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The Alberta oil sands community exposure to health effects assessment program

REPORT

July 1997

Alberta Health Services

Alberta Health Services

Northern Lights
Regional Health Authority



Alberta Energy
Securing Canada's Energy Future

Sinclair
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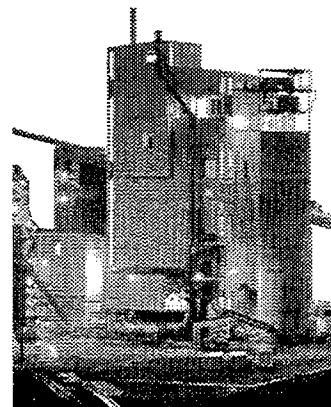
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EXECUTIVE SUMMARY

The Alberta Oil Sands Community Exposure and Health Effects Assessment Program was developed to ensure that a long-term, systematic approach to data gathering was implemented that would improve our knowledge about the link between the environment and human health. The purpose of the pilot study was to develop the methodology to be used in the main investigation and to address the technical, laboratory, and logistical aspects of the Program. This included developing the appropriate exposure assessment techniques, field activities, analytical laboratory testing procedures, and data analysis capabilities.

Specifically, the objectives of the pilot study were to develop a data collection method for personal/population exposure assessment of exposure to sulphur dioxide (SO_2), nitrous oxides (NO_x), ozone (O_3), volatile organic compounds (VOCs), particulates, and heavy metals (HM) using the Total Exposure Assessment method, including development of the protocols for field data collection, laboratory analysis, and quality assurance; development of methods for the collection of individual ancillary data on exposure conditions, health status, and nutrition; conducting a feasibility study on a convenience sample of the population; and development of a statistical analysis methodology for the environmental data.

Phase One: Developing and Testing the Measurement Instruments

The Personal Exposure Monitoring Devices (PEMs) were developed and tested in two phases. During the first phase, the initial design for the samplers was tested in several controlled environments to ensure that the data quality objectives were attainable. The second phase focused on developing and testing the PEMs in the field, to evaluate the applicability of the technology for testing exposure in a random population.

The SO_2 and NO_2 badges were developed for the study, because there was no commercially available instruments designed to measure relatively low levels of these contaminants over a short period of time (24 hours).

Initially, badges for both contaminant type were exposed under controlled laboratory conditions, using the Test

Atmosphere Generating System (TAGS), owned by Health Canada and operated by Bovar Environmental in Toronto; these tests would determine an accurate sampling rate for the badges. There were three separate 24-hour exposures for each type of sampler - SO_2 and NO_2 - at high (50 g/m^3), medium (10 g/m^3), and low (5 g/m^3) concentrations. Eighty samples for each contaminant type were collected.

Second, several samples were collected from locations in Fort McMurray where the values were expected to be high, to compare to the levels observed from blank samplers. The level of contaminant measured on the blank samplers was consistently lower than the level of contaminant measured by the exposed samplers, and the precision of the exposed samplers was deemed acceptable. There was a consistent trend

of measurable contaminant in relation to concentration and length of exposure.

Standardized, commercially available samplers were used for VOCs, ozone and particulates, so preliminary testing of the sampling devices was not required.

A number of survey instruments were developed to collect individual demographic, health, and time activity information.

Phase Two: The Field Study

The primary goals of the Field Study included generating preliminary exposure information to support the effective design of the Main Study, establishing and testing protocols for deploying, collecting, packaging/shipping, and analyzing exposure monitoring samples, and field testing of ancillary individual questionnaire instruments. In general, the pilot study sought to test the data collection instruments and methods on a small sample. Consequently many important aspects of the data were not examined, including analysis of the responses to the survey instruments.

Each of the sampler types was deployed to collect information on ambient conditions, using the outdoor monitoring sites located within the test area (Fort McMurray, Fort MacKay, and Suncor Plant Site), as well as to collect information about individual exposure conditions, using outdoor, indoor, and personal monitoring of specific individuals within the test area.

The NO₂ levels of all exposed samples exceeded the levels measured on blanks, indicating that measurable quantities of NO₂ do exist in the test area. In addition, neither the ambient nor outdoor locations show a markedly skewed distribution; the indoor and personal measures account for a large majority of the most extreme measures. Separate analysis of the results of ambient monitoring suggests that the Fort McMurray town site had higher levels of NO₂ concentration, and that the first day of testing showed generally lower levels of NO₂ concentration than did the two succeeding days. Neither of these effects was significant in conventional tests of significance, however.

Although the SO₂ levels of exposed samples generally exceeds the levels measured on blanks, the differences are slight. In fact, without the presence of extreme samples in the exposed samplers, we would not be able to conclude that measurable quantities of SO₂ exist in the test area. As with the NO₂ samplers, only a very small proportion of samples show high levels of exposure. In addition, median levels for outdoor and ambient levels tend to exceed those for indoor and personal levels. Separate analysis of the results of ambient monitoring does not provide strong evidence that the sites differ in SO₂ concentration. The analysis does show, however, that the third day of the test had lower ambient levels than did the first two days (Main Effect for Day, $F=3.8$, $df=2, 22$, $p<0.05$). This suggests that day to day variability could be of considerable importance in the monitoring of SO₂.

The distribution of exposure to O₃ was only mildly skewed. Only the Outdoor sample appears to differ from any other type including blank samples. Statistical analysis lends support to this last observation. Further analysis lends no support to for any variation in levels across ambient sites or days, or for any characteristic level of individual exposure. There is slight support for a relationship between personal and indoor exposure levels across individuals, but no support for a relationship between outdoor levels and either personal or indoor levels.

The distribution of VOC levels is extremely skewed, indicating that a small number of participants were exposed to relatively high levels of particular VOCs. None of the groups showed that the

ambient or outdoor levels different from blank levels (except for a very small number of extreme levels in outdoor samples). Indoor and personal levels exceeded blank levels and did not differ (with the possible exception that personal levels of the hexane group were

higher than indoor levels) for all chemical groups.

Very few particulate samples were obtained, so analysis was confined to description.

INTRODUCTION

The Alberta Oil Sands Community Exposure and Health Effects Assessment Program was established following public hearings conducted by the Energy Resources Conservation Board in relation to Syncrude's Mildred Lake Development Project (1994). Human health concerns related to air quality were raised by various participants including aboriginal groups, environmental associations, and Alberta Health. The Energy Resources Conservation Board views and recommendations of the human health issue were:

"The Board acknowledges the concerns of many of the interveners that atmospheric emissions from the oil sands plants are impacting on the health of the region's population. The Board believes that there is an obligation on industry to address this issue as effectively and rapidly as possible. The Board also acknowledges Syncrude's commitment to support and participate in a regional health study that is broadly based and involves all stakeholders. The Board notes, however, that concerns about the health effects from atmospheric emissions have, despite a number of efforts, continued to exist in the oil sands region as well as other areas of the province. The Board does not support a health study carried out simply for its own sake and expects any health study undertaken in the region to be meaningful, with terms of reference sufficiently broad to demonstrate both short and long term effects."

The Alberta Oil Sands Community Exposure and Health Effects Assessment Program was developed to ensure that a long-term, systematic approach to data gathering was implemented that would improve our knowledge about the link between the environment and human health. The Program combines two broad concepts in an integrated population-based environmental health framework: (1) the direct measurement of personal and population exposure to environmental factors, and (2) the epidemiologic surveillance of health outcomes in the population. The current document reports on activities relevant to the first objective; consideration of the second objective is deferred to the Main Study Proposal.

The approach to measurement of personal and population exposure was modeled after the United States Environmental Protection Agency approach for particle total exposure assessment method (TEAM). The purpose of the pilot study was to develop the methodology to be used in the main investigation and to address the technical, laboratory, and logistical aspects of the Program. This included developing the appropriate exposure assessment techniques, field activities, analytical laboratory testing procedures, and data analysis capabilities.

Specifically, the objectives of the pilot study were to:

- I. Develop a data collection method for personal/population exposure assessment of exposure to sulphur dioxide (SO₂), nitrous oxides (NO_x), ozone (O₃), volatile organic compounds (VOCs), particulates, and heavy metals (HM) using the TEAM methodology including:**
 - development of the field data collection protocol,
 - development of protocols for laboratory analysis, and
 - development of a quality assurance protocol;

- II. Develop methods for the collection of individual ancillary data on exposure conditions, health status, and nutrition;**

- III. Conduct a feasibility study on a convenience sample of the population; and**

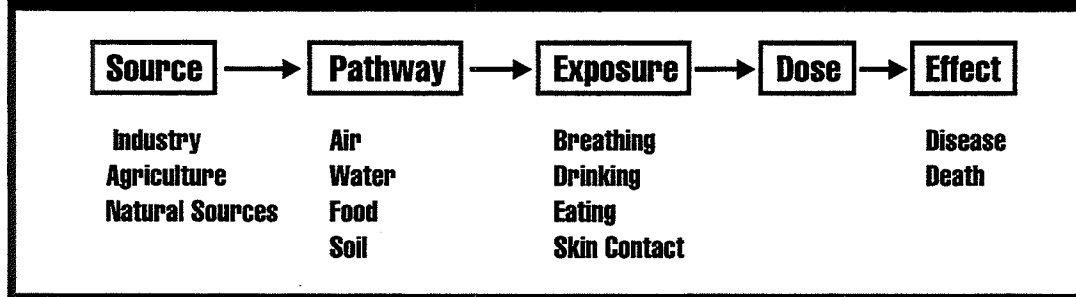
- IV. Develop a statistical analysis methodology for the environmental data.**

BACKGROUND AND RATIONALE

In general, exposure can be defined as 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, in 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.

Figure 1 Continuum of Exposure



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); and**
- **overt health effects (clinical disease, death).**

The output of each component in the chain of events serves as input to the next. The lack of information on any one component thus 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 increasing as the result of environmental monitoring programs, however, there is a need to integrate these data with information on population exposure, biological markers and health effects. This is very important in achieving new health based protection levels.

In dealing with population health outcomes which may be attributable to long-standing, 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 disease, chronic respiratory ailments, and many other diseases have important environmental, behavioral, social, and genetic links. The causes of these conditions are multifactorial in nature. 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.

Environmental health surveillance is a tool which can be used to gather data and information on the health of people for the purpose of tracking and detecting trends and associations among a broad range of environmental and health related variables. The process consists of an on-going, systematic collection, analysis, and interpretation of selected data on health outcomes, environmental quality parameters, and population exposure. In addition, data on behavioral, lifestyle, social, economic, and other confounding variables are also considered.

DEVELOPMENT OF MEASUREMENT INSTRUMENTS

The Personal Exposure Monitoring Devices (PEMs) were developed and tested in two phases. During the first phase, the initial design for the samplers was tested in several controlled environments to ensure that the data

quality objectives were attainable. The second phase focused on developing and testing the PEMs in the field, to evaluate the applicability of the technology for testing exposure in a random population.

Background: Active vs Passive Sampling

Five contaminant classes were designated for the study, including volatile organic compounds, sulfur dioxide, nitrogen dioxide, ozone, and inhalable particulates. All of the compounds, except for particulates, may be measured through the use of a passive sampling "sampler". A passive sampling sampler is a small plastic container that holds a pad saturated with a solution designed to react with specific chemicals in the air, such as ozone or sulphur dioxide. After the sampler is exposed to the air for a specific period of time, the pad is removed and treated to determine the amount of chemical that reacted with the solution, and the amount of chemical contaminant originally in the air can then be determined using a simple formula.

One chemical characteristic of gases in air is the diffusion coefficient. This parameter reflects the rate that gases disperse in air at a given temperature and pressure. Fick's First Law of Diffusion considers this "diffusion coefficient" and may be rearranged as an equation to

explain the principles of passive sampling. The following is taken from Shields and Weschler (1987):

(Eq. 1)

$$m / (t \text{ } C_a) = D (A / l) \text{ where}$$

$$m / (t \text{ } C_a) = \text{badge sampling rate} \\ (\text{mL of air per minute})$$

m = mass of substance that diffuses onto the sampler sorbent (ug)

t = sample duration (minutes)

C_a = time weighted average concentration of substance (ug/mL)

D = diffusion coefficient (cm²/minute)

A = cross-sectional area of the sorbent pad (cm²)

l = diffusion path length of the sampler (cm)

The sampling rate can be determined by exposing it to known concentrations of a contaminant (C_a) for known time intervals (t) and measuring the mass of contaminant (m) that it collects. Once

the sampling rate is established, the sampler can then be exposed to unknown concentrations of contaminant for a standard duration and the mass of contaminant can be measured in the lab, thereby solving for (Ca).

The primary benefit of passive methods is the ergonomically friendly nature of a small clip-on badge compared with a conventional battery-powered pumping systems typically used previously to identify exposure levels. The principles of passive sampling are simple; however, the challenge lies in the treatment, handling, and analysis of the sorbent pad used to collect the target compound from the air.

Active sampling must still be used for measuring inhalable particulates because this contaminant is not a gas. That is, there is no diffusion coefficient to govern any sample rate into a sorbent material. The preferred sampling method (as used by EPA, Research Triangle Institute) is to pull a known volume of air through a filter, determine the mass of particles collected over the sampling period and express the measure as a mass of particle per volume of air sampled. Once again, the fundamental principles are simple, but care must be taken in the preparation of the collection medium (a preweighed filter) and the handling of the filter in the field.

Data Quality Objectives

Uncertainties in data obtained from a sampling program may be attributed to the way that a sample was taken or the way it was analyzed. It is very important to explicitly recognize that there are inherent limitations to all types of sampling and analysis methods. Confidence in the results may be increased but are often dictated by factors such as cost, time, and availability of trained personnel. Lawrence Keith (1988) argues that all sampling programs must first define "data quality objectives" prior to deciding on the methodology required, and he lists those objectives as: accuracy, precision, representativeness, completeness, and comparability.

Accuracy

Accuracy is a measure of how close the resulting estimate is to the true value. In this case, the sample methods chosen for the Oilsands Program must be within a tolerable range of variance accepted by other methods that are formally recognized as "true" measures. A practical accuracy objective for the samplers is to remain within $\pm 25\%$ of the recognized reference sampling method. It is to be expected that this margin will increase significantly at very low contaminant concentrations. This is not a primary concern because the results from very low readings may be interpreted as being below a safe level of exposure.

