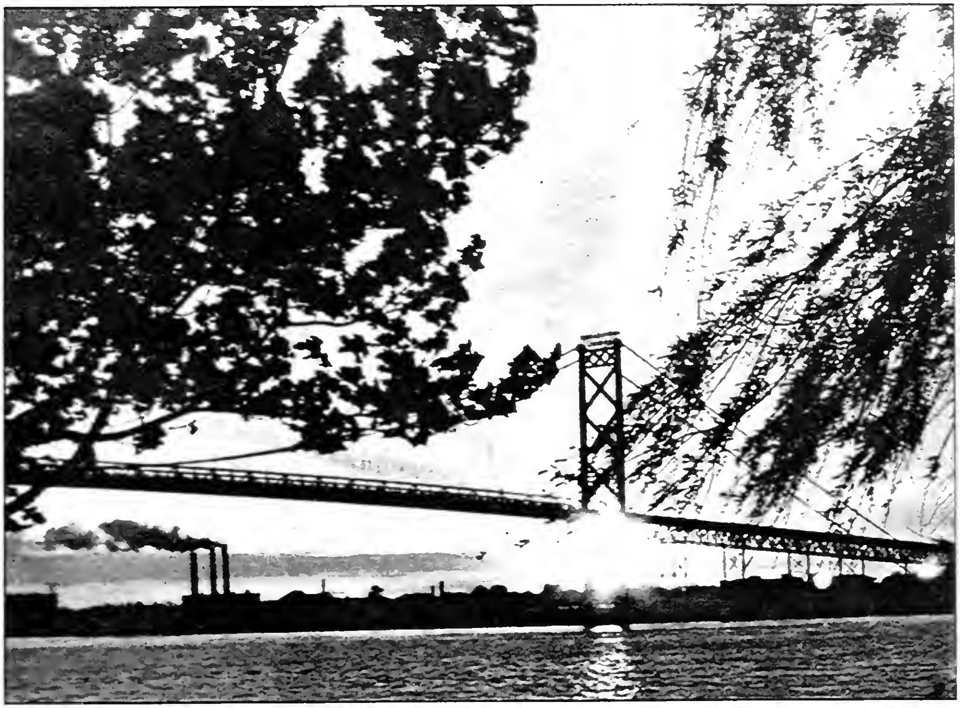

Windsor Air Quality Study
L'étude sur la qualité de l'air de Windsor

Windsor Air Quality Committee

Comité sur la qualité de l'air de Windsor

Personal Exposure Survey Results

REPORTS OF THE WINDSOR AIR QUALITY STUDY

1: Windsor Air Quality Study : Executive Summary
2: Windsor Air Quality Study : Emission Inventory for Windsor/Detroit Airshed
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WINDSOR AIR QUALITY STUDY:

PERSONAL EXPOSURE

SURVEY RESULTS

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Summary

The Windsor Air Quality Study was designed to deal with the total urban environment through monitoring of ambient (outdoor) air quality and personal air quality; inventory, monitoring and modelling of specific point and area pollutant sources; and the investigation of human activity patterns.

This report is one of a series of reports discussing the different topics listed above. All focus on measurement, modelling or assessment of airborne contaminants with the final objectives of trying to understand their potential effects on human health and the hope that the acquired information will lend to a better understanding of human exposure so that more realistic health risk assessments and abatement strategies can be developed.

Health concerns are often associated with questions such as, "What is my exposure to toxic (contaminants) chemicals in this city or in the vicinity of this plant and what does that mean (is the risk) to my health?". In order to reply, detailed life-style questionnaires and comprehensive personal air quality profiles have to be prepared for the individual who has asked the question.

This report addresses personal air quality: the air a person actually breathes. When and where ever possible, personal air sampling was the preferred method of sampling with the samplers being carried by the volunteers. When this was not feasible nor practical, stand-alone area samplers were placed in the major (micro)environments in which the volunteers lived, travelled and worked. For each volunteer, a 24-hour "snapshot" personal air quality profile was compiled and together with their time activity diary for these same 24 hours, an exposure profile was computed.

The study was conducted during the summer of 1991, the winter and early spring of 1992 and the early fall of 1992. The first 2 phases dealt with investigations of the home, office and commuting (micro)environments and the last phase dealt with the many other (micro)environments in which people spend their time on a regular basis. Where ever possible, air quality information for up to 39 different Volatile Organic Compounds (VOCs), 17 different Carbonyls (Cbyls; a different group of volatile organic compounds) and 8 different Trace Metals (TMs) were determined.

