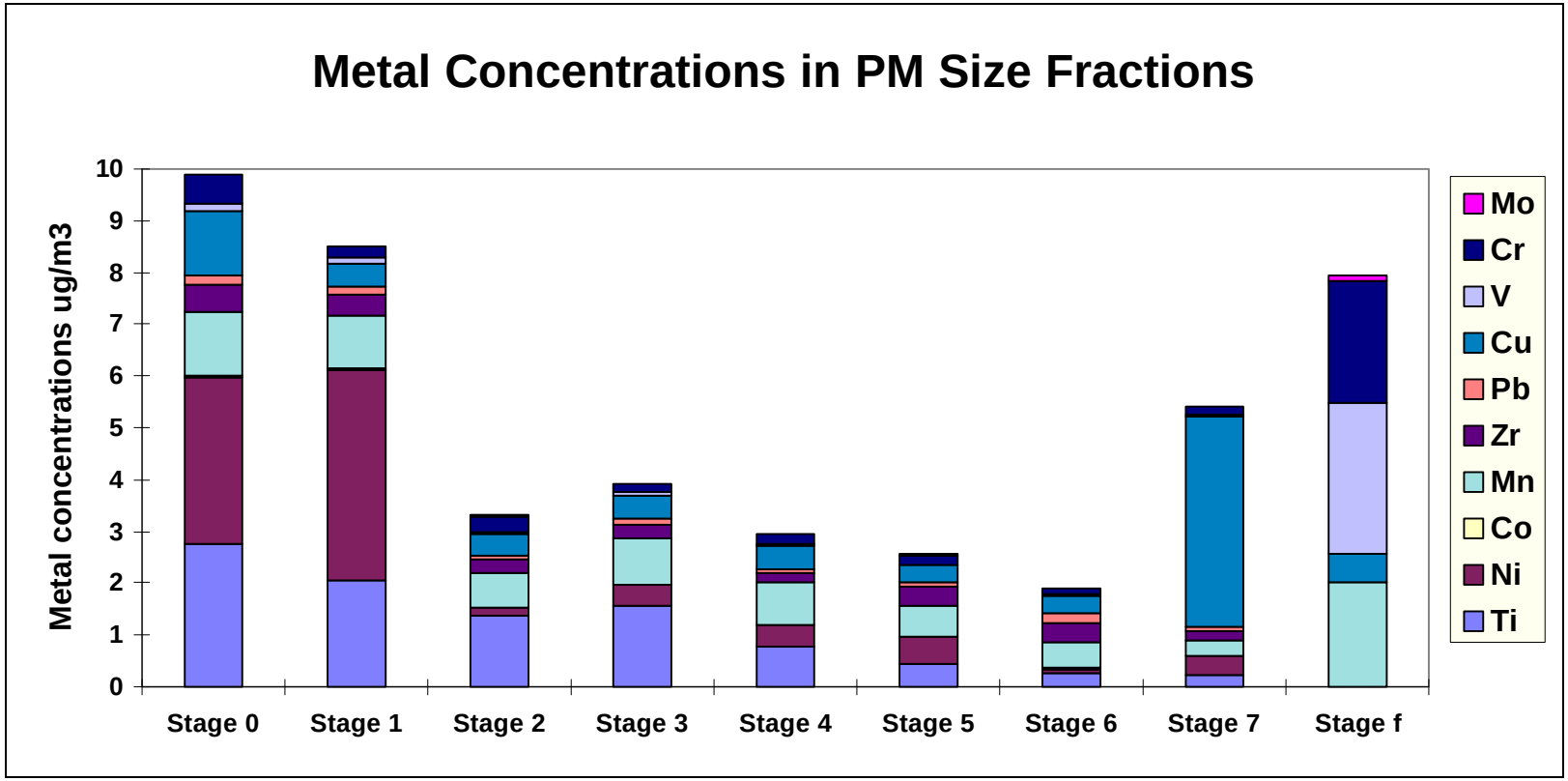
Five: Comparison of the chemistry of the PM shows clearly the difference in the two sites. The fine PM concentration is similar at Esther (3.1 µg/m^3) and Fort McMurray (3.7 µg/m^3) -- concentrations typical of rural sites in Alberta [Cheng, 1998]. However, the chemical components of the two sites are significantly different.



Six: Evidence of the impact of PM emissions from the industrial operations on the PM concentrations of the metals in air collected at the community of Fort McMurray is seen when the stack emissions (kg/day) are compared with the concentration fingerprints.



Seven: Some metallic species tend to show both a coarse and a fine fraction allowing the separation of the two source components. Species such as iron, aluminum, titanium, nickel and cobalt are elevated in the coarser fractions indicating a terrestrial source which could be natural or due to the mining operations. Meanwhile, zinc, lead, and manganese which are associated with fuel use are also elevated in the fine fractions. Species that are predominantly in the fine fraction include copper, vanadium, chromium and molybdenum implying that they may be due to combustion stack emissions. In addition, uranium and mercury (species not measured in Esther) are found almost exclusively in the very fine fraction of PM<0.43 microns indicating that an atmospheric gaseous source is the most likely mechanism for the PM.



Conclusions:

The comparison of Fort McMurray data with that from Esther has revealed some striking difference in the chemistry despite having similar levels of fine particulate matter mass. Measuring simply the PM mass has lead to misplaced conclusions that Fort McMurray can be considered a rural site. Clearly, the chemistry of the PM is not that found at the background site in Esther. To make an adequate assessment of human health risk, it is not sufficient to measure PM mass in an area under the influence of heavy industry.

The sample set collected in Fort McMurray is very rich and will require substantial statistical analysis to produce an excellent baseline for comparison with monitoring following future development in the area. The chemical components of the particulate matter (PM) will be helpful in determining source emission indicators. When coupled with the meteorology, the production and transport of PM from soil-based and combustion-based processes can be distinguished. The relative components of size fractions will allow a comparison with other communities to determine whether or not health impacts could be expected. Finally, the PM component of acidic deposition, ammonia deposition, and heavy metal deposition can be determined providing information filling important data gaps in other priority areas.

References:

Bailey, R. (1994) *Preliminary evaluation of the efficiency of the filter pack system in measuring particulate acid ion concentrations at Esther, Alberta*. Atmospheric Environment Service, Prairie & Northern Region report.

Bovar Environmental (1996) *Ambient air quality predictions in the Athabasca Oil Sands region* (Report 4), report prepared for Suncor Inc. and Syncrude Canada Ltd.

Cheng, L., H.S. Sandhu, R.P. Angle, K. McDonald, R.H. Myrick (1998) Inhalable particulate matter in rural Alberta, (in preparation).

Suncor (1998) *Project Millennium Application*, April 1998.

Appendix B

The Variation of Air Contaminant Levels in Selected Indoor and Outdoor Environments

SUMMARY

This investigation was undertaken to identify areas of high air contaminant concentrations in the indoor and outdoor environments that are not being detected in routine sampling. Evidence from a preliminary analysis of the data in the Alberta Oil Sands Community Exposure and Health Effects Assessment Program show personal exposures to some air contaminants (NO_2 and VOCs) at levels higher than were predicted by the measured indoor and outdoor concentrations. One possible explanation for the higher personal exposures is the sampling program did not completely characterize indoor and outdoor environments and there existed localized areas of high contaminant concentration that were undetected. This study investigated the variations in air contaminant concentration in an attempt to identify areas of high concentrations.

The investigation was carried out by exposing passive air samplers for eight days in areas suspected of not being represented by the sampling in the main study. These areas included three gas stations, four vehicles, six residential garages, and 12 locations in each of two homes.

The results of the investigations found that generally SO_2, NO_2, O_3, and VOC concentrations were adequately characterized by the indoor and outdoor sampling in the main study with the following exceptions:

- VOC concentrations were orders of magnitude higher in gas stations and higher still in residential garages (this may explain high personal exposures to VOCs in the main study).
- Concentrations of limonene in home laundry rooms and residential garages can be an order of magnitude higher than other areas in the home.
- SO_2 and NO_2 concentrations at gas stations were higher than ambient outdoor levels.

Other interesting results of the study are as follows:

- Concentration of NO_2 and VOCs (except limonene) was consistent throughout the indoor home environment.
- Concentrations of SO_2 and O_3 are low in homes but significantly variable with the kitchens showing highest levels.
- These data do not provide an explanation for the finding in the core study that personal NO_2 exposures were higher than both indoor and outdoor levels.