Precision

Precision is a measure of the mutual agreement among individual measurements. For example, when two samples are placed side-by-side for the same amount of time there should be little difference in the measurement of air contaminant concentration. A workable precision data quality objective would be $\pm 25\%$ between duplicate samples. Again, this margin is expected to increase during low level monitoring.

Representativeness

Representativeness refers to the degree to which the measures obtained from the samples describes the environment being sampled. For example, an environmental sampler that is placed in a volunteer's living room can not be interpreted to be representative of the entire home. Furthermore, it must be recognized that it is merely an assumption that personal exposure monitors measure the same air that the volunteer is actually inhaling. Accordingly, the objective here is to properly describe and define all data to avoid underestimating the inherent limitations of the samplers.

Completeness

Completeness measures the amount of valid data obtained from the research compared to the amount expected to be obtained under absolutely correct conditions. Temperature, pressure, wind

velocity, and humidity are constantly changing in both indoor and outdoor environments. It is theoretically conceivable that these changes in environmental conditions may alter the sampling rates of both the passive, and to a lesser extent, the active samplers. Sources of bias are also introduced during transport, storage, and handling of the samplers. The objective is therefore to recognize uncontrollable sources of bias and account for as many as possible through a sound sampling protocol and blank sample analysis.

Comparability

Comparability concerns the confidence with which the results of the research can be correlated to data from the same study or other studies of similar design. The reason for including the objective of comparability in the Oilsands Program is to establish consistency with previous TEAM studies (where technology permits) and to maintain a standard methodology and protocol for sampling and analysis so that results obtained from the different components of the Oilsands Program are comparable to each other.

Phase One: Developing and Testing the Measurement Instruments

Sulphur Dioxide (SO₂)

Like most gases, the measurement of sulfur dioxide (SO₂) in the air has traditionally been performed through active sampling. For example, NIOSH Method 6004 is the typical method used in the workplace for measuring SO₂ exposure and it involves using a pump to pull a known volume of air through a filter that has been treated with sodium carbonate. Researchers have known for years that sodium or potassium carbonate will collect SO₂ from the air. After the sample is exposed, the treated filters are processed in the lab with hydrogen peroxide and the lab can then determine the mass of SO₂ collected per sampler.

The filters used for the NIOSH method 6004 (filters treated with Na₂CO₃) were also used in passive samplers to measure high levels (such as 500 ppb) of SO₂ in workplace environments. The OGAWA passive sampler was originally identified as the most appropriate sampler for measuring SO₂ in the Pilot Study. However, field tests carried out by Alberta Environmental Protection and the Clean Air Strategy for Alberta found that the blank levels of the samplers were very irregular and that the small size of the surface area of the sampler would render it virtually useless for 24-hour ambient air monitoring.

Leaderer, et al. (1994) used a passive sampler badge to measure typical urban air concentrations over 24 hour periods.

The sampling rate of the badge was determined to be 41.1 mL/minute and the sensitivity of the sampling method was 200 ppb over a 4 hour sample duration. Assuming a constant sampling rate, this would translate into sensitivities of about 35 ppb over a 24 hour sampling duration. Unfortunately, this poses some problems for the Oilsands Program because the 1993 Air Quality Monitoring Report For Alberta (Myrick, 1995) indicates that typical concentrations of SO₂ in Fort McMurray and Fort McKay are between 5 and 10 ppb (13 to 26 ug/m³).

The Science Team agreed that the Leaderer design was acceptable, but the sorbent pad area needed to be larger to facilitate the collection of more contaminant. In addition, the diffusion path between the diffusion membrane and the treated sorbent pad needed to be decreased to increase the badge sampling rate (See Equation I). The final sampler badge design for the Oilsands Program is a clear light-weight plastic holder with a diameter of 55 mm. The cost of the badge is approximately 1/4 the price of the originally planned OGAWA samplers and is similar in appearance to the OVM-3500.

The badge is constructed from a modified 55-Plus Millipore Filter Holder with a removable TEFLON diffusion barrier designed to protect the sorbent pad from wind and rain. The sorbent

pad is cleaned and treated at the Foothills Laboratory and loaded into the holders under zero-air conditions. A specially designed TEFLON ring is used to hold the filters in place and a standard bull-dog clip is used to attach the sampler badge to the volunteer. The badges are shipped from the laboratory to the field study office in groups of three in an air-tight vial purged with nitrogen prior to leaving the Foothills Laboratory.

Preliminary Tests of the SO₂ Sampler

An estimate of the required blank levels was determined based on predicted exposure measurements of SO₂ in Fort McMurray and Fort McKay. The Foothills Laboratory met this stringent requirement by cleaning the filters prior to treatment and ensuring that there were no sources of SO₄ contamination in the analytical equipment. When these conditions were maximized, a small number of SO₂ samplers were sent to the field to determine the viability of this approach.

To observe the performance of the badges under relatively high SO₂ exposures, two SO₂ passive samplers were placed at an air monitoring station at Suncor for 48 hours (twice the normal sample duration). Mid- and low-level exposures were generated by sampling at the Fort McMurray air monitoring station for 48 and 24 hours respectively. The key issue in this evaluation was to determine if the level of SO₄ on the blank samplers was significantly lower than the SO₄ levels on the exposed samplers. Further, the standard deviation, or overall variability, of the blanks would be key to calculating the limit of detection for the badge.

Table 1 illustrates the results of this preliminary evaluation. The level of SO₄ measured on the blank samplers was consistently lower than the level of SO₄ measured by the exposed samplers. The precision of the exposed samplers is acceptable (based on the previously established data quality objectives), and there is a consistent trend of mass of SO₄ in relation to concentration and length of exposure.

Table 1 Preliminary Tests of the SO₂ Sampler

Sample Location	Sample Duration	Reference Concentration	Reported Mass of SO ₄
Suncor	48 hours 48 hours Blank	3 to 6 ppb (TWA) 3 to 6 ppb (TWA) —	3.3 µg/filter 2.9 µg/filter 0.8 µg/filter
Fort McMurray	48 hours 48 hours Blank	n/d to 2 ppb (TWA) n/d to 2 ppb (TWA) —	1.0 µg/filter 1.2 µg/filter 0.5 µg/filter
Fort McMurray	24 hours 24 hours Blank	2 ppb (TWA) 2 ppb (TWA) —	0.9 µg/filter 0.9 µg/filter 0.5 µg/filter

Nitrogen Dioxide (NO₂)

The traditional approach to measuring nitrogen dioxide is through active sampling with a pump and a sorbent tube. For example, the Occupational Safety and Health Association (OSHA) Method # 182 involves pulling air through a triethanolamine (TEA) treated filter media to collect NO₂ gas from air. Articles dated as far back as 1964 (Ripley, et al.) have used this approach for sampling the contaminant. The TEA collects nitrogen dioxide gas from air

(NO₂) as nitrite (NO₂⁻) and is quantified in the analysis as a mass of nitrite ion. The mass of the nitrite ion is equivalent to the mass of the nitrogen dioxide gas sampled from the air.

The OGAWA sampler was originally chosen for Oilsands program, because it was the most frequently recommended method for sampling NO₂ gas from air. However, it was found that the blank levels of the samplers were highly

variable and the permeation membrane (drilled holes) allowed dust to migrate onto the sorbent pad as an artifact. Tests performed by Alberta Environmental Protection and the Clean Air Strategic Alliance for Alberta demonstrated the inability of the sampler to perform reliably under typical Alberta conditions.

Mulik (1989) published research on high-efficiency passive samplers designed for monitoring NO₂ in ambient air over exposure durations as low as 8 hours. He provided a description of a sample holder that was very similar in design to the SO₂ sampler discussed above, using the sorbent material mentioned above (the TEA solutions).

The Science Team determined that an adaptation of the SO₂ samplers using the TEA solution to collect NO₂ would be the most appropriate method for the Alberta application of the technology, and the Foothills Laboratory agreed to prepare and load the sorbent pads with the TEA solution. This ensures that the Oilsands Program maintains the highest standards of laboratory quality control, which translates into fewer concerns about the detection limits of the NO₂ samplers. There are fewer sources of contamination from the sampler and analytical equipment materials in comparison to SO₂ and the typical levels

of NO₂ in the urban air should be much higher than the levels of SO₂, due to the common anthropogenic sources found in an urban environment.

Preliminary Tests of the NO₂ Sampler

After the laboratory had an opportunity to eliminate any sources of contamination and produce consistently low sorbent blanks, a small number of NO₂ samplers were sent to the field to determine the viability of the method. To observe the performance of the samplers under relatively high NO₂ exposures, two NO₂ passive samplers were placed at the Fort McMurray air monitoring station for 48 hours. A mid-level exposure was obtained by sampling for 24 hours at the Fort McMurray station and a low-level exposure was obtained by sampling over 48 hours at a remote Syncrude monitoring station located in a rural setting along the highway to Fort McKay.

Table 2 shows the results of the preliminary co-location evaluation. The level of NO₂ measured by the blank samplers is consistently lower than the level of NO₂ measured by the exposed samplers. The precision of the exposed samplers is acceptable, on the previously established data quality objectives, and there is a consistent trend of mass of NO₂ in relation to concentration and length of exposure.

Table 2 Preliminary Tests of the NO₂ Sampler

Sample Location	Sample Duration	Reference Concentration	Reported Mass of SO ₄
Fort McMurray	48 hours 48 hours Blank	6 to 7 ppb (TWA) 6 to 7 ppb (TWA) –	6.1 µg/filter 5.4 µg/filter 0.5 µg/filter
Fort McMurray	24 hours 24 hours Blank	6 to 7 ppb (TWA) 6 to 7 ppb (TWA) –	3.1 µg/filter 3.4 µg/filter 0.5 µg/filter
Syncrude	48 hours 48 hours Blank	3 to 4 ppb (TWA) 3 to 4 ppb (TWA) –	1.6 µg/filter 1.5 µg/filter 0.4 µg/filter

As discussed above, the sampling rate for a passive sampler is calculated using known exposure concentrations, sampling durations, and mass of collected contaminant on the sampler. An approximate sampling rate may be determined from the above information; however, a more accurate sampling rate can be obtained by exposing the samplers under controlled laboratory conditions.

Tests to determine the sampling rate of the two samplers developed for the purposes of this study were carried out in the Test Atmosphere Generating System or TAGS owned by Health Canada and operated by Bovar Environmental in Toronto. There were three separate 24-hour exposures for each type of sampler — SO_2 and NO_2 — at high ($50 \text{ } \mu\text{g}/\text{m}^3$), medium ($10 \text{ } \mu\text{g}/\text{m}^3$), and low ($5 \text{ } \mu\text{g}/\text{m}^3$) concentrations. The three data sets comparing known versus sampler concentrations are intended as a calibration of sampler accuracy. Precision of the samplers is determined by evaluating the variation of the samplers when exposed to similar SO_2 and NO_2 concentrations. Altogether 80 samples for each sampler type were collected.

Face velocity effects were evaluated and quantified by comparing samplers exposed to similar concentrations in different wind speeds. Lastly, a portion of the exposed samplers were analyzed at Bovar to provide insight into interlaboratory variability in the analysis of the samplers. It is important to note that this validation does not provide information related to the effect of relative humidity, temperature, or interference from other air contaminants.

Analysis consisted of multiple regression prediction of the collected weights using known concentration, known wind velocity, and laboratory of analysis as predictors. Figure 3 shows the best linear estimates for SO_2 collected weight from known SO_2 concentration with different curves for each lab.

Briefly, the results show that the sampling rate for the SO_2 sampler is 218 mL/min (with a standard error of 11 mL/min). There is no reliable difference between the analyses at the two laboratories. There is, however an effect for wind velocity such that increased velocity leads to increases in the sampling rate. The effect on the sampling rate, while statistically significant, is small.