Thirty-one volunteers participated in the first 2 phases and analysis of their personal diaries indicated that apart from a ½-hour commute, they spent, on the average, 57% of their time indoors at home, 21% at the office (indoors), 8% indoors at other locations, 5% outdoors at work and 9% outdoors at other activities. Indoor concentrations for some of the volatile organics were found to be 3 or 4 times and as much as 7 times greater than those measured outdoors. For the trace metals, comparable or lower concentration levels were measured indoors.

For VOCs, the relative contributions to total exposure from air were found to be ≈70% indoors at home, ≈20% indoors at the office, ≈7% while commuting and only ≈3% outdoors. For the carbonyls, the corresponding relative exposure figures were ≈83% indoors at home, ≈15% indoors at the office, (no commuting samples were collected) and ≈3% outdoors. For the trace metals, the relative exposure figures were ≈60% indoors at home, ≈18% indoors at the office, (again, no commuting samples were collected) and ≈22% outdoors.

After examining the different indoor locations during the last phase of the study, the air quality was determined to be rather poor in bingo halls; in new office buildings; in the car; and in garages when comparisons were made to the outdoor air quality standards and criteria. The presence of environmental tobacco smoke was noted in many places.

Also during the last phase, a new sampling and analytical method was developed and implemented for hexavalent chromium; the most toxic (from a risk perspective) of the target compounds designated for this study. From this limited work, typical hexavalent chromium concentrations were found to be in the range of 0.5 to 6 nanograms per cubic metre in the Windsor airshed.

Although many more contaminants were detected during this personal air quality survey in the various locations, for 6 of the 10 highest risk contaminants, the following airborne concentrations were measured.

Contaminant		Outdoors		Indoors at Home		Indoors at the Office		Commuting	
		# of Smpls	Arith. Mean*	# of Smpls	Arith. Mean*	# of Smpls	Arith. Mean*	# of Smpls	Arith. Mean*
Benzene	1	112	2.7	59	3.1	43	3.2	59	15.7
1,3-Butadiene	1	112	na	59	0.5	43	na	59	1.1
Carbon Tetrachloride	1	112	2.8	59	3.6	43	na	59	6.6
Formaldehyde	2	49	3.3	36	31.2	18	17.6	na	na
Cadmium	3	49	1.3	37	0.7	17	0.8	na	na
Hexavalent Chromium	3	16	2.0	3	1.2	na	na	na	na

[1] Volatile Organic Compounds - Concentration Units are $\mu g/m^3$ (micrograms per cubic metre)
[2] Carbonyls - Concentration Units are $\mu g/m^3$
[3] Trace Metals - Concentration Units are ng/m^3 (nanograms per cubic metre)
* Arithmetic means were only computed if the compound was detected in more than 20% of the collected samples. One-half of the appropriate method detection limits were substituted for the non-detects for this calculation. Smpls - Samples na - not available / applicable

The outdoor measurements of this study agreed favourably with the regional fixed network area monitoring results but when personal "contact" time was considered, the volunteers' exposure to the outdoor airborne contaminants was only 3% of their total exposure for both groups of volatile organics and 22% for the trace metals.

The personal exposure data contained in this report suggests that perhaps one of the best ways for one to reduce his or her risk to a volatile airborne contaminant would be to re-evaluate his or her life-style. Rather than source abatement strategies, one may simply replace or eliminate a product that one uses; separate or isolate its source; or ventilate the area in which one works and lives. Education and public awareness may become the main endpoints for many future abatement strategies.

1.0 Study Rationale

The Windsor Air Toxics study was designed to investigate the Windsor airshed characteristics with respect to airborne toxic/carcinogenic compounds and to determine the personal exposure to these same compounds through a multi-media risk assessment approach. This multi-media philosophy of population risk determination in different airsheds is the fundamental principle behind this study. This program encompasses the total urban community through monitoring of ambient and personal air quality, specific sources of pollutants (microenvironmental, point and area sources, and long-range transport) and human activity patterns. The program focuses on measurement, modelling and assessment of the exposure and effects of contaminants in an airshed and the abatement, enforcement and education activities related to the understanding and control of same.