INTRODUCTION

One of the major investigations in the main study of the Alberta Oil Sands Community Exposure and Health Effects Assessment Program was the measurement of air contaminants in outdoor air, indoor air, and personal exposure. Passive samplers were the method used to measure the contaminants SO_2, NO_2, O_3, and VOCs by placing samplers on individuals, in homes, and outside homes. Evidence from a preliminary analysis of the main study data in the Oil Sands Community Exposure and Health Effects Assessment Program show personal exposures to some air contaminants (NO_2 and VOCs) at levels higher than were predicted by the measured indoor and outdoor concentrations (refer to *Technical Report*). One possible explanation for the higher personal exposures is the sampling program did not completely characterize indoor and outdoor environments and there existed localized areas of high contaminant concentration the were undetected. Other investigators have reported difficulties characterizing personal exposures to air contaminants and have speculated that variations in outdoor levels within communities as a possible source of error (Liu, L.-J. et al., 1997). This study investigated the variations in air contaminant concentration in an attempt to identify areas of high concentrations.

This investigation was undertaken to identify any isolated areas with high air contaminant concentrations in the indoor and outdoor environments that are not being detected in the core study. The investigation was carried out by exposing passive air samplers for eight days in areas suspected of not being represented by the sampling in the core study. These areas included three gas stations, four vehicles, six residential garages, and 12 locations in each of two homes.

METHODS

Passive samplers with an eight-day exposure were used to measure the air concentrations of SO_2, NO_2, O_3, and VOCs in this study. The SO_2 and NO_2 samplers used in the study were developed at the Center for Toxicology, University of Calgary by Dr. Siu Chan. The O_3 sampler used was the Ogawa sampler cartridge that was loaded at the Center for Toxicology. The VOCs sampler used was the commercially available 3M sampler with the extraction and analysis (GC-MS) of the collected samples done at the Center for Toxicology. The individual VOC compounds that were part of this analysis can be found in Table 1. Work from pervious studies and analysis of blank samples taken during the present study were used to determine the detection limit and precision of passive samplers used (refer to *Methods Report*). The detection limit was based on three standard deviations of the method blank and the precision was estimated by dividing the standard error by the average measurements of five collocated samplers. The estimated precision of the samplers was valid for the concentration noted and would likely be more precise at high concentrations and decline rapidly at low concentrations. A summary of this information is contained in the following Table 1 (refer to *Methods Report*).

Table 1: Summary of Passive Sampler Performance

Sampler Compound	Units	Detection Limit	Precision Estimate	Concentration
NO_2	ug/m^3	0.07	9%	0.49
SO_2	ug/m^3	0.46	6%	2.90
O_3	ug/m^3	1.32	7%	64.71
HEXANE	ng/m^3	548	2%	1007
BUTANONE	ng/m^3	0	7%	932
METHYHEX	ng/m^3	0	2%	503
BENZENE	ng/m^3	0	1%	2625
HEPTANE	ng/m^3	0	3%	594
TOLUENE	ng/m^3	689	3%	2301
OCTANE	ng/m^3	0	-	-
ETHYBENZ	ng/m^3	0	2%	563
MPXYLENE	ng/m^3	0	1%	1745
OXYLENE	ng/m^3	0	-	-
NONANE	ng/m^3	0	1%	836
DECANE	ng/m^3	0	-	-
LIMONENE	ng/m^3	738	-	-

The samplers were deployed in the designated areas following protocols established in the main study (refer to *Technical Report*). Examples of the sampler placements are in Figures 1 and 2 which shows passive samplers placed in two locations of the living room of home B and the laundry room of home A. Examples of the sampling locations at two gas stations are shown in Figures 3 and 4. The owners volunteered the locations used in the study. The only gas appliances in the homes selected for the study were forced air furnaces.

Figure 1: Example of Sampler Placement in Living Room of Home B

Figure 2: Example of Sampler Placement in Laundry Room of Home A

Figure 3: Example of Sampler Placement at a Gas Station.

Figure 4: Example of Sampler Placement at a Gas Station

RESULTS

The results of the sampling program have been plotted with bar charts in Figures 5 to 19 for each individual compound in the analysis. The charts include error bars that represent the 95% confidence interval of the value based on 2 times the precision estimates of Table 1.

The following sections discuss the findings of the SO_2, NO_2, O_3, and VOCs samplers.

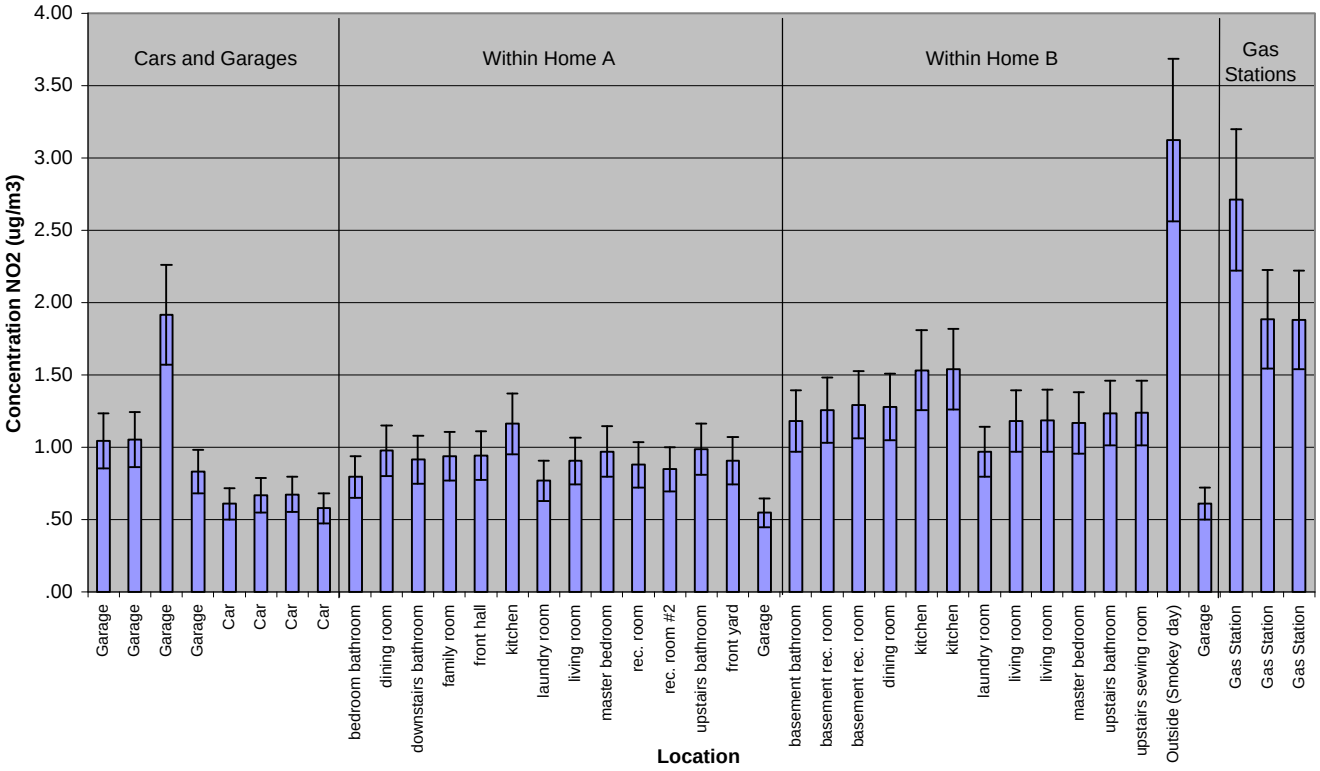
Nitrogen Dioxide

Figure 5 contains the NO_2 results showing the concentration of NO_2 roughly 25% higher in home B than A with the levels in the 12 areas within the homes consistent. In both homes the only areas with significantly different levels of NO_2 were the kitchens (the highest levels) compared to the laundry rooms (the lowest levels). The level of NO_2 outside of home A was not significantly different than the level measured at the 12 areas in the home. The level of NO_2 outside of home B was three times the level in the home (this may explain the levels within home B being 25% higher than home A).

The levels of NO_2 measured in all except one of the residential garages were similar to the levels in the homes. One of the residential garages showed significantly higher levels. The concentration of NO_2 in the four cars investigated showed significantly lower levels compared to the homes and residential garages. The NO_2 concentrations measured at the three gas stations were roughly twice as high as the levels in the homes, cars, and residential garages investigated. Compared to the outdoor concentration measured at the ambient station for the same time period we see the levels at the gas stations were higher.

The variability in outdoor NO_2 levels within the community is evident by the outdoor measure of NO_2 at home B showing three times that of homes A.