Figure 3 SO_2 Calibration in Chamber Studies

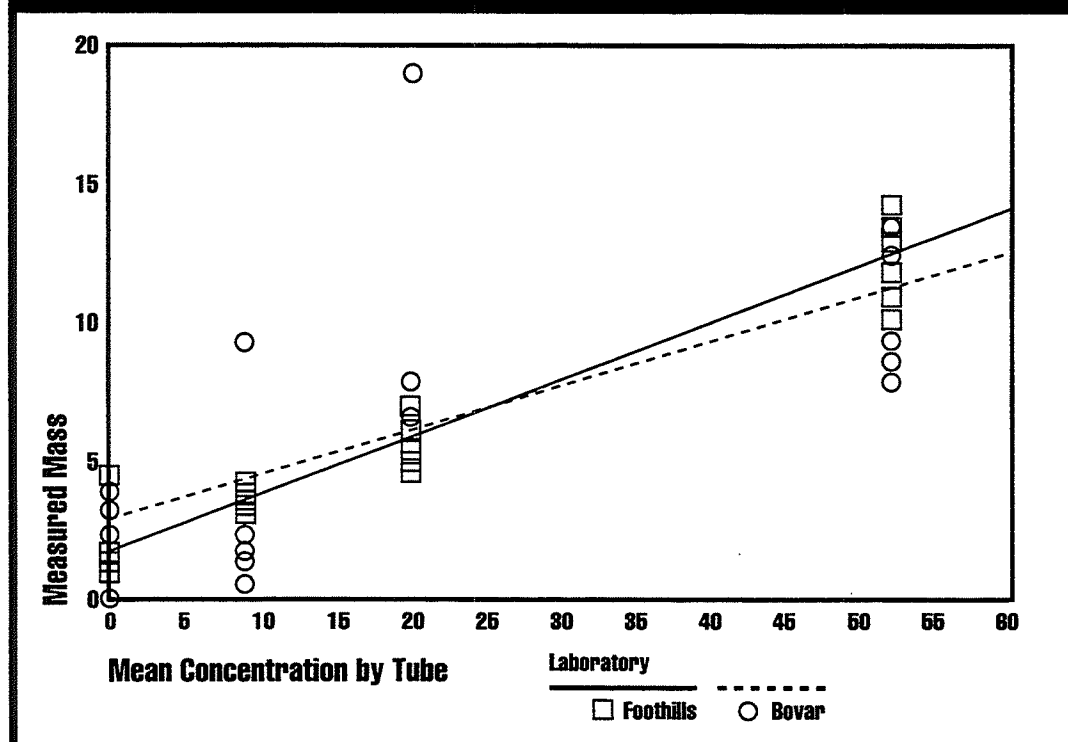


Figure 4 NO₂ Calibration in Chamber Studies

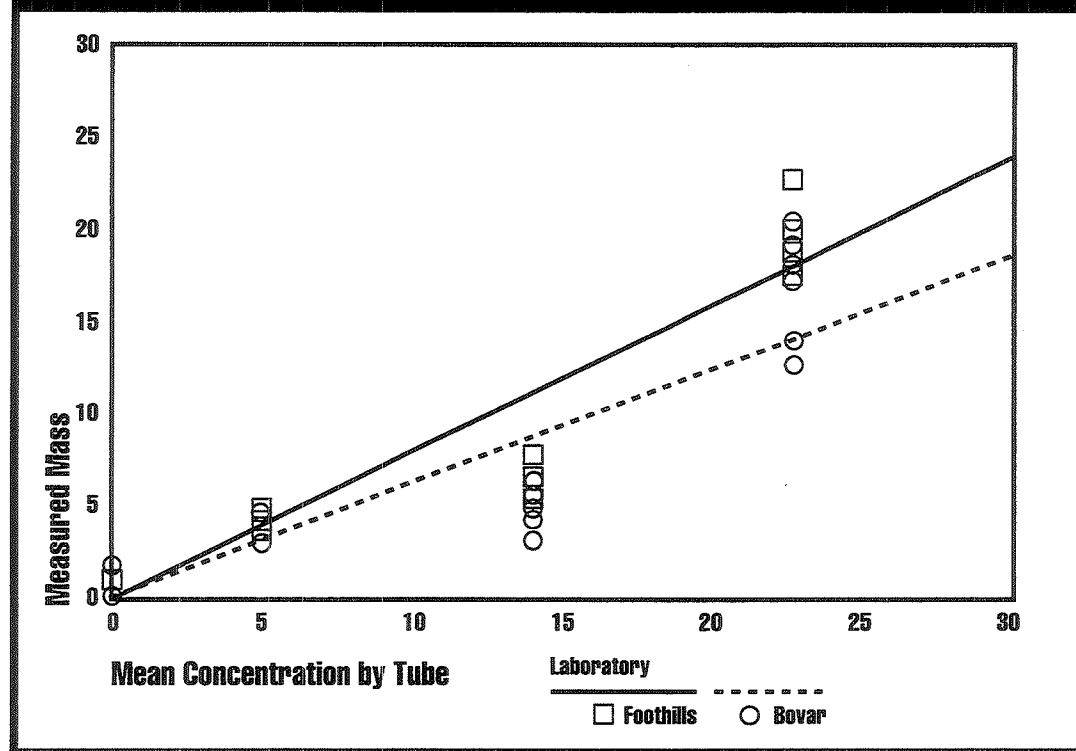


Figure 4 shows similar data for NO₂ samplers. For NO₂, the estimated sampling rate is 720 mL/min (with a standard error of 25 mL/min). Interpretation of these results is complicated by the fact that the relationship between concentration and exposure is apparently nonlinear. Thus the sampling rate is overestimated for small concentrations. If smaller concentrations are considered alone, the analysis provides an estimate of 525 mL/min (with a standard error of 46 mL/min). This suggests that the chamber studies at medium and high concentrations should be repeated. Though wind velocity does not have an effect, there is an effect for laboratory such that the difference in estimated sampling rates between the labs is 130 mL/min (with a standard error of 49 mL/min).

Ozone (O₃)

The Ogawa sampler is recognized by several research institutions (EPA Research Triangle Institute, Harvard School of Public Health, Gage Research at University of Toronto) as the preferred

sampling method for ozone. The sampler was originally designed by Harvard and is currently receiving royalties from Ogawa & Co. USA, Inc. who serve as the North American distributors. The Ogawa sampler has been used extensively in the United States and Japan for monitoring both personal and stationary ambient air exposure to ozone. Extensive validation studies are also available that indicate the variability of the sampler sampling rate and possible sources of bias.

The original selection of the sampler came on the recommendation of Dr. P. Koutrakis, while subsequent support for the sampler has been received from Dr. J. Mulik (RTI), Dr. Broder (Gage Research), and from field studies carried out by Alberta Environmental Protection and the Clean Air Strategic Alliance for Alberta.

The design of the sampler makes it very compact and ergonomically friendly. It is a small cylindrical polymer body (2 cm diameter x 3 cm wide) with treated filters mounted at each end. The diffusion barrier, as mentioned earlier, is not a membrane but rather a plastic cover with several holes. This is preferred for

sampling gases such as ozone because it is high reactivity with many substances including porous materials that may be used in other passive sampler applications. The cylinder holder is mounted in a small support with a pin attached to the back.

Unlike the SO₂ and NO₂ samplers, the O₃ sampler sorbent filter pads are patented and must be ordered from the supplier. The sorbent pads are ordered separately from the holders and loaded under zero air conditions in the laboratory. The active ingredient on the pads is nitrite (NO₂-), which collects ozone as nitrate (NO₃) and is reported from the lab as a mass of nitrate ion. The mass of nitrate ion is equivalent to the amount of ozone that was absorbed. The sampling rate reported by Koutrakis, et al. (1993) is 24.5 mL/minute.

The Ogawa ozone sampler was not pre-tested for this study. However, laboratory analysis of blank sorbent pads that were sent by Ogawa generated valuable preliminary results. During testing in the lab, it was found that the level of nitrate

on the blanks were variable and increased considerably with the time of storage. Due to this potential contamination, a direct link was established with Harvard laboratories where pads may be made "fresh" and shipped immediately upon request.

Given the amount of external research that has been invested into these samplers, it was decided that it was not a rational expenditure to perform exposure chamber tests. However, a number of samples were co-located at the Fort McMurray and/or Fort McKay air monitoring stations. The purpose of these co-location tests was to determine an estimate of confidence in the sampler results based on consistency of field blanks and proportion of blank values versus those exposed over 24 hours.

Ozone exposures to the Ogawa sampler are reported as a mass of nitrate ion. This mass of analyte is translated into a time-weighted average concentration through the predetermined and validated sampling rate. A sampling rate has been theoretically determined and empirically validated at 24.5 mL/minute.

Table 3 Compounds above Detection Limit

Compound	Oilsands		Fort McMurray		Personal
	Outdoor	Indoor	Outdoor	Indoor	
Benzene					*
2-Butanone					*
2,3 Dimethylpentane					*
Heptane	*	*			*
1-Heptane	*	*			*
Hexane	*	*			*
D-Limonene		*		*	*
3-Methyl Hexane	*				*
Methylcyclohexane					*
Octane	*				
Toulene				*	*
MP Xylene					*
O-Xylene					*

Volatile Organic Compounds (VOC s)

Volatile Organic Compounds, or VOC s are a group of contaminants that includes a number of individual chemical compounds. In an initial review of local and national ambient and indoor air quality studies (Health Canada, Environment Canada, Alberta Environmental Protection, Suncor, and Syncrude), it was found that over 75 volatile organic compounds were regularly being monitored to determine the potential impact on human health.

In order to obtain a general sense of the proportion of VOC species in the local air, 10 VOC samplers were deployed for 48 hours on-site at the oil sands (4 samplers), inside (2 samplers) and outside (2 samplers) a residential home in Fort McMurray, and on a person (2 samplers) who worked in the oil sands industry and resided in Fort McMurray.

Table 3 shows the compounds that were measured above detection limits in this small sample.

Based on these results and a series of selection criteria, the Science team identified ten VOC s to be monitored during the pilot study. The criteria used for selection of the primary VOC s for sampling were: level of toxicity, potential for exposure, availability of scientific method for measuring as a biomarker, and the known association with industrial or domestic sources.

The final list of VOC s to be measured for the field study is shown in Table 4. The list includes the main toxicological group of VOC s (BTEX and hexane), some aliphatic hydrocarbons with possible links to Oilsand emissions, and a terpene-based compound that may be representative of a large proportion of VOC exposure in the region.

The 3M Brand Organic Vapour Monitor #3500 is the passive air sampling device that was selected for use in the Oilsands Pilot Study. For personal sampling the sampler is worn near the breathing zone on the human host lapel or shirt collar, while ambient indoor and outdoor monitoring involves placing the sampler

in an open area with sheltering from the elements if required. The OVM-3500 has a metal collar clip that is attached to a plastic sorbent pad holder containing a charcoal pad. The sorbent is protected by a porous material that serves as a diffusion membrane.

The 3M sampler was introduced in the early 1970's as an occupational hygiene air sampler. Since this time, research by Coutant and Scott (1982), Sheilds and Weschler (1987), and Otson (1990) have combined to build a considerable level of confidence in the methodology. Moreover, Gagner (1996) performed exposure chamber, field, and personal validation studies at low temperatures in direct support of the Oilsands Program mandate.

The exposed sampler is processed in the lab by rinsing the carbon with a solvent to desorb the VOCs that were collected by the carbon. In many cases, the solvent retrieves about 100% of the VOCs, however when one assumes this to be the case it leaves the data open to justifiable criticisms. To avoid this, a desorption efficiency is determined for each VOC species by spiking the samplers with known

amounts and rinsing the samplers with the solvent. If the amount recovered equals the amount spiked, then there is 100% desorption efficiency. Any significant deviation from this must be accounted for in the data interpretation.

Exposed samplers are often stored in the field prior to shipping and/or in the laboratory prior to analysis. Testing must be completed to ensure that the VOCs that were collected by the sampler remain stable on the charcoal sorbent. To test for this, samples are spiked and stored for a time period similar to that expected during the study. After storage, the samples are analyzed and the stability evaluated according to losses or gains of analyte.

Table 4 Compounds Chosen for Inclusion in the Oilsands Pilot Study

Selected Compound	Rationale
Benzene	a. toxicity: aplastic anaemia, leukemia b. biomarker: phenol muconic acid c. source: tobacco smoke, automobile, occupation
Toluene	a. toxicity: CNS effects, building related illness (BRI) b. biomarker: hippuric acid, benzoic acid, o-cresol c. source: domestic products, solvents
Ethyl Benzene	a. toxicity: CNS effects, BRI b. biomarker: mandelic acid c. source: alkylbenzines linked to petroleum distillation
Xylene (m, p, o)	a. toxicity: CNS effects, respiratory tract irritation b. biomarker: methylhippuric acid c. source: cleaning agents, paint thinner
n-Hexane	a. toxicity: respiratory irritation, BRI b. biomarker: 2-hexanol, 2,5-hexanedion c. source: domestic and industrial solvent
n-Decane n-Heptane n-Octane n-Nonane Methyl Ethyl Ketone	These compounds were selected based on the results of preliminary sampling on-site at the Oilsands. Exposure measures in Ft. McMurray / Ft. McKay are intended to serve as a possible marker of oil-sand emissions.
D-Limonene	Preliminary sampling indicates that concentrations of this compound were relatively high compared to concentrations of other VOC compounds.

The two main objectives in a sample rate validation are to determine the accuracy and the precision of the sampler. Accuracy is estimated by comparing sampler readings to the readings from a certified reference method. Precision may be determined concurrently by performing the exposures in duplicate or triplicate and comparing the results between similar samplers. All of the sampling rates to be used for the VOC interpretations have been empirically tested by 3M or by Health Canada, who uses this sampler for monitoring VOCs included in the Federal Priority Substance List. The Environmental Health Directorate at Health Canada in Ottawa operates a laboratory that has been measuring VOCs with the OVM-3500. As mentioned, their work is in support of developing methods for the Priority Substances List and a considerable amount of testing has been performed in the past to ensure confident results. This laboratory has and will be used intermittently as a check on the Foothills Laboratory contracted by the Oilsands Study to develop our own methods for OVM-3500 analysis.

The detection limits of the entire sampling method are dictated by the background contamination on the sampler and the ability of the analytical instruments to register the presence of analyte. To assess detection, the amount and variability of the VOC masses are measured from a number of blank samplers. The standard deviation (SD) of these blank readings is then determined and used in the calculation of statistical confidence. To be considered detectable (minimum limit of detection) the exposed sampler must register a mass higher than 2 SDs above the average sampler background levels. In order for 95% confidence in the measurement (reliable detection limit), the sampler analyte mass must measure 4.66 SDs above the blank average. Blank samplers were processed prior to going to the field and throughout the Oilsands Pilot study.

Particulates (PM₁₀ and PM_{2.5})

The measurement of particulates in air is achieved by pulling a known volume of air through a filter, determining the net gain of particulate mass collected during

To minimize bias due to variable storage times, the samplers were shipped twice weekly to the Foothills Laboratory for analysis. All shipments included a Chain of Custody/Analytical Request Form with date of submission, date required, a project submission number, sample ID, sampling crew ID, exposure duration, compound to be analyzed, data reporting address, phone number, number of samples submitted, number of coolers/boxes, and a relinquishing signature and date.

At the lab, the sampler ID numbers are removed by support staff, who translate the sampler number into different laboratory ID numbers. This ensures that the test is blind — that is, that the laboratory testing procedure is not affected by the knowledge of the duration of the sampling period. The samplers were then processed with a 1.5mL carbon disulfide rinse and analyzed through gas chromatography with mass spectrometry detection operating in selection ion monitoring mode. A mass of the preselected VOC species was reported per mL of extract and translated into mass per sampler.

The reported mass of the compound was then translated into a time-weighted average concentration using a predetermined and validated sampling rate. There are several lists of sampling rates that have been determined through field and chamber tests. The list of sampling rates that was been selected for use in the pilot study was the 3M Organic Vapour Monitor Sampling and Analysis Guide for the OVM-3500/3501, published in 1993. For reference, these sampling rates (as well as the rates discovered for SO₂ and NO₂ samplers) are presented separately in Appendix A. Large discrepancies in sampling rates between 3M and Health Canada were noted, and when justified, expressed as two separate numbers.

the sampling period, and interpreting the results as a mass of particulate per unit volume of air. Impactor heads are used at the sampler inlet to govern the

Table 5 Expected Particulate Rates

Flow Rate (L/min)	Concentration ($\mu\text{g}/\text{m}^3$)	Mass Collected (μg)
4	10	58
4	30	173
4	60	346
10	10	144
10	30	432
10	60	864

size of the particulate to be collected by the sampler filter. The particles collected by the impactor plate are discarded and the particles on the filter are weighed (as mentioned) and sometimes analyzed for chemical composition.