This study is one of a series being prepared by the Ministry in its assessment of risk for the population of Windsor to a selected target group of airborne contaminants but it does not look at all media of exposure. It only looks at inhalation and the period of exposure to estimate total exposure from the air. This study is not a multi-media assessment but rather, the results can be used to apportion more accurate figures of specific airborne contaminants (chemicals) to air for multi-media assessments of exposure.

1.0.1 Risk and Personal Exposure Assessment

The first of the many steps necessary for assessing population risk to a particular toxic substance is the accurate determination of the population's exposure to that substance. This must involve statistically sound sampling designs and the accurate determination of not only airborne contaminant concentrations but also the concurrent spatial and temporal information collected with each bit of data[1]. A substance can enter a person's body through dermal contact and absorption, ingestion and/or inhalation. For different substances, different routes dominate but for the toxic compounds under review for this study, the primary investigations dealt with the inhalation (airborne) pathway - namely, personal air quality.

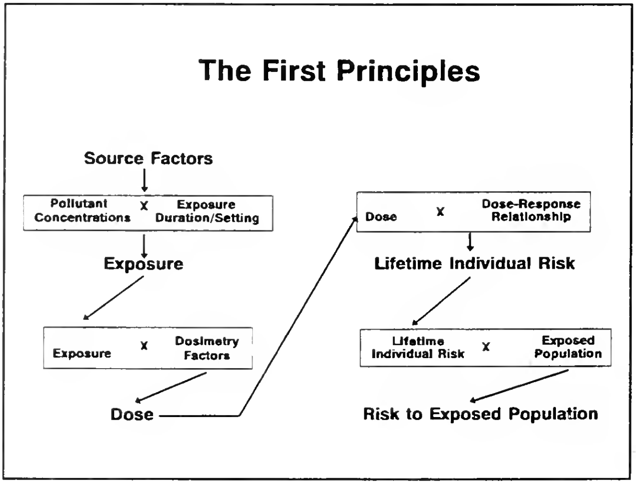
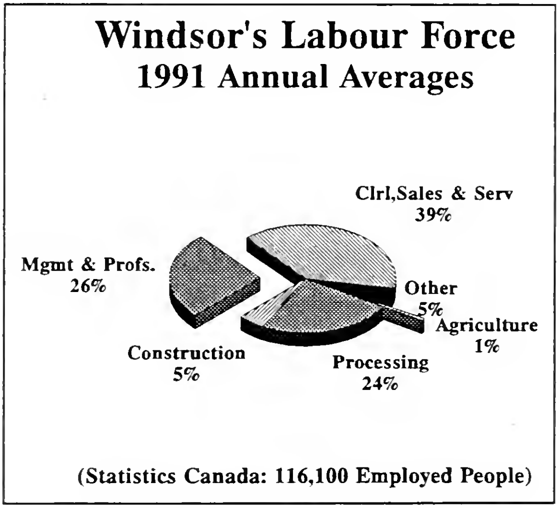


Figure 1

Historically the majority of the Ministry's air toxics investigations has concentrated on ambient (outdoor) monitoring but this information has limited relevance to total personal exposure assessment. People today spend less than 10% of their time outdoors except for persons in occupations such as farming, fishing, and forestry, who comprise a small proportion of the population. The 1986 Canadian census reports that occupations designated as being rural accounted for only 2% of the total population of Ontario.

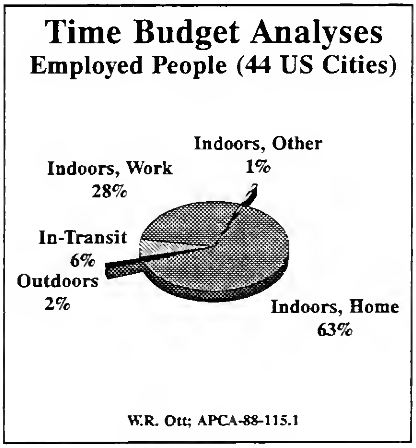
The 1991 Statistics Canada Labour Force Survey reports the population of Windsor was 206,400. Of these, 36% were considered not to be in the labour force, 8% unemployed, 11% part-time employed and 45% employed. Of the employed people (116,100), only 800 workers were in the agricultural sector. The main occupations were the clerical, sales and services people (39%), the management and other professionals (26%) and the processing people (24%). An occupation that could be considered as having a major outdoor component was the construction worker but they only represent 5% of the work force. Of the 36% not included in the labour force; the majority of these were students, homemakers and the elderly - all of whom spend appreciable time indoors. Children under the age of 15 were not considered in the labour force survey but this group together with the elderly may be more susceptible to toxic compounds and they may spend the majority of their time indoors, very close to the major indoor sources (such as carpets, dust, cleaners, waxes, etc.) and often have little choice as to the quality of their own environment especially ETS (environmental tobacco smoke), HVAC (heating, ventilation and air conditioning) systems and the building characteristics.