Figure 5: Variability of NO_2 levels between the different areas of the study

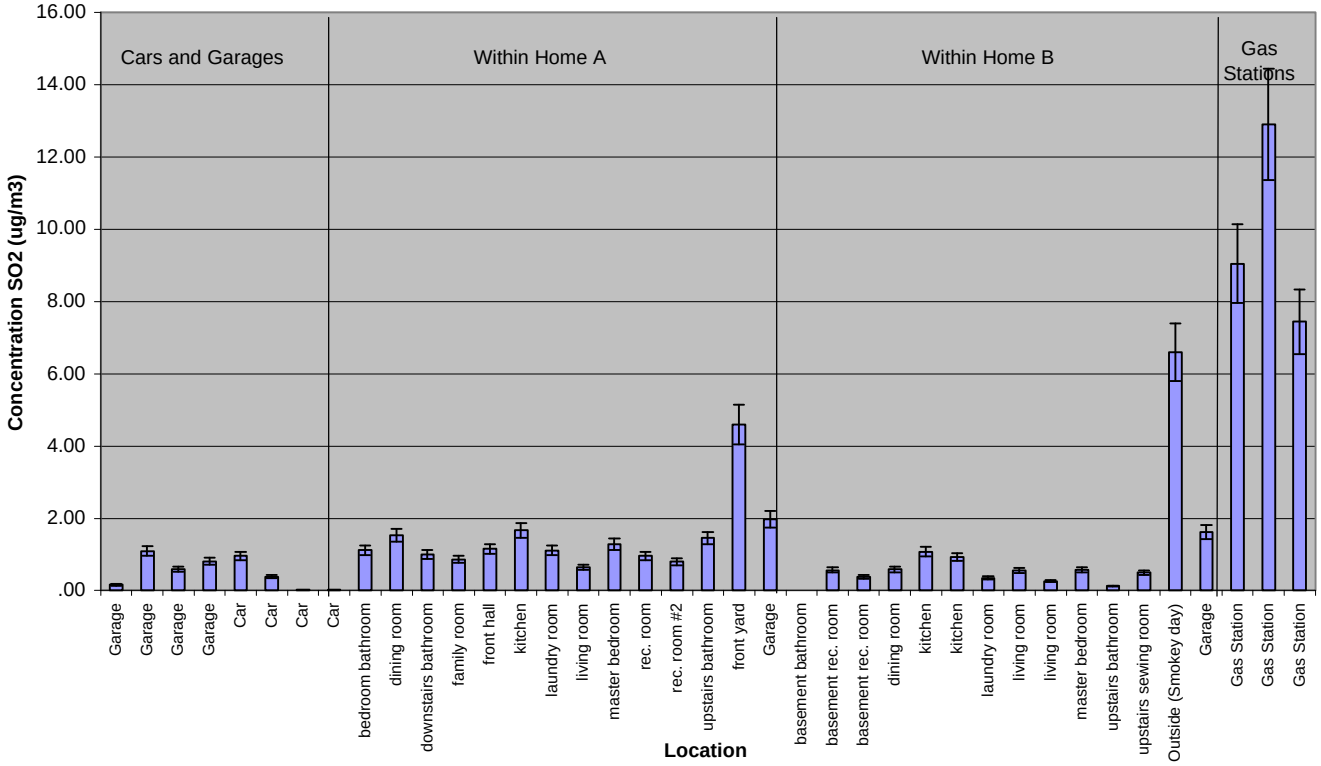


Sulfur Dioxide

In Figure 6, the SO_2 results show the concentration of SO_2 was roughly 50% higher in home A than home B. There was significant variability in the concentration of SO_2 within the 12 areas of the two homes with some areas having two or three times as much SO_2 as other areas. In both homes the kitchens show the highest levels of SO_2 while the lowest levels were found in the living room of home A and the upstairs bathroom in home B. The level of SO_2 outside of the homes was several times higher than the levels inside.

The SO_2 levels in the garages at homes A and B were higher than the levels within the homes but were much lower than the outdoor levels. The levels of SO_2 measured in the four other residential garages were lower than the garages at homes A and B but similar to the levels within the homes. The concentration of SO_2 in two the four cars investigated was essentially non-detectable while the other two cars had levels similar to areas within homes A and B. The SO_2 concentrations measured at the gas stations were the highest of any area in the investigation. The levels at these gas stations were 1 to 1.5 times higher than the concentrations measured at the ambient station for the same time period.

Figure 6: Variability of SO_2 levels between the different areas of the study

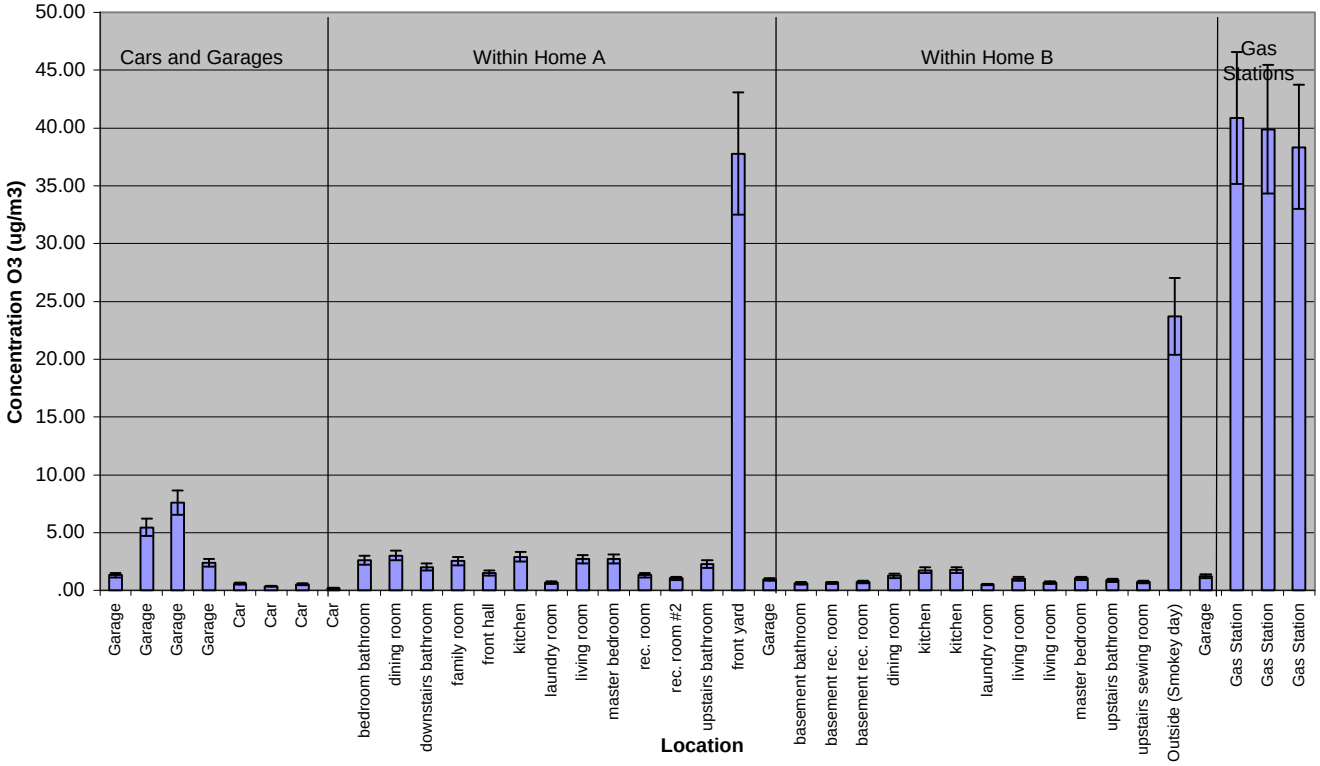


Ozone

The results of the sampling of O_3 are summarized in Figure 7. The average concentration of O_3 within home A and B were 2 and 1 ug/m^3 while the outdoor concentrations were 37 and 27 ug/m^3, respectively. The levels varied significantly in the different areas of the homes.

The O_3 levels measured at the gas stations were comparable to the outdoor ambient levels. The levels of O_3 in the residential garages were similar to the levels measured in the different areas of home A and B. The O_3 levels in the four cars were very consistent and were the lowest levels measured at any of the areas in this investigation.