There are a number of methods outlined by Chow (1995) for separating different strata of particulate from air. It was the intention of the Science Advisors to select a method that had been used in scientifically recognized studies, that were applicable for personal and ambient air monitoring, and were of a simple enough design to allow operation by a person with introductory training to environmental sampling.

The Marple Personal Exposure Monitor or PEM was first recommended by Petros Koutrakis from Harvard University. Follow-up conversations with Steve Ferguson from the School of Public Health at Harvard eventually led to the Research Triangle Institute where they are currently administering an extensive sampling program for PM_{10} and $\text{PM}_{2.5}$ in Toronto, Ontario. The Science Team determined that this sampler offered the most reliable method for sampling PM_{10} and $\text{PM}_{2.5}$ for the pilot study.

As with all types of matrix sampling, it is necessary for the sample of interest to be significantly higher than the normal background levels. Shaole Wu, from the Alberta Environment Centre, identified the minimum mass of particulate required to be collected on the Marple filters as $100 \text{ } \mu\text{g}$. Although the true indication of detection would be determined through the analysis of field blanks, this mass was assumed to be an appropriate estimate on which to base our initial sample method design.

Particulate measures in Fort McMurray and Fort McKay are not taken at the local ambient air monitoring stations; however, an estimate of PM_{10} was made based on readings of coefficient of haze (COH). Based on ad hoc methods, a best guess PM_{10} concentration was determined to be 10 to $30 \text{ } \mu\text{g}/\text{m}^3$ in Fort McMurray and Fort McKay.

Table 5 shows the calculations of expected particulate mass collection over a 24 hour exposure with flow rates set at 4 and 10 L/min. Based on the assumption that the estimates are somewhat representative of outdoor air and that trends of higher personal exposure remain consistent with PTEAM findings (Pellizari, 1993), the Science Team determined that a 4 L/min flow rate should collect enough particulate matter for detection by the laboratory. A review of commercially available personal sampling pumps found that a pump manufactured by SKC Inc. would be the most appropriate brand for the pilot study. The SKC pump had the benefits of being supplied locally, recommendations from several safety professionals, and SKC pump is very competitive in price. The Occupational Hygiene Group at Suncor endorsed the SKC product and also agreed to loan the Alberta Oilsands Community Exposure and Health Effects Assessment Program six of their pumps and two recharging units for the duration of the study.

Environment Canada donated the use of nine "Minivol" particulate samplers that operate at 5 L/min flow rates. There is high confidence in these samplers as they have been used extensively in several parts of Alberta and under a variety of climatic conditions. However, in an effort to address the possibility of non-detect values, additional larger units were constructed to operate at 10 L/min at existing air monitoring stations. The design of the stationary units was patterned after a pump designed at Harvard that are regularly used by the EPA.

Prewieghed filters were sent to the study office with assigned identification numbers. Personnel at the field preparation area checked the filters for any obvious physical changes during shipment. Care was taken to ensure that the sintered metal impaction surface inside the Marple Head was properly treated with oil. A special press was used to load the sampler with a support pad, drain disc, and preweighed filter. While in the field, a pre- and post-sampling check of the pumping system was carried out to ensure flow rates were consistently maintained.

All personal samples include a specially designed elutriator head that eliminates the effect of the volunteer's "personal cloud" of particulate on the sample mass.

The stationary units that were used to measure indoor particulates are equipped with a timer that shuts off in the event of the power being disconnected. The construction of the unit is also such that it withstands typical activity in the field. The sampling head is elevated away from the pumping system to provide measurements somewhat representative of an adult's normal breathing area. Lastly, safety of the unit is imperative and all efforts were made to maximize safety of both the individuals wearing the monitors and other household residents - especially children.

Two Health Inspectors wore the personal exposure monitors during the Field Study. The Inspectors also placed the stationary samplers in and outside of their homes for six separate 24-hour

sampling periods. Stationary units used to monitor the outdoor air were positioned in a location facing the major access road and sheltered, within reason, from the elements. Weather in Fort McMurray and Fort McKay can be quite severe and it was considered important that the units were tested in extreme winds and temperatures.

The main source of variability in particulate samples is related to the consistency of the air flow rate of the pumps. Measures are taken before and after the sample run, adjusted for temperature and pressure, and averaged as a common rate for the sample duration. Notwithstanding this limitation, the results of the samplers can be interpreted as a single time-weighted average value or as a range reported within the context of this assumption.

DEVELOPMENT OF ANCILLARY INDIVIDUAL MEASURES

The Time Activity Diary

Activity logs and diaries are an important part of exposure assessment. The time activity diary can indicate potential sources of exposure to a particular contaminant, because many of our daily activities, such as taking a shower, driving a car, or hobbies, are known to be associated with exposure to particular air-borne contaminants. Activity diaries are widely recommended in the literature (Freeman et al, 1991; Nelson et

al, 1994), and have been proven to be valuable to the interpretation of the measured exposure levels. The collection instrument was a simple design that allowed the participant to identify their daily activities and the time at which these activities were undertaken. Participants were asked to include all activities undertaken while wearing the sampler, including periods of sleep, bathing, and eating.

Demographic and Exposure Questionnaire

The Demographic and Exposure Questionnaire was designed to collect information about participant demographics, occupational health, and work and home environments including potential sources of contaminants. It

included all of the questions on the Basic Standard Environmental Inventory Questionnaire developed by Lebowitz et al (1989), designed to help classify relative concentration estimates.

The Health and Nutrition Survey

The Health And Nutrition Survey was designed to collect a variety of health indicators including both mental and physical health, physical activity levels, and nutritional intake. Two standardized scales are included: the General Health Questionnaire (GHQ), and the Short-Form-36 Health Survey (SF-36). Both questionnaires are well-validated and documented tools for assessing health.

The GHQ assesses psychological well-being, and the SF-36 assesses physical functioning, role limitations, bodily pain, social functioning, general mental health, vitality and general perceptions. Additional measures from the National Population Health Survey conducted by Statistics Canada were also included to provide information about physical activity level.

FIELD STUDY

Goals

The primary goals of the Field Study included:

- **Generating preliminary exposure information to support the effective design of the Main Study;**
- **Establishing and testing protocols for deploying, collecting, packaging/shipping, and analyzing exposure monitoring samples;**
- **Field testing of ancillary individual questionnaire instruments.**

In general, the pilot study sought to test the data collection instruments and methods on a small sample, consequently many important aspects of the data were not examined.

For the purposes of Main Study design, the following questions related to exposure assessment were paramount:

- **Which exposure components should be monitored and under which conditions?**
- **What level of monitoring is required?**
- **Specifically, how many individuals should be monitored to establish stable estimates of community exposure?**
- **In addition, how many samples are required to determine stable estimates of exposure levels for each participating individual in order to support joint analysis of exposure levels, biological marker information, and health status information?**

Design

As detailed above, the candidate procedures included distinct exposure monitoring samplers for

- **Sulphur Dioxide (SO₂),**
- **Nitrogen Dioxide (NO₂),**
- **Ozone (O₃),**
- **Volatile Organic Compounds (VOCs), and**
- **Particulates**

Each of these sampler types was deployed under two general sets of conditions:

- **Ambient outdoor monitoring in 3 sites within the test area (Fort McMurray, Fort MacKay, and Suncor Plant Site).**
- **Outdoor, Indoor, and Personal monitoring of specific individuals within the test area.**

The design of the Exposure Assessment component of the Pilot Study focused on obtaining multiple samples from each location and/or participant. For ambient monitoring, the basic sampling unit was an exposure sample from each of the

three stationary locations over a 24 hour period. At least two sampling units were to be collected on each of three separate days.

For individual monitoring, the basic assessment unit was a single sample of each of three exposure types (Indoor, Outdoor, and Personal) from a single participant over a 24 hour period. For each participating individual, four samples were collected, each on a separate day. Measures for only one type of contaminant were collected for each individual participating in the pilot study. Participants were selected to ensure that homes with identifiable sources of contaminants (such as natural gas ranges) were evenly distributed across the contaminant groups. The initial goal was to test a minimum of 10 individuals for each of the NO₂, SO₂, O₃, and VOC exposure assessment procedures.

All samples were collected between September 3 and October 11, 1996. Due to sample size limitations and pragmatic considerations, no systematic design component for the sampling of particular days for exposure assessment was

attempted, although trends across particular days were examined during analysis. Variations from this design were introduced for a variety of reasons including difficulties in volunteer recruitment, equipment procurement, equipment failure, data recording, and analysis. Because of the broad goals of the Field Study, these are not considered critical.

Due to the differences in measurement technology previously discussed, limited sampling of particulate exposure was possible. A similar protocol was intended for Particulate assessment, though with further reduced sample sizes (5 households) since two types of particulate sampling (PM_{2.5} and PM₁₀) were to be collected. During assessment, it was determined that personal monitoring would be generally unworkable for volunteers. Alternative methodologies are being considered for the Main Study.

Sampling

Participants were recruited through an advertising campaign in various local media. Respondents were initially screened to ensure that the pilot study sample included only non-smoking adults. Children were excluded from the study sample for several reasons:

- **very young children cannot carry the personal exposure monitor;**
- **older children who could carry the monitor would be less likely than adults to wear it because it would interfere too much with their normal activities;**
- **children might not be able to provide reliable time-activity data;**

- **children are likely to have higher exposures to particles and chemical constituents than adults because of their activity patterns;**
- **ingestion may be an important route of exposure to particulates for children that would not be evaluated within the parameters of the pilot study.**

Smokers were excluded from the pilot study sample in line with previous TEAM studies. However, non-smokers living in homes with other smokers were included in the sample for the pilot study. This decision will be reviewed prior to the Main Study.

Field Operations

Interview Teams

Five teams of interviewers conducted the various field activities, including interviewing the selected respondents, locating and handling of the Personal Exposure Monitoring devices, and returning the samplers and completed questionnaires to the field office. The Field Coordinator was responsible for coordinating the flow of samples, sampling time information and respondent data, ensuring that the correct information was collected from each of the participant groups, and sending spent samplers to the laboratory for testing.

Housing

Dedicated space was allocated at the regional health facility, where the Field Coordinator was provided with office space. Air flow cartridges were stored in another location in the hospital to avoid contamination prior to sampling.

Data Entry

Data entry of all questionnaires and log sheets was completed by the Field Coordinator using Microsoft Access and QDATA (a shareware data entry program). Error correction was completed by members of the Science Team.

ANALYSIS OF EXPOSURE DATA

Analysis

In part due to the wide scope of the Field study, the number of samples collected for any particular procedure is insufficient to allow strong conclusions or rigorous tests of hypotheses related to differences between particular exposure conditions. As a consequence, the analysis of exposure data described below are primarily descriptive and intended to be suggestive of hypotheses to be further examined with data from the main study.

For each of the different types of exposure assessment the following general questions guided the analysis:

- **Do exposure levels exceed detection limits?**
- **Under what conditions would differences between Ambient, Indoor, Outdoor, Personal exposure levels be detectable?**
- **Under what conditions would**

differences in exposure levels between particular individuals be detectable?

- **What is the potential influence of day to day variation on exposure levels?**

Where feasible, preliminary analyzes of additional questions were also attempted, including:

- **Are there relationships between Indoor, Outdoor, and Personal exposure levels?**
- **Are there relationships between exposures levels for particular classes of compounds; specifically, different VOCs analyzed from a single sample, and different heavy metals analyzed from a single sample?**

In general, the results presented below are organized around these questions.

Results

Analyzes are reported by sampler type, with each distinct type reported in a separate section. In general these analyzes utilize weights (typically in $\hat{\text{Eg}}$) collected on the sampler. Since actual exposure times were collected as part of the protocol, weights were time corrected to yield the weight that would

have been expected over a precise 24 hour period. Conversion of weights to concentrations requires the use of sampling rate information which is presented in Appendix A. The development of sampling rates for the NO_2 and SO_2 samplers is described in Appendix B.

Nitrogen Dioxide (NO_2)

Samples were collected from 11 individuals for 4 days, and 2 individuals for 3 days. When aberrant samples were eliminated, this resulted in 49 Outdoor samples, 47 Indoor samples, and 49 Personal samples. Three samples were also collected from the three stationary sites on three consecutive days. When aberrant samples were eliminated, this resulted in 22 ambient samples. Chemical analysis was also performed on 11 blank (unexposed) samplers.

The time-corrected weights from all 165 exposed filters is presented in Figure 5. These weights follow a skewed distribution typical of those encountered in studies of exposure. Thus only a very small proportion of samples indicate high levels of exposure (relative to the mode of the distribution).

Figure 6 shows box plots of Log NO₂ weights according to sample type. The log transformation is utilized to normalize individual distributions. In these box plots, the middle 50% of the samples had values contained inside the span of the box, while the extreme quartiles on each side of the box are contained within the extended lines. Extreme outlying samples are marked by separate symbols.

Several properties should be noted. First, the NO₂ levels of all exposed samples exceeds the levels measured on blanks, indicating that measurable quantities of NO₂ do exist in the test area. Second, neither the ambient nor outdoor locations show a markedly skewed distribution; the indoor and personal measures account for a large majority of the most extreme measures. Third, median level for personal exposure exceeds that for outdoor and ambient levels, which in turn exceed the indoor level. Statistical analysis lends additional support to this last observation:

nonparametric tests confirm that the central tendencies differ among personal, indoor, and outdoor samples (Median Test, $2=14.5$, $df=2$, $p<0.001$).