Figure 7: Variability of O_3 levels between the different areas of the study



Volatile Organic Compounds

There were three distinct patterns of concentration distribution evident from the individual VOC compounds quantified in this analysis. The individual VOC compounds that followed the first pattern were hexane, methylhexane, and benzene with the results of these compounds shown in Figures 8 to 10. The first pattern showed very low concentrations within the homes and cars and much higher levels at gas stations and even higher in residential garages (considerable variability between garages). The individual compounds that followed the second pattern were heptane, toluene, octane, ethylbenzene, m-, p-xylene, o-xylene, nonane, and decane with the results of these compounds shown in Figures 11 to 18. The second pattern showed levels of similar magnitude in the homes, cars, and gas stations with much higher and variable levels in residential garages. The only VOC compound measured that follows the third pattern was limonene shown in Figure 19. This third pattern showed low levels at gas stations, outdoors, and residential garages with higher levels in homes and cars while the highest levels were measured in the laundry room of the homes.

Figure 8: Variability of Hexane Levels between the Different Areas of the Study

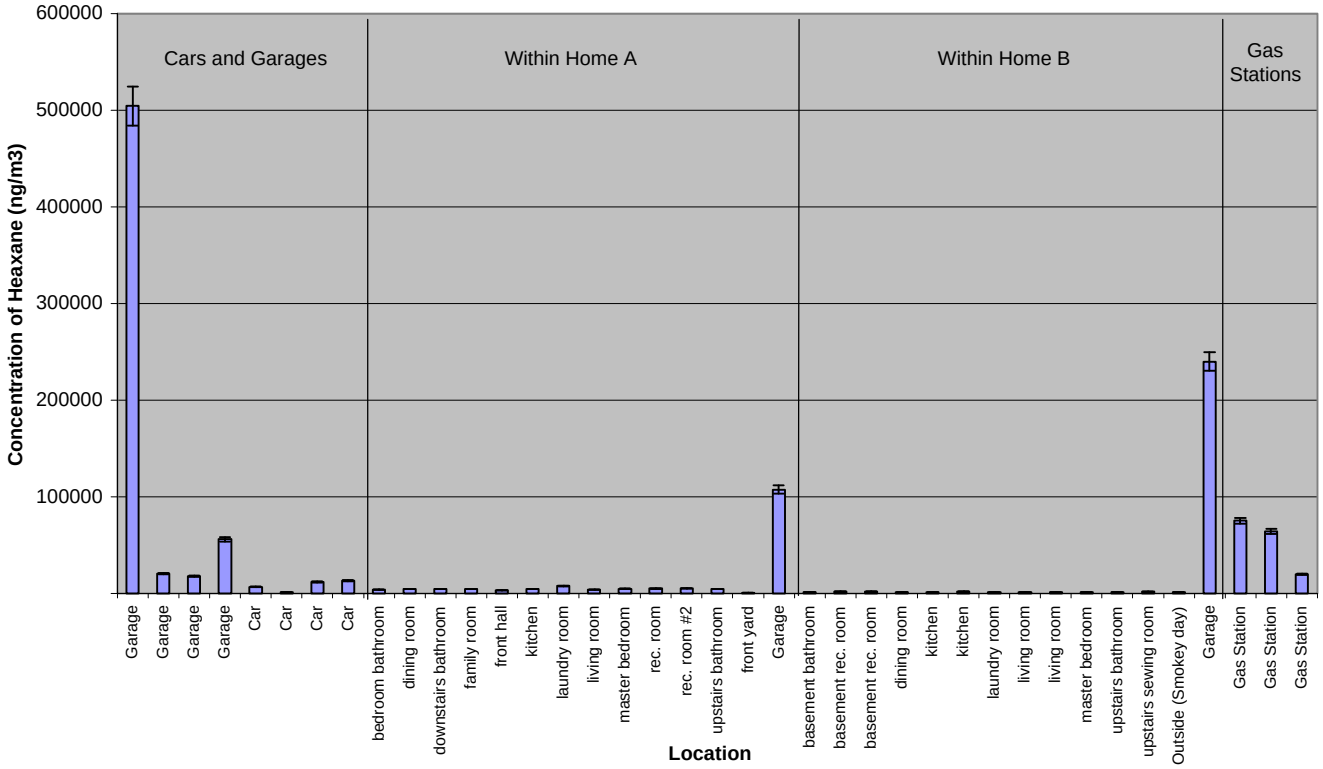


Figure 9: Variability of Methylhexane Levels between the Different Areas of the Study

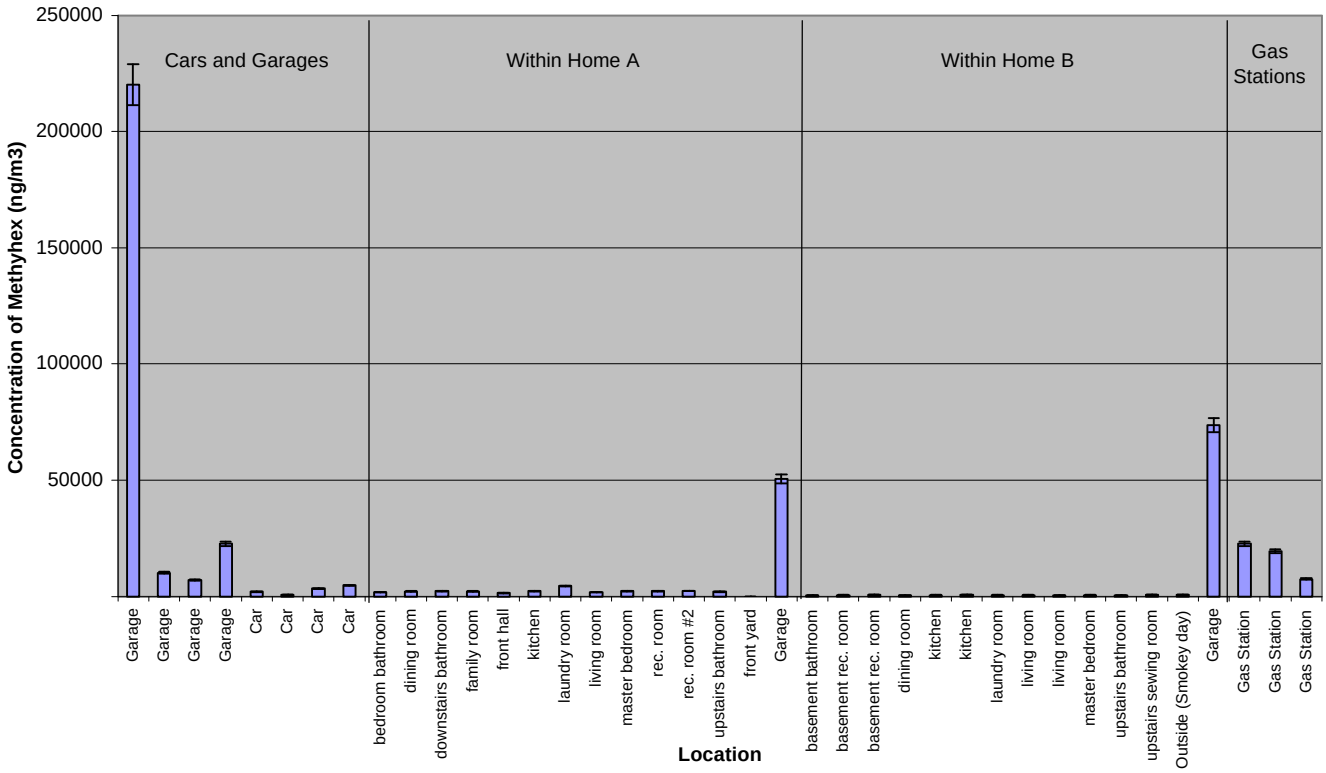


Figure 10: Variability of Benzene Levels between the Different Areas of the Study

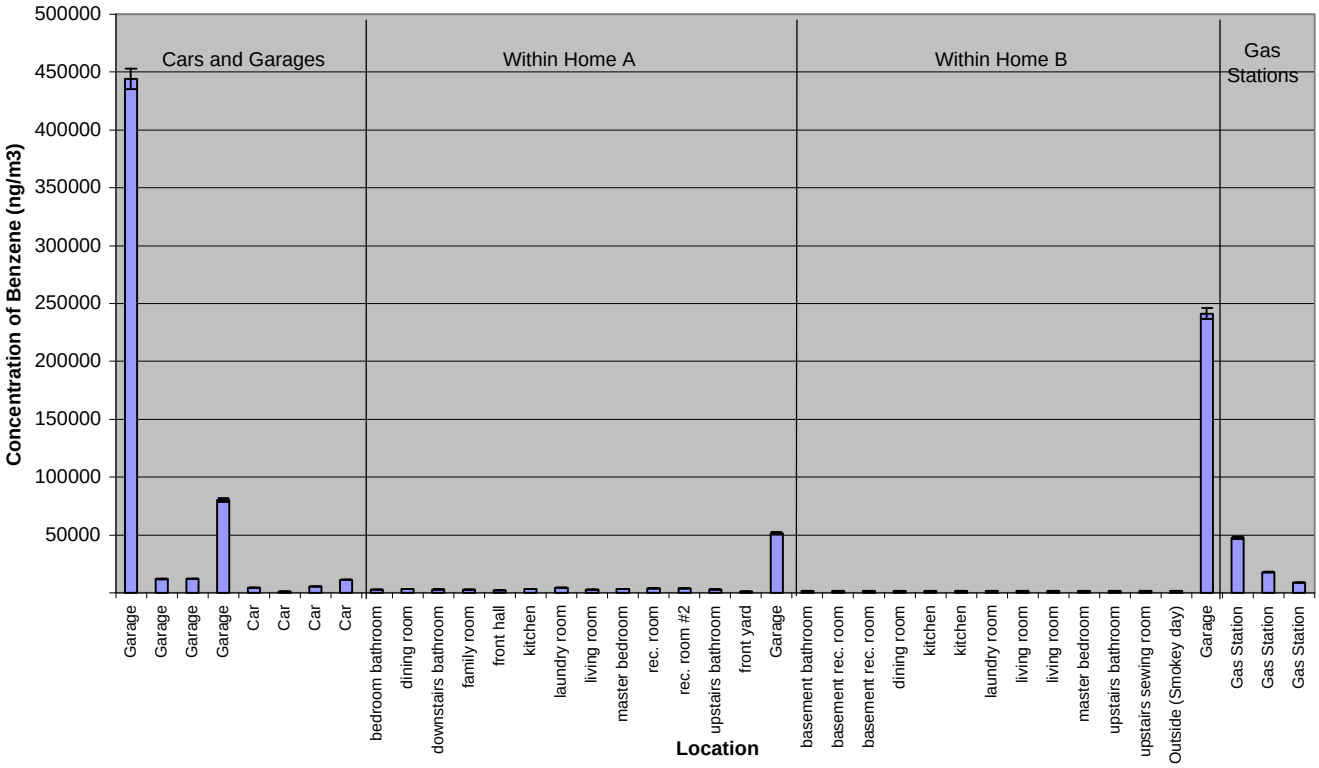


Figure 11: Variability of Heptane Levels between the Different Areas of the Study

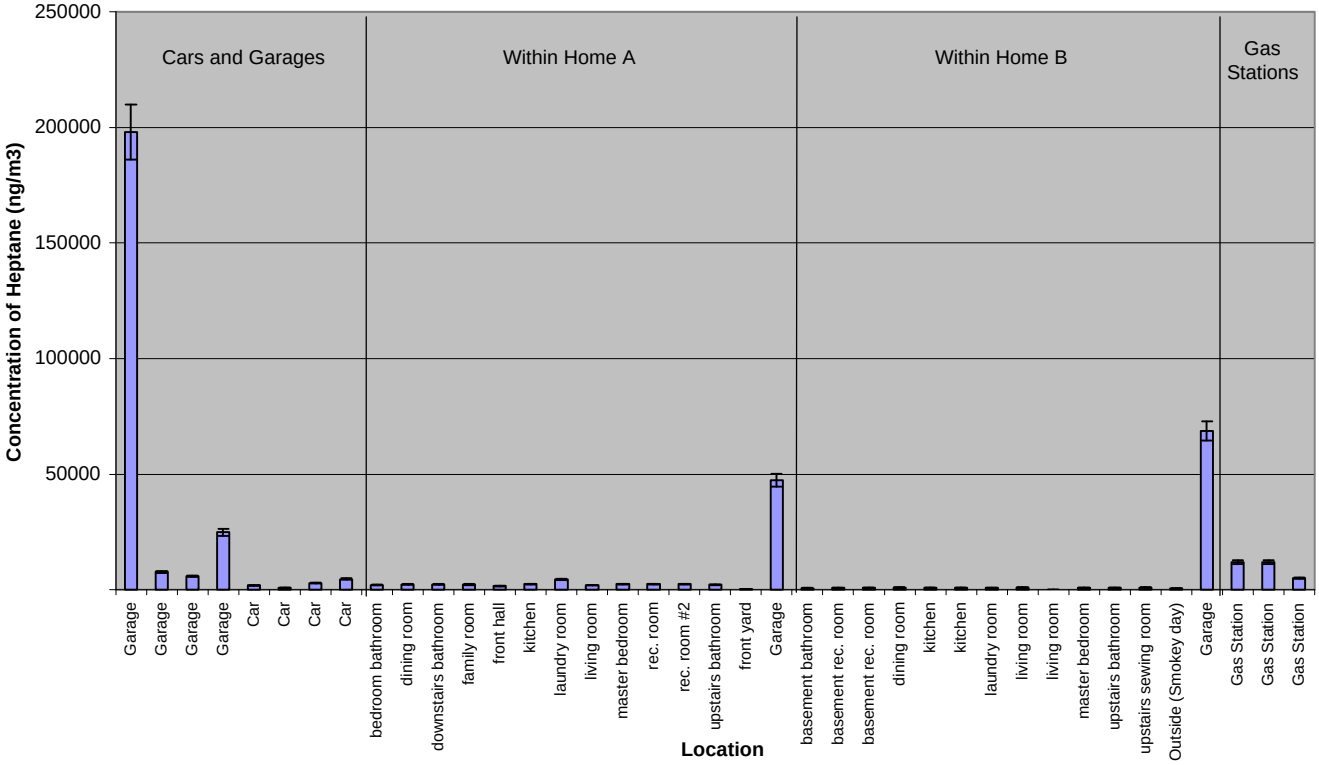


Figure 12: Variability of Toluene Levels between the Different Areas of the Study