Separate analysis of the results of ambient monitoring is suggestive both that the Fort McMurray town site had higher levels of NO₂ concentration, and that the first day of testing showed

Figure 5 NO₂ Calibration in Chamber Studies

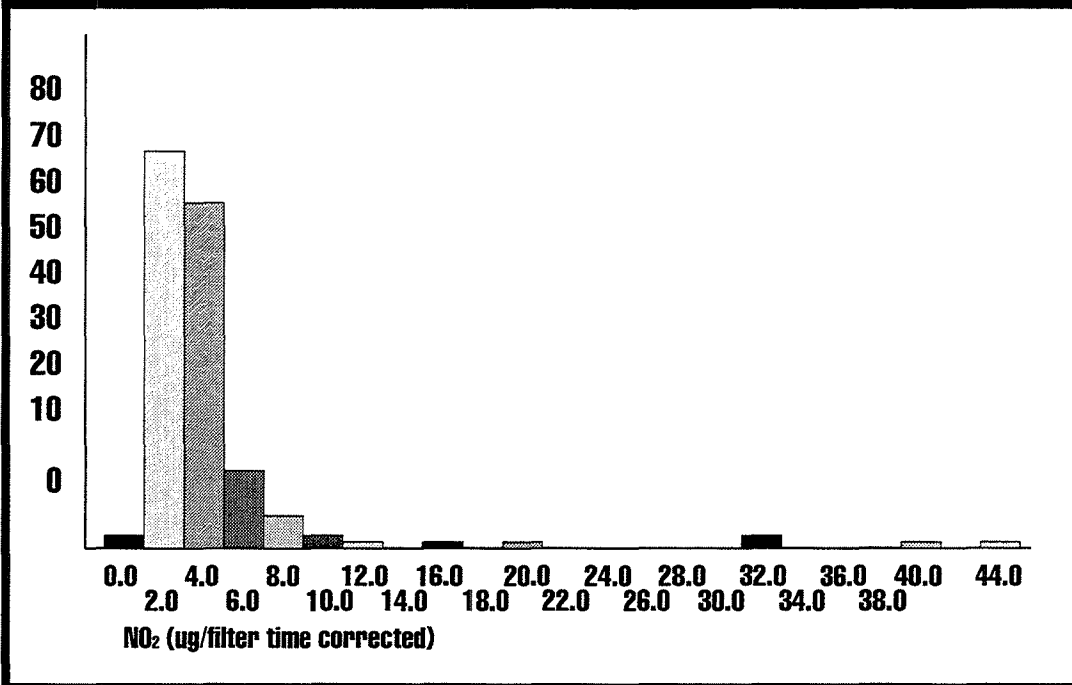


Figure 6 Box Plots of Log NO₂ by Location

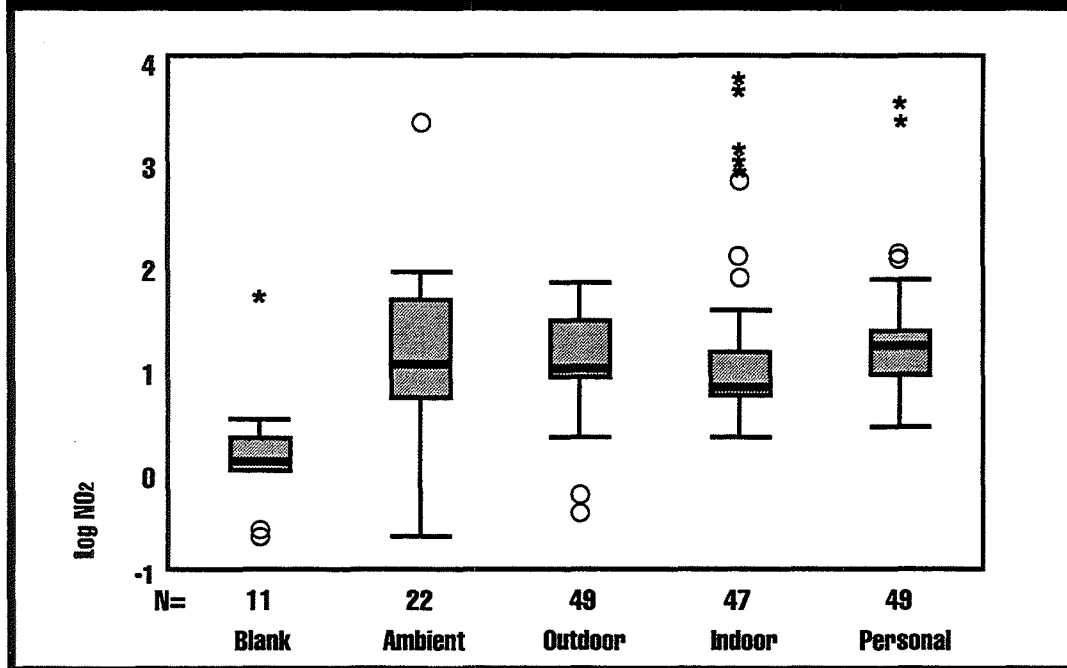


Table 6 Log Means NO₂ Weights at Ambient Monitoring Sites

Site	Day of the Year		
	281	282	283
Fort McMurray	1.59	1.70	1.73
Sucor	0.54	1.31	1.27
Fort MacKay	0.71	1.53	1.57

generally lower levels of NO₂ concentration than did the two succeeding days. Neither of these effects was significant in conventional tests of significance, however. The means of the log NO₂ weights are presented in Table 6.

Further analysis focused upon estimating exposure variability and the reliability of the sampling technology. Three sources for estimating the variability of individual samples exist: the variability of the blanks, the variability of ambient measures corrected for the effects of site and day, and the variability of the individual samples corrected for subject and type of sample. Each of these estimates requires a different procedure. Nevertheless, as Table 7 shows, the estimates of error of measurement are consistent with each other.

Table 7 Estimated Error Variability of NO₂ Samples (in Log Units)

Source	Estimated Standard Deviation
Blank	0.59
Ambient (Corrected)	0.50
Individual (Corrected)	0.41

The procedure employed to estimate the variability of individual samplers (variance component analysis) also provides an estimate of the variability in the exposure measures due to differences in particular individuals. This analysis suggested that particular individuals have characteristic levels of exposure across multiple measures, though only for indoor and personal exposures, and with substantially less variability than is present in the error variability of the sample measures themselves. This strongly suggests that multiple exposure samples will be required to estimate an individual's characteristic level of indoor and personal exposure to NO₂.

Figure 7 Log Mean NO₂ Weight by Sample Type and Subject

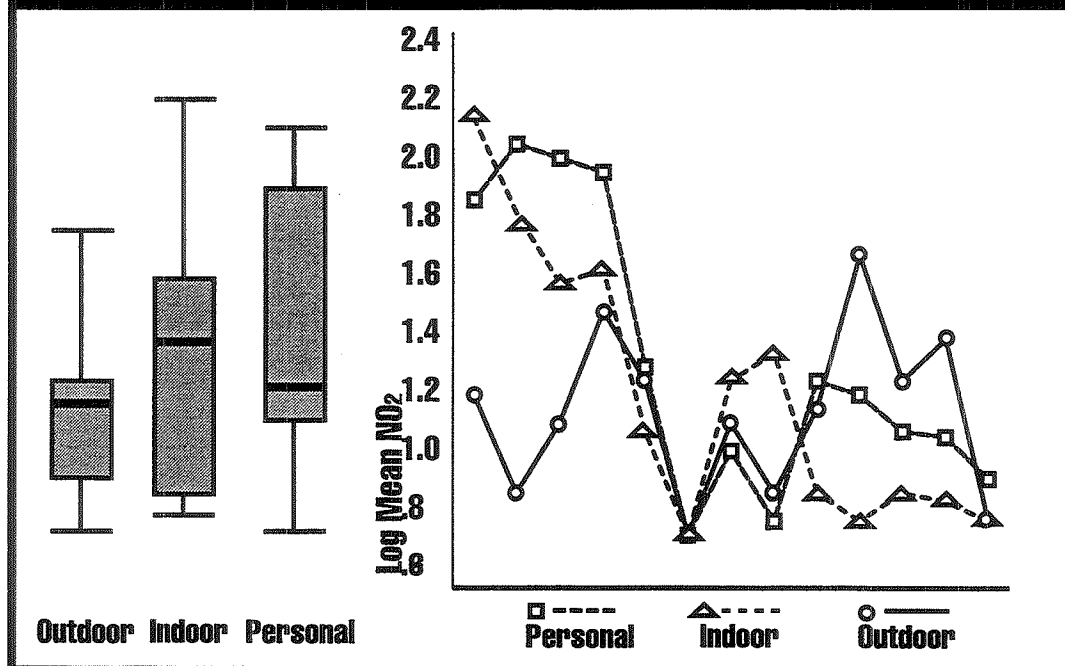


Figure 7 illustrates this graphically. The right panel of the graph shows mean log NO₂ weights for outdoor, indoor, and personal exposure measures for each individual in the study. The left panel shows the corresponding distributions of the mean exposure levels by type, and clearly illustrates that the indoor and personal exposures are more variable across subjects than are the outdoor exposures. The right panel has the extra benefit of representing the relationship between indoor, outdoor, and personal

measures within particular individuals. Individuals have been ordered by decreasing scores on a composite measure of overall exposure (technically the first principal component of the indoor, outdoor, and personal measures). Examination of the trend lines in this diagram illustrate that indoor and personal exposure levels are associated, while outdoor exposure level does not appear to be strongly associated to either personal or indoor levels.

Sulphur Dioxide (SO₂)

Samples were collected from 11 individuals for 4 days, and 2 individuals for 2 days. When aberrant samples were eliminated, this resulted in 47 Outdoor samples, 47 Indoor samples, and 47 Personal samples. Two samples were also collected from the three stationary sites on three consecutive days. This resulted in 18 ambient samples. Chemical analysis was also performed on 11 blank (unexposed) samplers.

The time-corrected weights from all 159 exposed filters is presented in Figure 8. As with the NO₂ samplers, only a very small proportion of samples show high levels of exposure.

Figure 9 shows box plots of Log SO₂ weights according to sample type. Several properties should be noted. First, though the SO₂ levels of exposed samples generally exceeds the levels measured on blanks, the differences are slight. In fact, without the presence of extreme samples in the exposed samplers, we would not be able to conclude that measurable quantities of SO₂ exist in the test area. Second, median levels for outdoor and ambient levels tend to exceed those for indoor and personal levels. Statistical analysis lends only mild support to this last observation: nonparametric tests suggest that the central tendencies differ among these types (Median Test, 2=1.76, df=1, p<0.20).

Figure 8 Distribution of Exposed SO₂ Filters

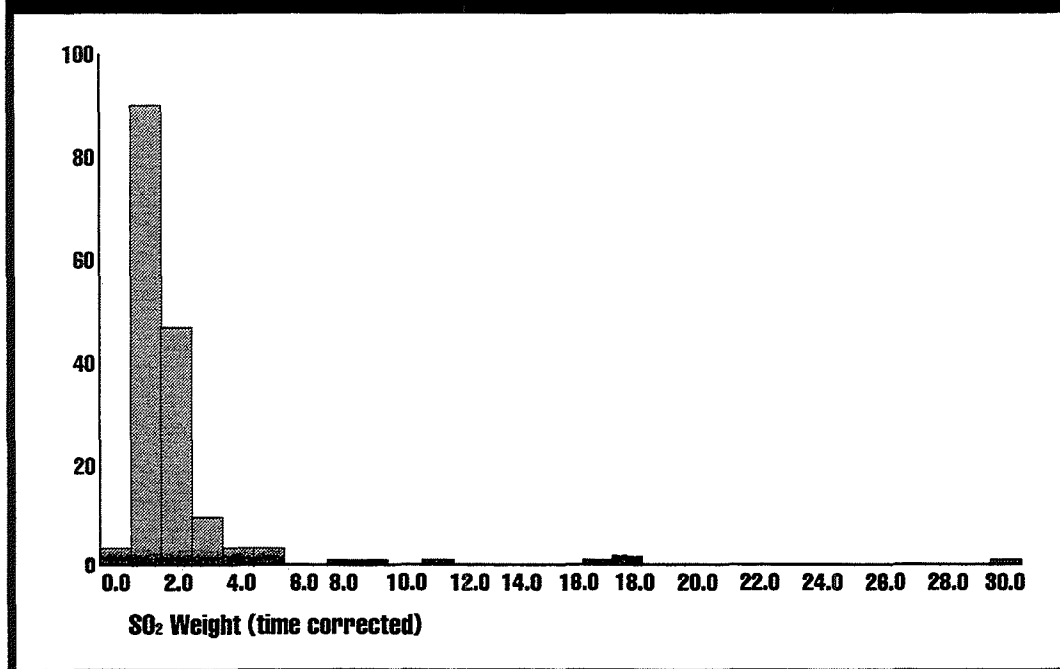
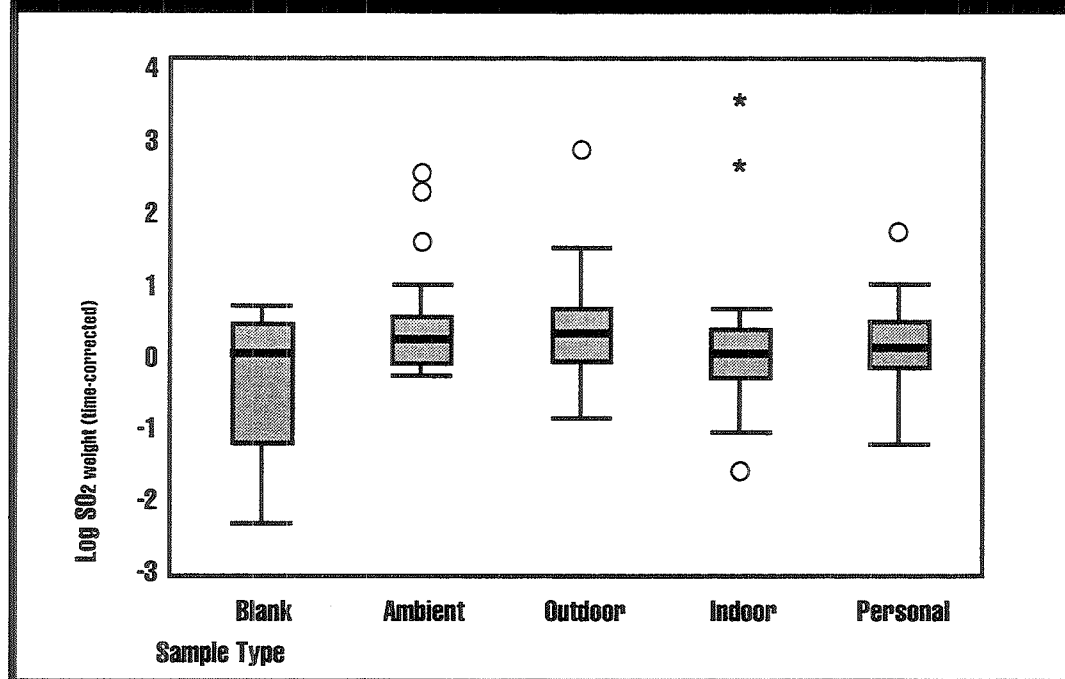


Figure 9 Box Plots of Log SO₂ by Location



Separate analysis of the results of ambient monitoring does not provide strong evidence that the sites differ in SO₂ concentration. The analysis does show however that the third day of the test had lower ambient levels than did the first two days (Main Effect for Day, $F=3.8$, $df=2, 22$, $p<0.05$). This suggests that day to day variability could be of considerable importance in the monitoring of SO₂. The means of the log SO₂ weights are presented in Table 8.