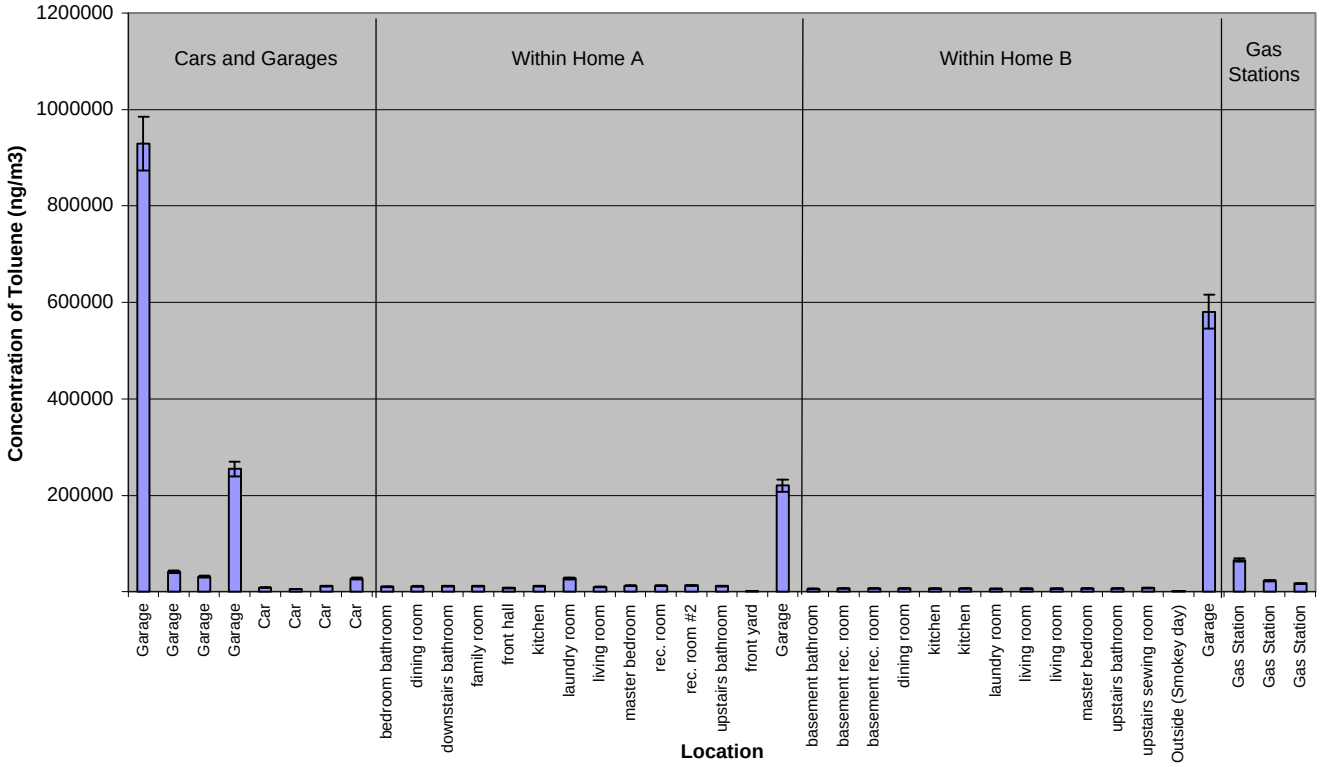


Figure 13: Variability of Octane Levels between the Different Areas of the Study

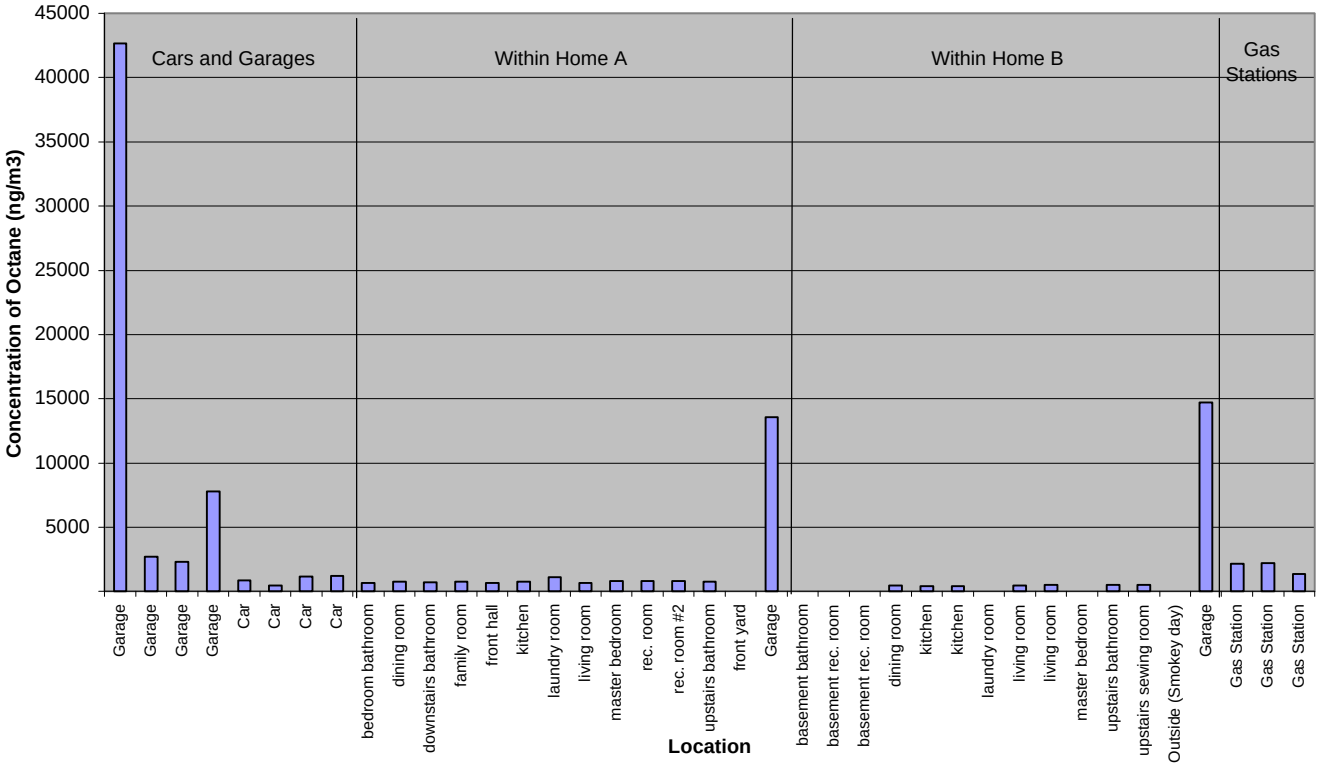


Figure 14: Variability of Ethylbenzene Levels between the Different Areas of the Study

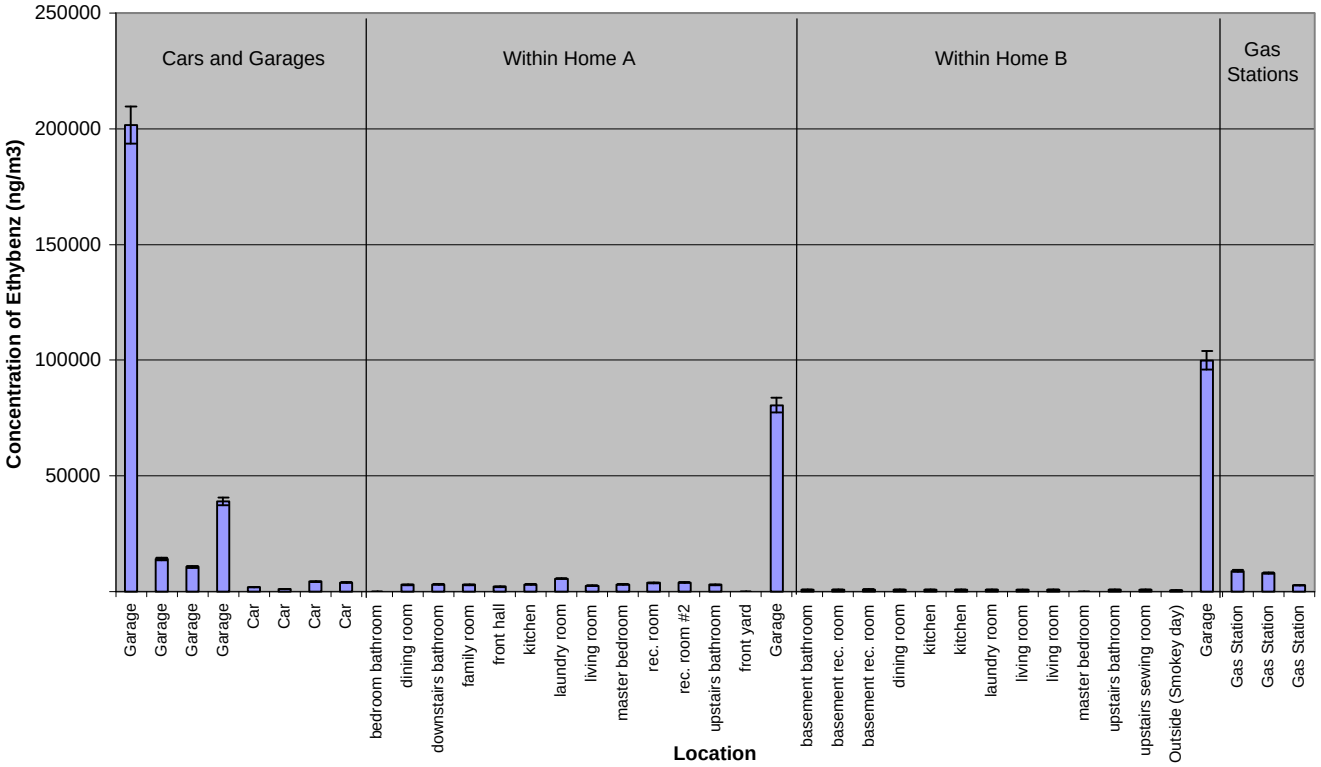


Figure 15: Variability of m-, p-Xylene Levels between the Different Areas of the Study