Further analysis focused upon estimating exposure variability and the reliability of the sampling technology. Three sources for estimating the variability of individual samples exist: the variability of the blanks, the variability of ambient

measures corrected for the effects of site and day, and the variability of the individual samples corrected for subject and type of sample. Each of these estimates requires a different procedure. Table 9 shows these estimates. No explanation for the relatively high variability of the blank samples suggests itself.

The procedure employed to estimate the variability of individual samplers (variance component analysis) also provides an estimate of the variability in the exposure measures due to differences in particular individuals. This analysis suggested that particular individuals have characteristic levels of exposure across multiple measures.

Table 8 Log Means SO₂ Weights at Ambient Monitoring Sites

Site	Day of the Year		
	281	282	283
Fort McMurray	0.60	0.33	-0.04
Sucor	1.51	0.24	0.07
Fort MacKay	0.61	1.14	0.13

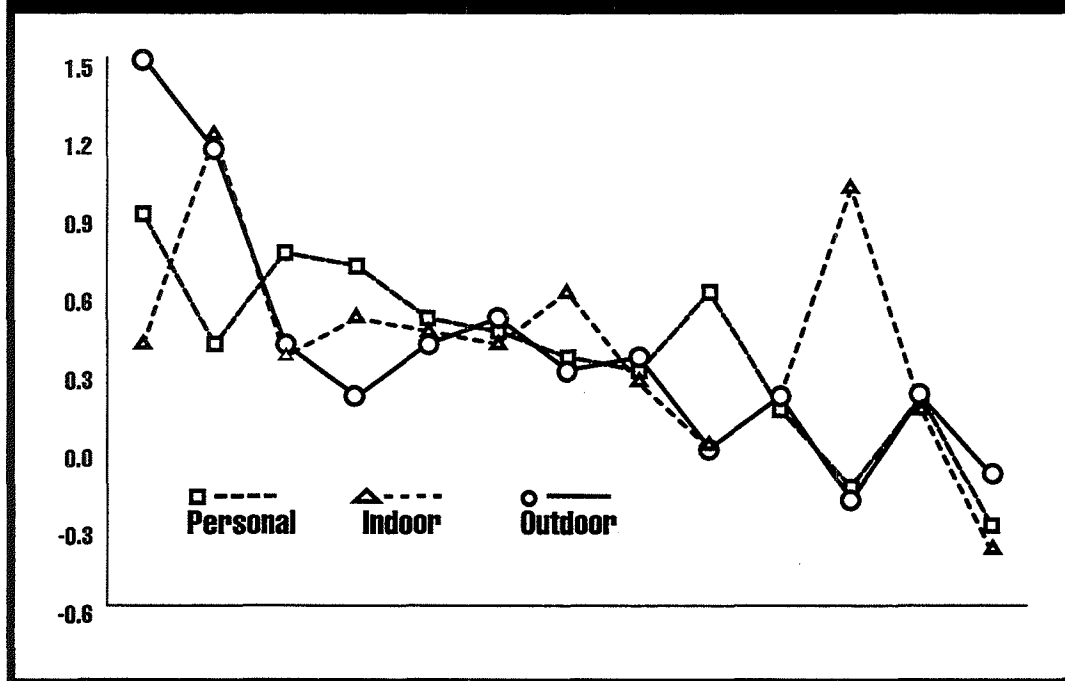
Table 9 Estimated Error Variability of SO₂ Samples (in Log Units)

Source	Estimated Standard Deviation
Blank	0.89
Ambient (Corrected)	0.37
Individual (Corrected)	0.44

Figure 10 is an illustration of the relationship between indoor, outdoor, and personal measures within particular individuals. Examination of particular levels revealed an anomaly with data collected on day 267: outdoor exposure levels were very high, but indoor and personal exposure levels were very low. The data collected on this day were excluded from Figure 7 to allow the relationships to be more readily viewed, however, the inclusion of these data would not have changed the basic

pattern of results. In the Figure, individuals have been ordered by decreasing scores on a composite measure of overall exposure (technically the first principal component of the indoor, outdoor, and personal measures). As can be seen, exposure levels between all three types of sample are intercorrelated such that the higher the level of outdoor exposure, the higher the level of indoor and personal exposure as well.

Figure 10 Log Mean SO₂ Weight by Sample Type and Subject



Ozone (O₃)

Samples were collected from 6 individuals for 4 days, 3 individuals for 3 days, 3 individuals for 2 days and 1 individual for 1 day. When aberrant samples were eliminated this resulted in 38 Outdoor samples, 41 Indoor samples, and 42 Personal samples. Two samples were also collected from the three stationary sites on three consecutive days (with one extra sample collected). This resulted in 19 ambient samples. Chemical analysis was also performed on 17 blank (unexposed) samplers.

The time-corrected weights from all 140 exposed filters is presented in Figure 11. For O₃, the distribution was only mildly skewed.

Figure 12 shows box plots of O₃ weights according to sample type. Only the Outdoor sample appears to differ from any other type including blank samples. Statistical analysis lends support to this last observation.

Figure 11 Distribution of Exposed O₃ Filters

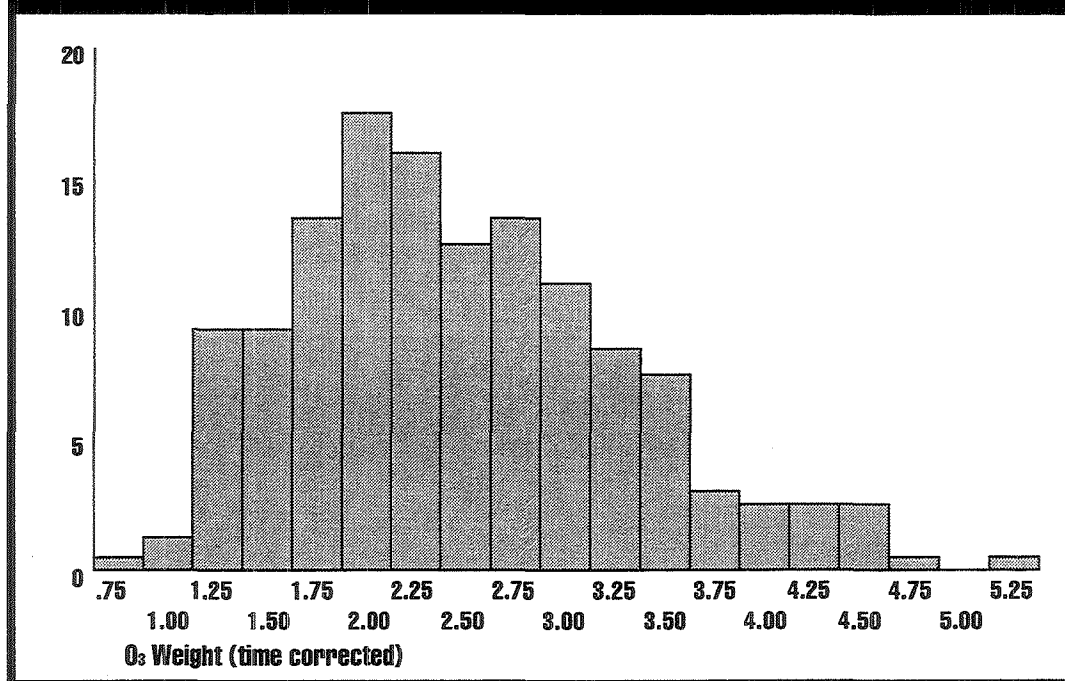
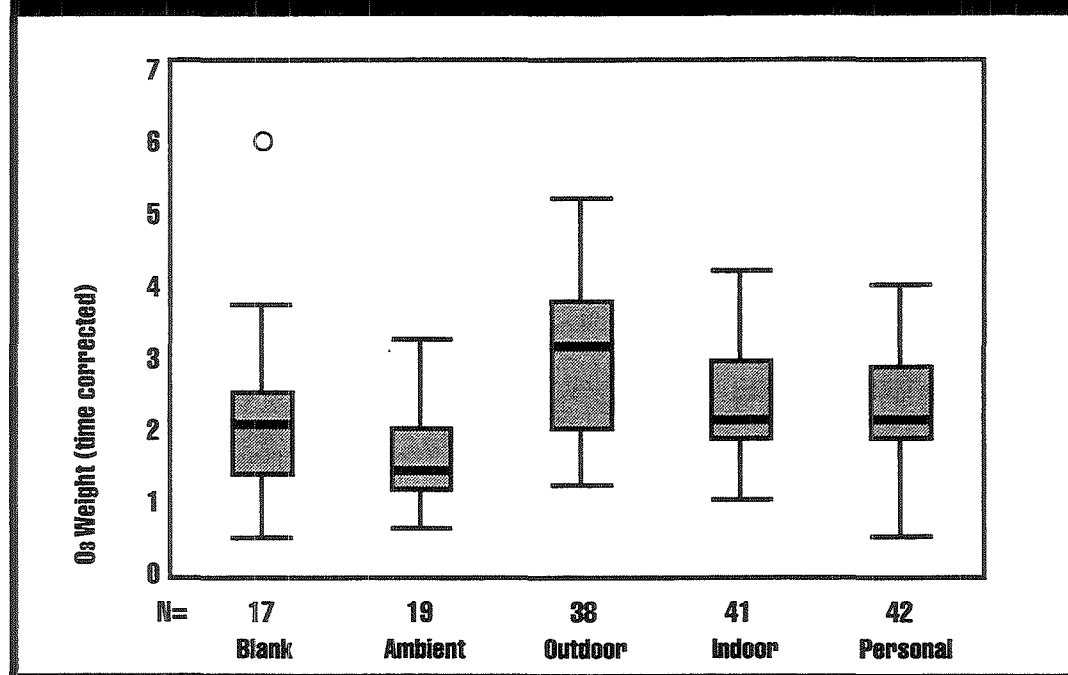


Figure 12 Box Plots of Log O₃ by Location



Further analysis lends no support to for any variation in levels across ambient sites or days, or for any characteristic level of individual exposure. There is slight support for a relationship between personal and indoor exposure levels across individuals, but no support for a relationship between outdoor levels and either personal or indoor levels. Table 10 presents estimated levels of error variability for the O₃ samplers.

Table 10 Estimated Error Variability of O₃ Samples (in Log Units)

Source	Estimated Standard Deviation
Blank	0.85
Ambient	0.43
(Corrected)	
Individual	0.61
(Corrected)	

Volatile Organic Compounds

Samples were collected from 12 individuals for 4 days, 4 individuals for 3 days, and 4 individuals for 2 days. When aberrant samples were eliminated this resulted in 69 Outdoor samples, 67 Indoor samples, and 67 Personal samples. Three samples were also collected from the three stationary sites on three consecutive days. When aberrant samples were eliminated this resulted in 21 ambient samples. Chemical analysis was also performed on 13 blank (unexposed) samplers.

Data from these samples was reported as nondetectable for those samples where levels did not exceed traditional analytic limits. Table 11 shows the proportion of samples of the various types that failed to exceed detection limits for the 12 chemicals analyzed from each sample.

In the first stage of analysis, the correlations between the levels of the twelve chemicals were examined. It was anticipated that the chemicals would group in a manner that would allow a consideration of a small number of groups rather than all 12 chemicals. Specifically, a principal components analysis with subsequent varimax rotation was performed. Five factors were extracted. The factor loading matrix is presented in Table 12 and shows that 5 groups of chemicals whose levels varied similarly across samples could be isolated. Further analysis proceeded on 4 of these groups (the Octane, Hexane, Toluene, and Limonene groups) using combined scores for the chemicals in the group. The fifth group consisting of Butanone alone was undetected in almost all samples and was therefore not considered further.

Table 11 Proportion of Samples Below Detection Limits

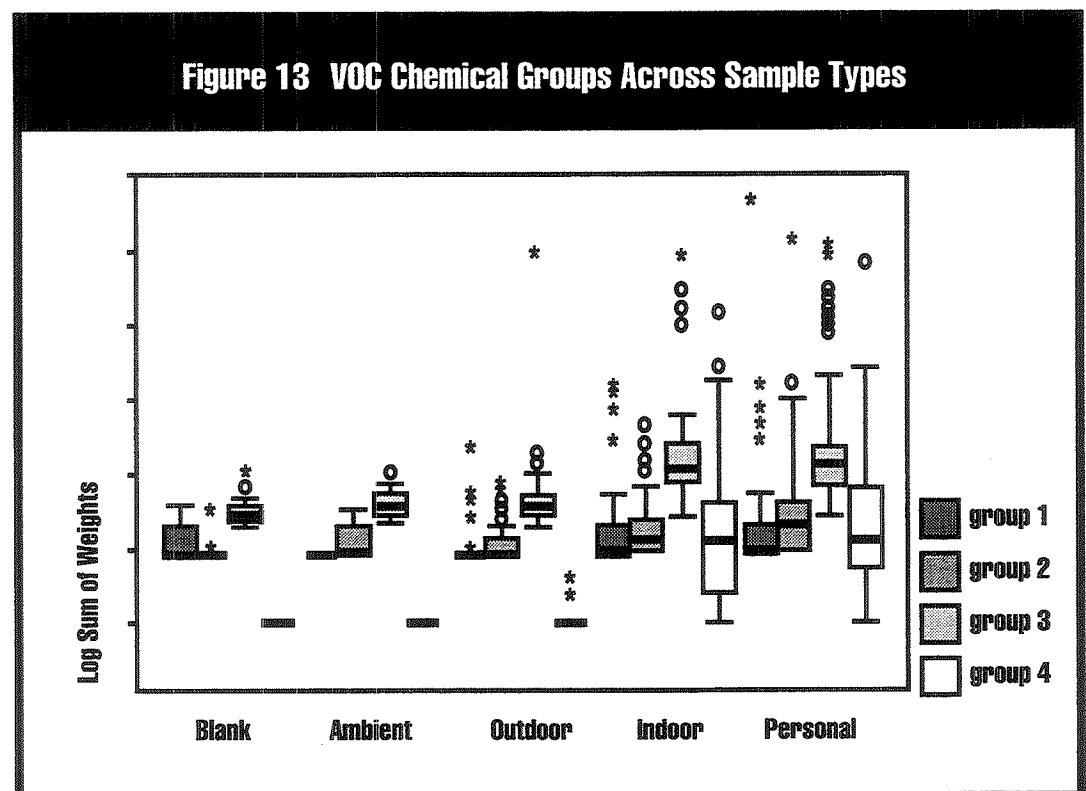
Contaminant	Location			
	Outdoor	Indoor	Personal	Group Total
Butanone	0.98	0.94	0.96	0.96
Ethylbenzene	0.99	0.90	0.81	0.91
Nonane	0.99	0.87	0.81	0.90
Octane	0.99	0.85	0.78	0.88
Decane	0.94	0.57	0.58	0.72
Methylhexane	0.81	0.66	0.37	0.63
Heptane	0.82	0.54	0.27	0.57
Xylene	0.84	0.33	0.15	0.48
Limonene	0.98	0.10	0.06	0.44
Hexane	0.57	0.39	0.25	0.42
Benzene	0.58	0.30	0.10	0.35
Toluene	0.010	0.01	0.00	0.01

Table 12 Factor Loading Matrix for Grouping of VOCs

Group	1	2	3	4	5
Octane	.97**	.01	.19**	-.02	.03
Nonane	.99**	.01	.22**	-.01	.06
Decane	.99**	.01	.24**	-.00	.06
Hexane	-.01	.97**	.08	.25**	.00
Methylhexane	.01	.98**	.12	.02	-.01
Heptane	.04	.98**	.05	.02	-.00
Toluene	.05	.08	.92**	.12	-.00
Xylene	.50**	.05	.62**	-.01	.03
Ethylbenzene	.41**	.03	.55**	-.03	-.03
Benzene	.02	.09	.50**	.01	.07
Limonene	-.01	.12	.09	.99**	.01
Butanone	.05	-.00	.01	.01	.99**

Figure 13 shows box plots of the levels of VOC groups across sample types. Several important features emerge. First, in all chemical groups, the distribution of levels is extremely skewed such that a small number of samples are extremely far removed from the bulk of the observations. Second, for none of the groups were the ambient or outdoor

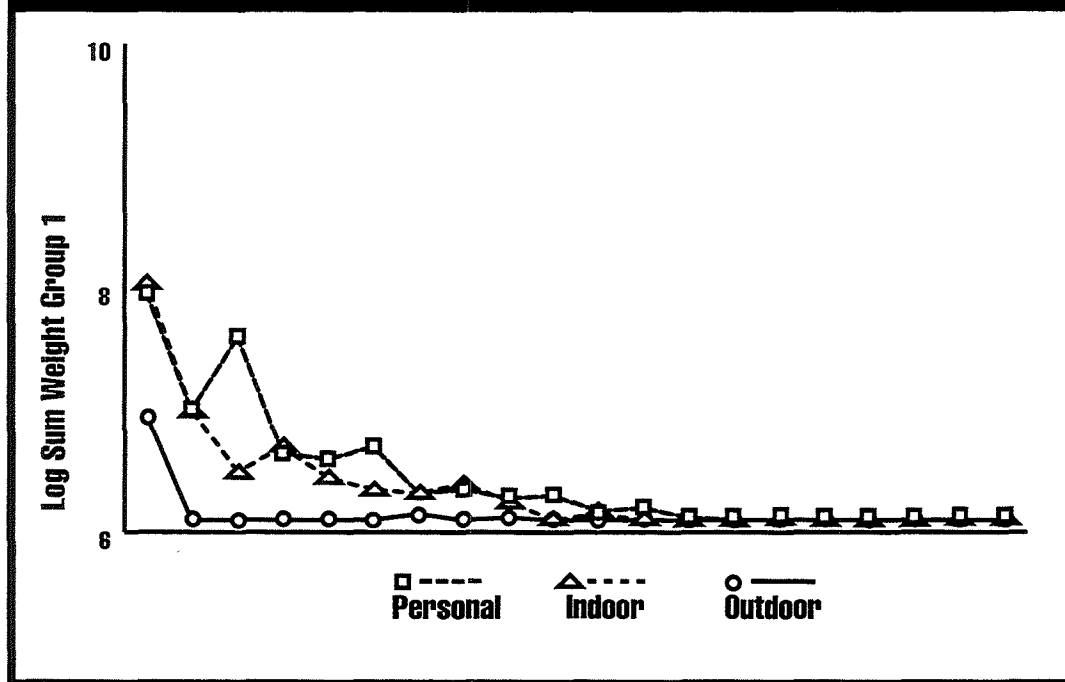
levels different from blank levels (except for a very small number of extreme levels in outdoor samples). Third, for all chemical groups, indoor and personal levels exceeded blank levels and did not differ (with the possible exception that personal levels of the hexane group were higher than indoor levels).



The suspicion that personal and indoor levels for the VOC chemical groups may be strongly correlated with each other and that particular individuals may have characteristic levels of exposure to particular VOC groups is strongly confirmed for all four chemical groups.

Figure 14 shows this relationship for the Octane chemical group. The relationships for the Limonene group is very similar, while the relationships for the Hexane and Toluene groups appear slightly less strong but nevertheless marked.

Figure 14 Relationships between Sample Types Across Individuals for Octane Group



Particulates

As a result of the technology for particulate measurement, and the necessity to measure two separate filter sizes for each assessment, a substantially smaller number of individual samples were collected. Specifically, three individuals supplied 4, 4, and 3 samples respectively of each filter size for indoor and outdoor samples. One of these individuals supplied two personal samples while two additional individuals contribute a total of 2 PM_{10} and 3 $PM_{2.5}$ personal samples. Twelve ambient samples of each type were collected from the Suncor and Fort McMurray sites, and 11 of each from the Fort MacKay site. Because of the small number of samples collected and the large number of heavy metals analyzed, only descriptive analyzes were performed. The results reported below must be considered highly tentative.

Figure 15 shows the concentrations for both particle sizes. This figure indicates that particle concentrations are highest from indoor and personal exposures.

Figure 15 Sample Weight by Sample Type

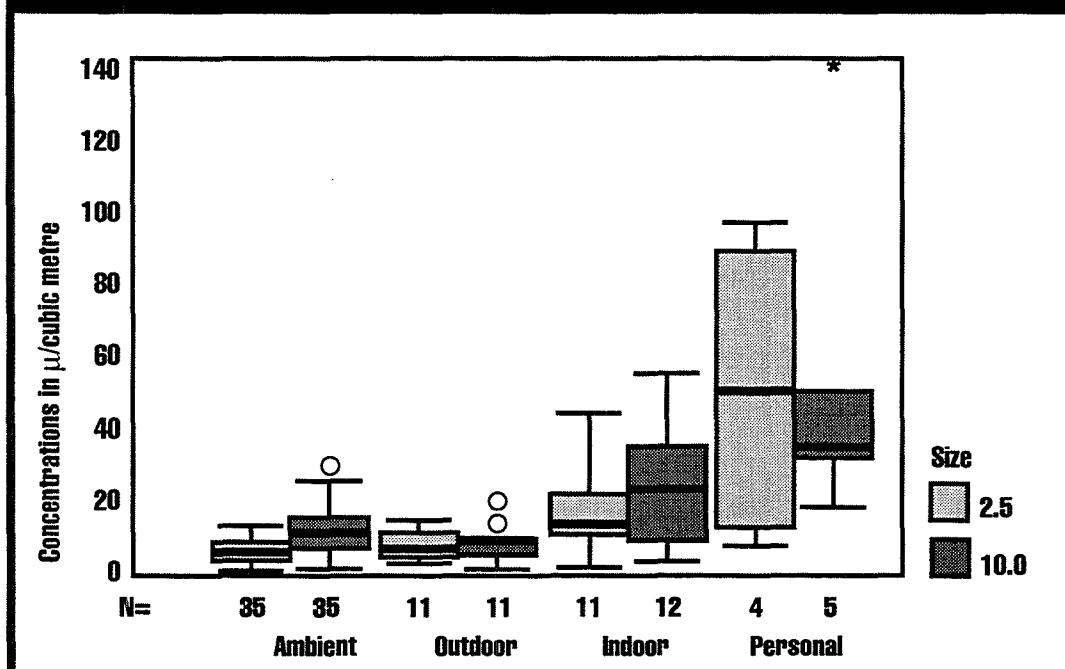


Figure 16, which is presented in 8 panels on the next pages, presents the concentrations of heavy metals for both particle size and for ambient, outdoor, indoor, and personal samples. The elements have been ordered from top to bottom in each graph by the overall order across all samples. It is important to remember during interpretation of these numbers that PM10 should theoretically contain all of the materials also

contained in PM_{2.5} samples plus additional materials present only in large particles not captured in the PM_{2.5} samples. In the current case, the direct comparison is made more difficult because PM₁₀ and PM_{2.5} samples were not always collected at the same time (and never at the same time for personal samples). It should also be noted that the horizontal scale is logarithmic in micrograms per cubic metre.

Figure 16a Heavy Metal Concentrations by Sample type and Particle Size
Ambient PM₁₀

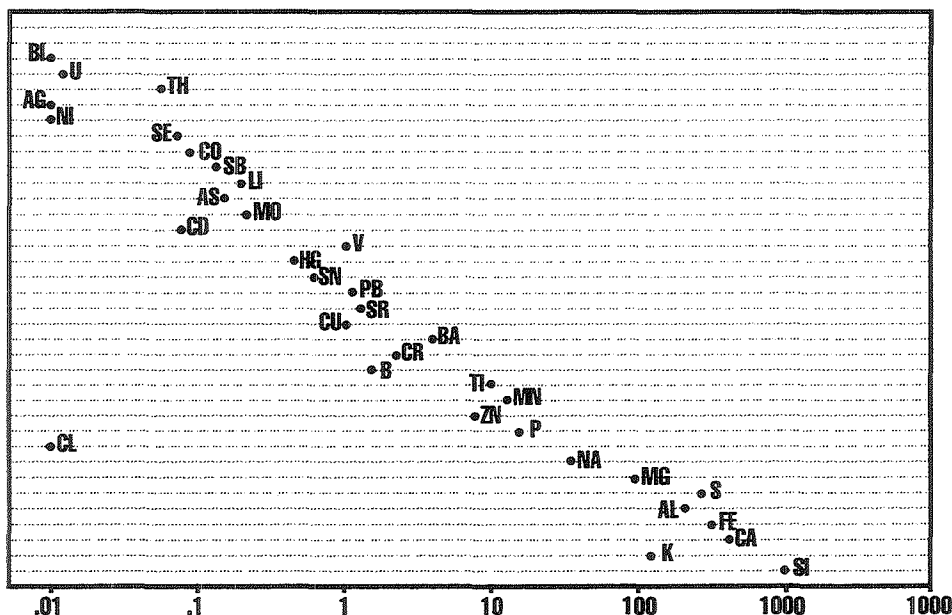
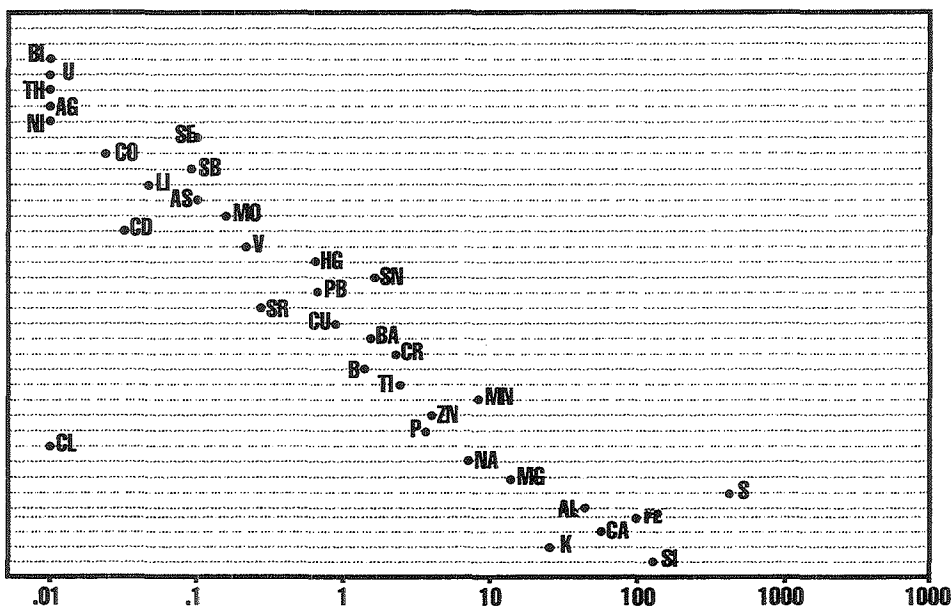
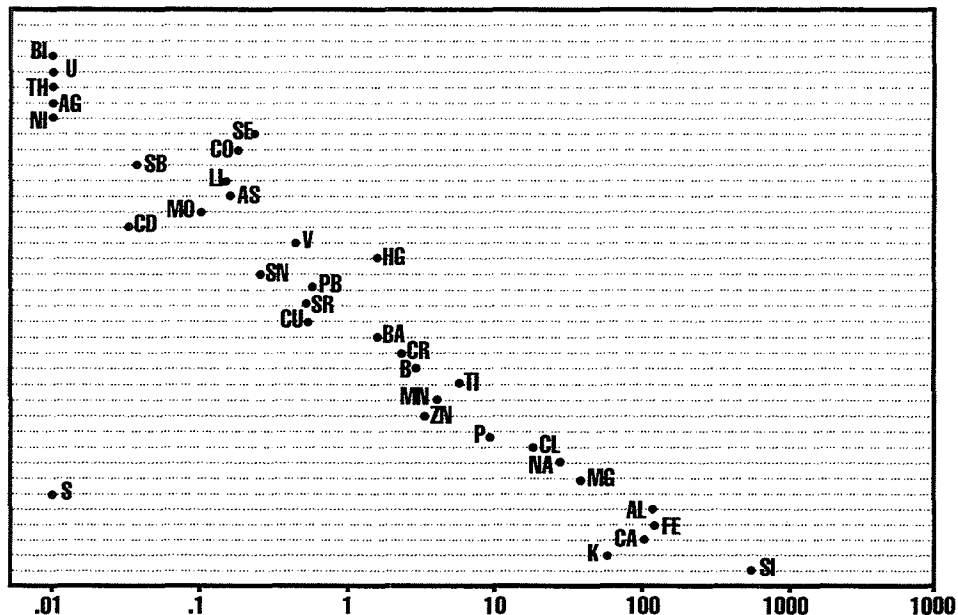