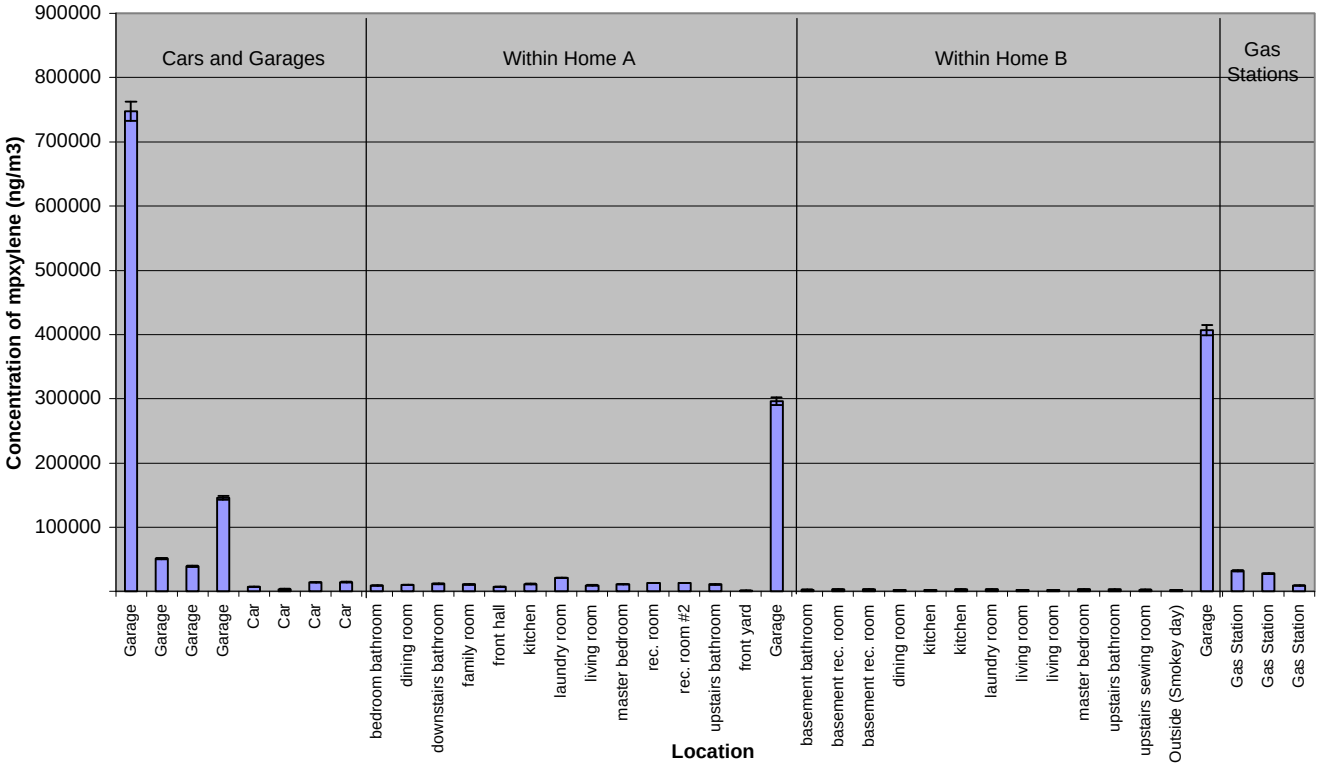


Figure 16: Variability of o-Xylene Levels between the Different Areas of the Study