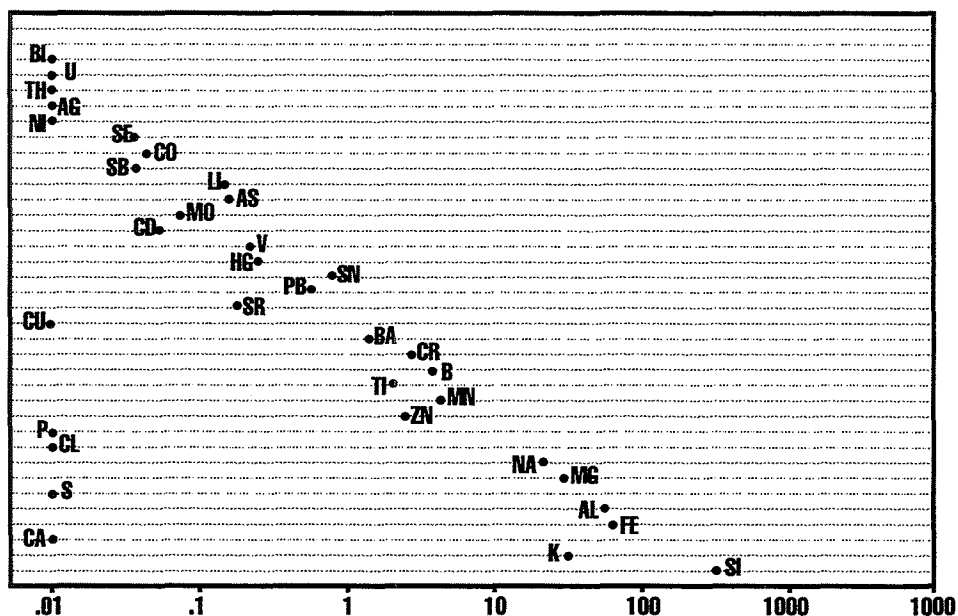
Figure 16b Heavy Metal Concentrations by Sample type and Particle Size
Ambient PM_{2.5}



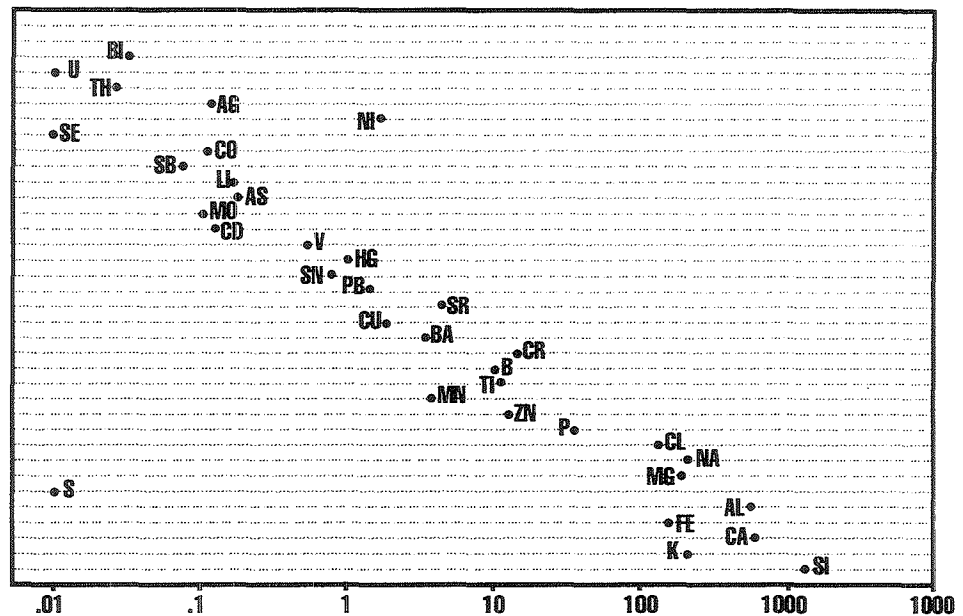
**Figure 16c Heavy Metal Concentrations by Sample type and Particle Size
Outdoors PM₁₀**



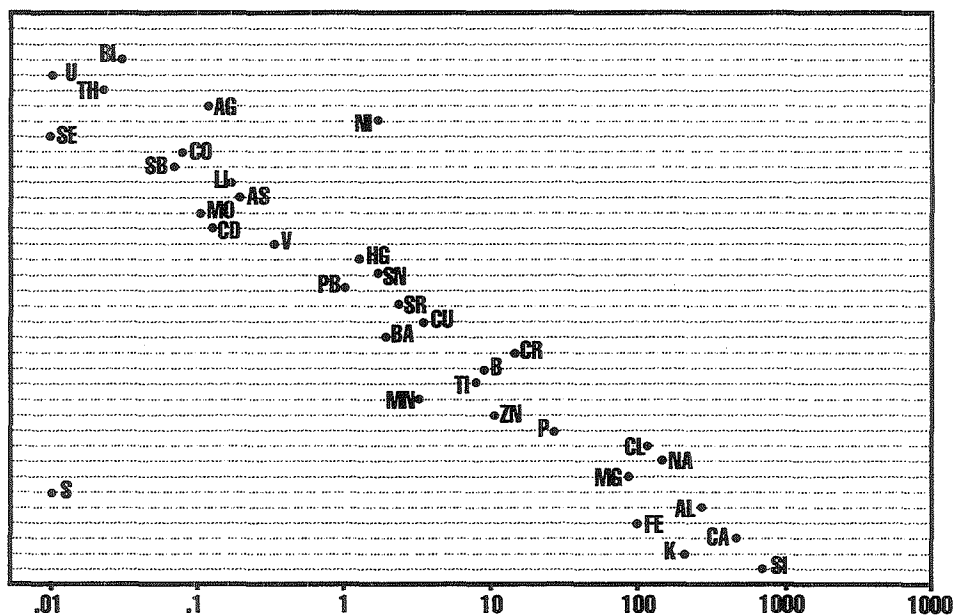
**Figure 16d Heavy Metal Concentrations by Sample type and Particle Size
Outdoors PM_{2.5}**



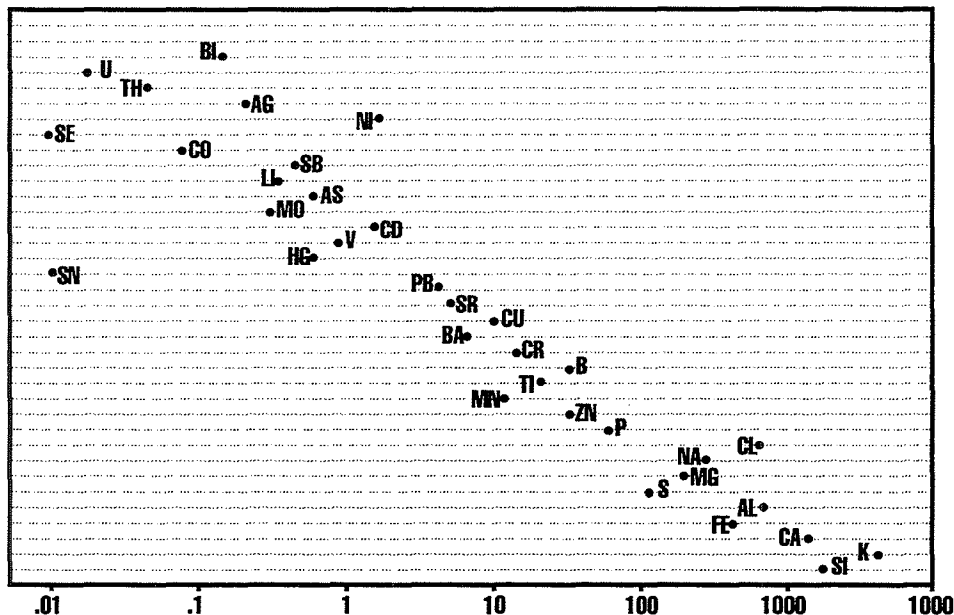
**Figure 16e Heavy Metal Concentrations by Sample type and Particle Size
Indoors PM₁₀**



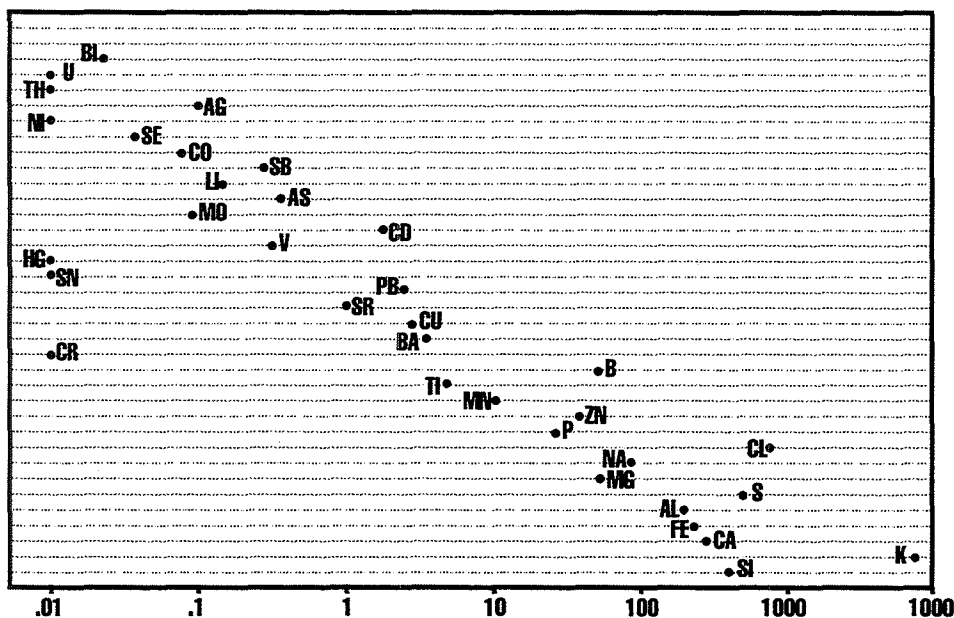
**Figure 16f Heavy Metal Concentrations by Sample type and Particle Size
Indoors PM_{2.5}**



**Figure 16g Heavy Metal Concentrations by Sample type and Particle Size
Personal PM₁₀**



**Figure 16h Heavy Metal Concentrations by Sample type and Particle Size
Personal PM_{2.5}**



Conclusions and Recommendations

The analyzes above point to the viability of the exposure monitoring procedures. Specifically the following general conclusions can be made:

- The tested methodologies are sufficient for detecting levels of the chosen chemicals in the test area. The exception is Personal exposure monitoring of Particulates for which alternative methodologies should be explored prior to the implementation of the Main Study.
- For many of the chemicals assessed, there is reason to believe that individuals will vary in the characteristic levels to which they are exposed.
- Individual sampled levels are quite variable, suggesting that multiple measures will be necessary for each individual in order to accurately assess the characteristic level of exposure.
- Variability across a particular day appears to be a factor for some chemical measures, and provides additional justification for multiple samples of particular individuals. It also leads to the

suggestion that ambient data collected on a daily basis might have a role in interpreting the data collected in the main study

Some more specific findings should also have a role in determining the specific nature of analyzes in the main study:

- There is no evidence of personal exposure to O_3 in the Pilot study.
- Indoor and personal levels of exposure are higher and appear to be associated for particulates and the Volatile Organic Compounds. This may also be true for NO_2 although ambient levels may be typically higher than indoor levels.
- Some VOCs which were assessed were virtually undetectable in the test area, while others are highly associated with other chemicals of their class. A careful consideration of which VOCs to assess for the main study is necessary.
- Levels of SO_2 are highest outdoors, and personal and indoor levels tend to be related to outdoor levels.

ANALYSIS OF ANCILLARY INDIVIDUAL MEASURES

The purpose of collecting ancillary individual measures during the field study was to examine administration time, establish whether questionnaires required administration or could be self-administered, gather comments and suggestions on the particular procedures (including instructions and particular content), determine the time and methods required to enter data to electronic media, etc. It was not intended that the data from such a small sample be analyzed unless particular exposure results should require it. This proved unnecessary, and no quantitative analysis of particular data was undertaken.

It was determined that questionnaire administration could proceed without interviewers, and would typically take 25-35 minutes for each questionnaire. A number of suggestions on content and procedure were forwarded by interviewers and participants to the Science team for incorporation into the Main Study procedures.

It was also determined that the Time Activity diary format allowed sufficient information to be gathered to determine potential sources. Volunteers had no difficulty completing the forms.

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APPENDIX A

Sampling Rates For Field Study

Compound	Sampling Rate (in mL/min)
SO ₂	218
NO ₂	720
O ₃	24.5
Benzene	35.5
Butanone	36.3
Decane	23.1
Ethyl Benzene	27.3
Heptane	28.9
Hexane	32.0
Limonene	NA
Methylhexane	NA
Nonane	24.6
Toluene	31.4
Xylene	27.3

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