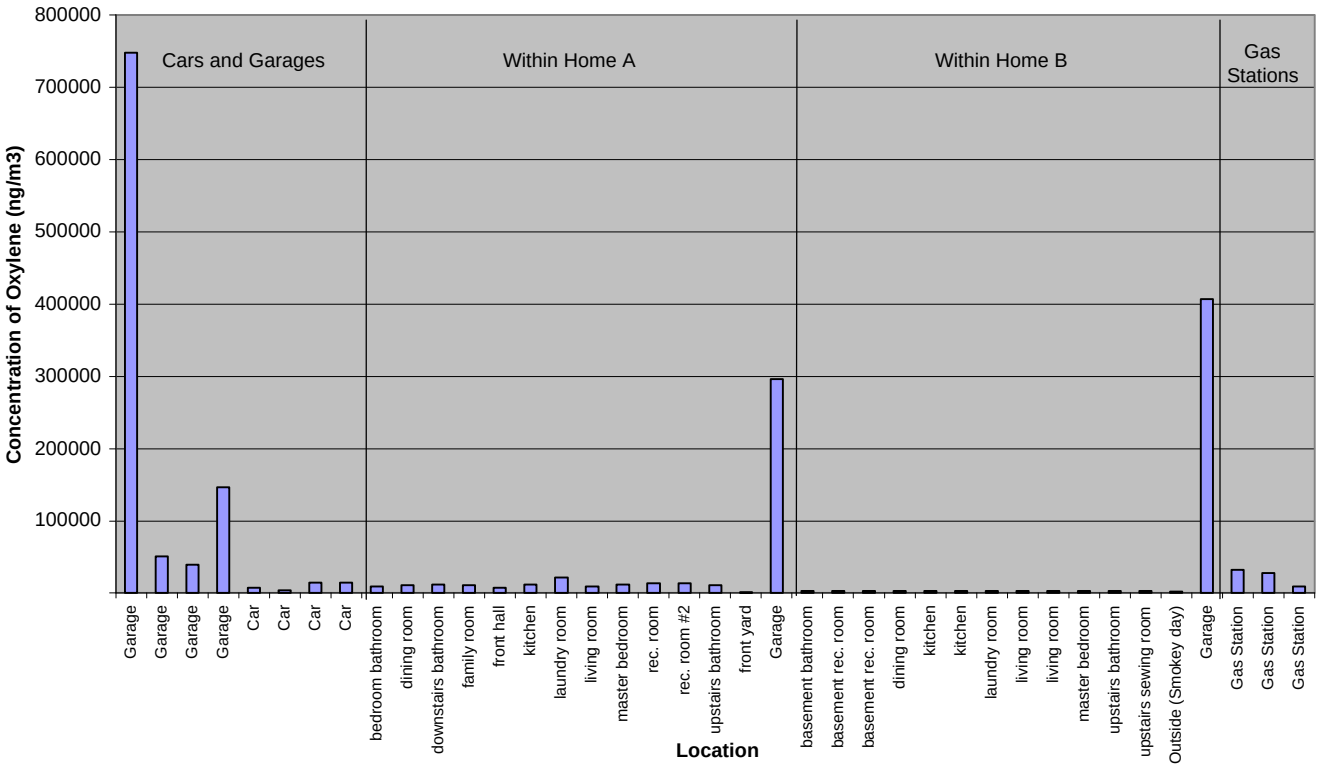


Figure 17: Variability of Nonane Levels between the Different Areas of the Study

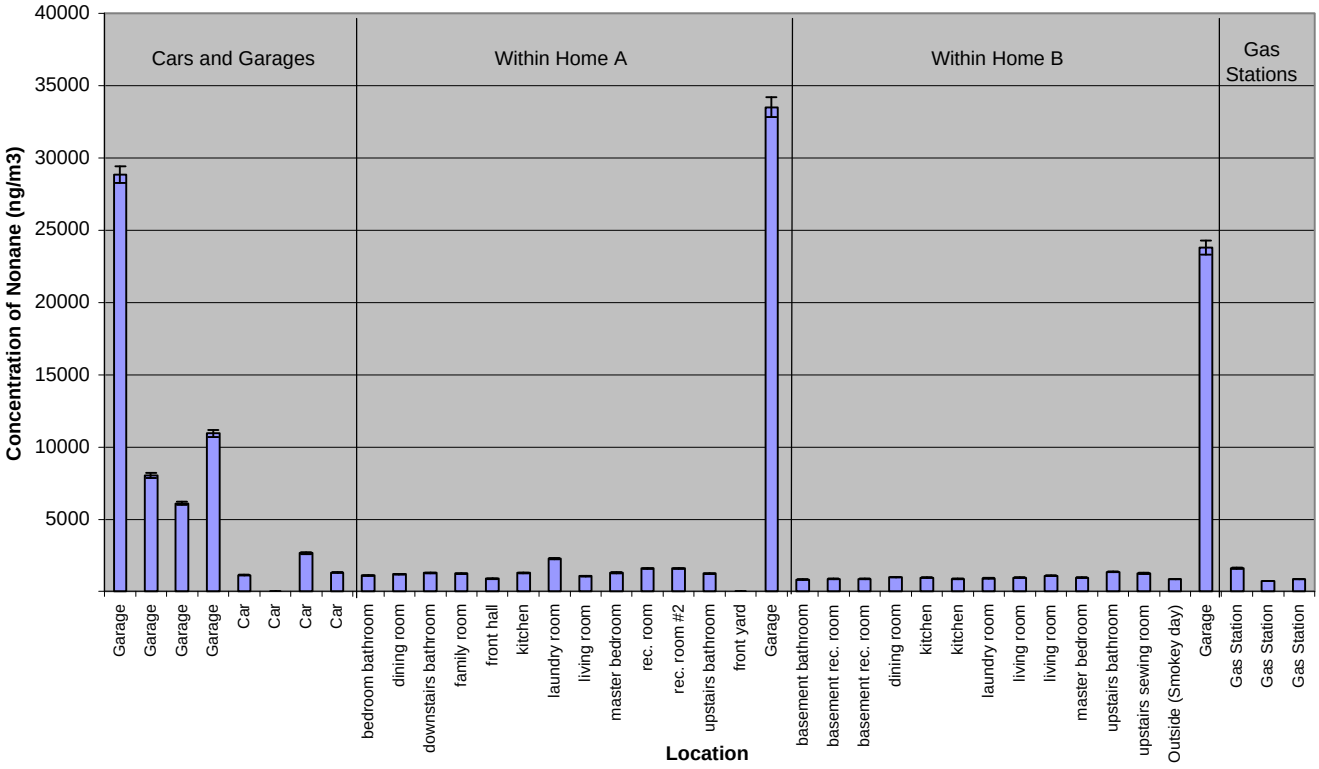


Figure 18: Variability of Decane Levels between the Different Areas of theStudy

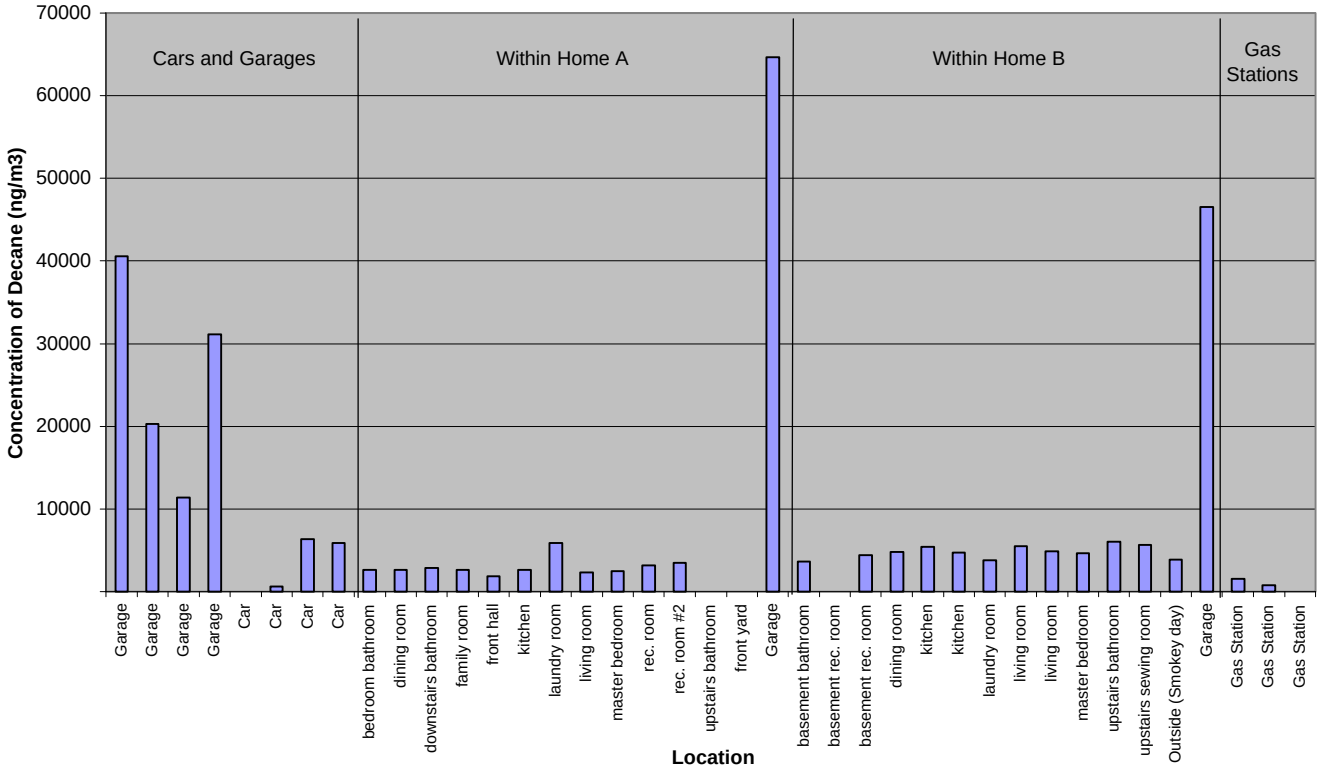
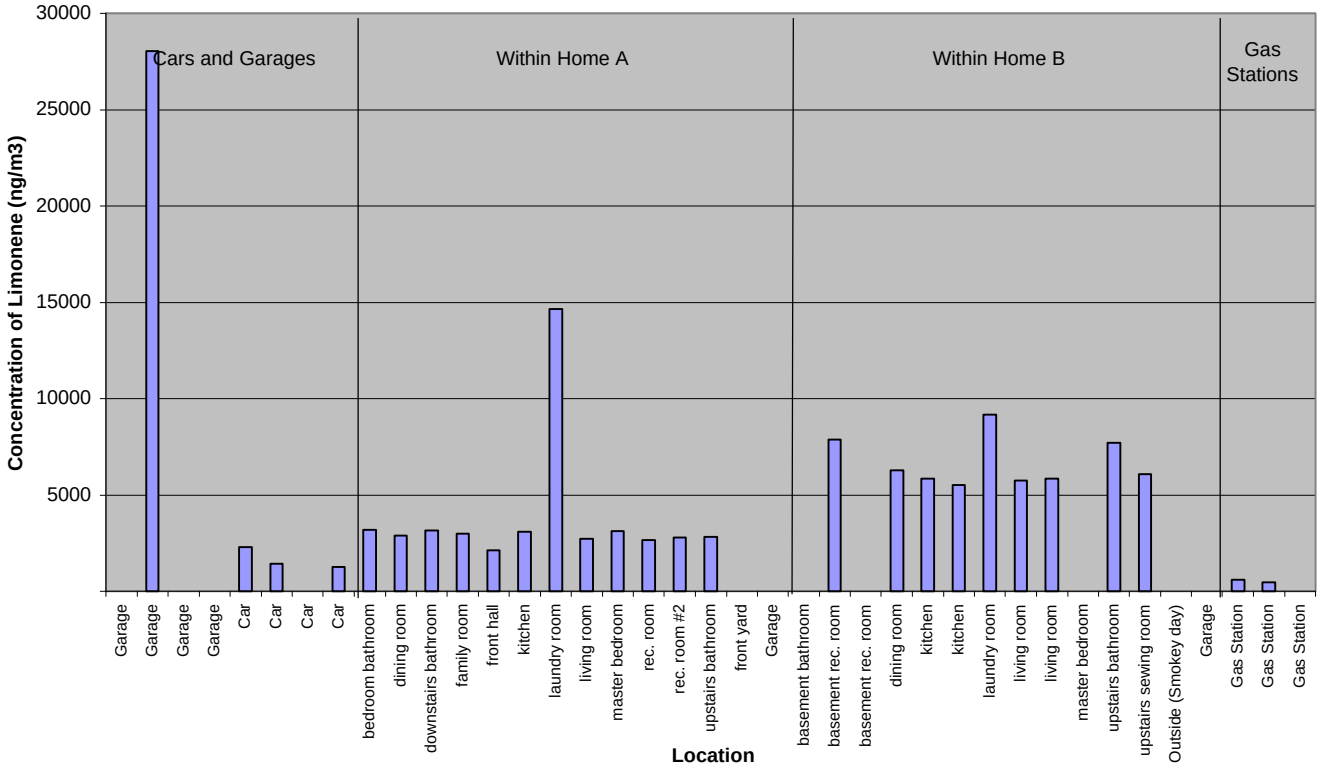


Figure 19: Variability of Limonene Levels between the Different Areas of the Study



Discussion

These results identify the gas stations and one of the six garages as areas of relatively high NO_2 concentrations. While the kitchens are the areas of highest NO_2 concentration within homes, generally the levels throughout the homes are quite similar. The investigation demonstrates that the single indoor measurements of NO_2 taken in the core study are representative of the levels throughout the home. These data do not provide an explanation for the finding in the core study that personal NO_2 exposures were higher than both indoor and outdoor levels.

The investigation of SO_2 showed gas stations with relatively high levels while concentrations indoors, in cars and garages were lower but still variable. The indoor sampling of SO_2 in the core study was likely representative of the indoor levels because the variations identified indoors were small in magnitude.

This investigation indicates that the levels of O_3 are low and variable indoors. The indoor variability of O_3 is statistically significant but the magnitude of the variation is small. The O_3 sampling in the core study was likely representative of average indoor levels.

This study shows the levels of the VOCs (except for limonene) in homes is low and stable throughout and the single indoor samples taken in the core study are representative of the average levels in the home. The relatively high levels of VOCs found in the garages and gas stations may explain the finding in the core study that showed personal VOC exposures higher than both indoor and outdoor measured concentrations. The sampling in the core study was representative of indoor levels but did not characterize the high concentration of VOCs that can exist in garages and laundry rooms.

References

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