(Statistics Canada: 116,100 Employed People)

Figure 2

The results of an extensive time-budget study[2] of employed workers in 44 cities in the United States are shown in Figure 3. These results are also similar to those of the volunteers in Windsor. When asked of the first group during the Summer'91 study to estimate their time spent in various microenvironments, they stated that on the average, they spent 11% of their



W.R. Ott; APCA-88-115.1

Figure 3

time outdoors (this was a summer study), 4% of their time commuting and the remainder indoors at home, at work or at the bingo hall, theatre and shopping centre.

An assessment of personal exposure is necessary not only for proper determination of the health effects of many toxics to which modern man is exposed; but, also for effective abatement strategy development. Benzene is an example. Smoking, the use of household products, exposure to automobile exhaust and paint solvents may be the source of more than 80% exposure to benzene rather than the "traditional" point sources (refineries, petrochemical plants, gas stations, etc.). The most effective pathway for protecting the population of Ontario from exposure to benzene may therefore be public education and product replacement rather than the control of industrial point sources of benzene emissions to the atmosphere. The TEAM (Total Exposure Assessment Methodology) studies[3] in the United states found that smokers had 2-4 times as much benzene in their breath as non-smokers. Benzene levels in smokers' homes were 30-50% higher than in non-smoking household. The most dramatic finding was that about 60% of U.S. children live in homes with smokers and their exposure to benzene, a known leukaemogen, would be high, especially during their early formative years.

How does one determine personal exposure? Paul Lioy[4] states that "Personal air (breathing zone) monitoring is the most direct approach for assessing human exposure to airborne pollutants and the next is microenvironmental monitoring accompanied by detailed time-budget analysis and questionnaires." Charles E. Rodes et al.[5] further elaborated by stating that "Arbitrary area sampling at a single (microenvironmental) location, even for long integration intervals, will not necessarily provide a representative measurement of inhalation exposure." He found that for gases and aerosols, the "Ratios of concentration measurements from personal exposure monitors (those on a person and sampling directly within the inhalation (breathing) zone) to those made by microenvironmental exposure monitors can be typically 3 to 10 times for an occupational setting and 1.2 to 3.3 for a residential setting." Keeping these factors in mind and realizing our limited resources, we designed our studies to incorporate both types of monitors: personal and microenvironmental with the understanding that the personal monitors would best reflect what is being inhaled by the volunteers.

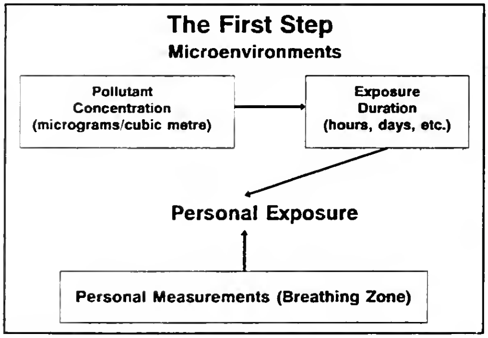


Figure 4

1.0.2 Survey Strategy

The Windsor exposure study was carried out in 3 phases; each dealing with personal exposure assessments to airborne volatile organic compounds (VOCs), trace metals (Tms) and carbonyls (Cbyls). Phases 1 and 2 dealt with investigations of the home, office and commuting microenvironments and phase 3 dealt with the scoping (characterization) aspect for the many different places in which people find themselves (such as the bus, bingo hall, tavern, taxi, etc.). These studies were pilot studies since the number of volunteers were less than 20 for each phase. Although 20 respondents per study is small and statistical limitations are imposed, some trends and observations were obvious from the resulting data sets. Support for this statement arises from the fact that the number of respondents was similar to some of the TEAM^3 studies conducted in the early '80s in North Carolina and New Jersey. Wallace et al. conducted a TEAM study with 24 subjects in Greensboro, NC in 1982 and drew conclusions, observations and trends indicative of a population of 131,000 people.

The target airborne contaminants for this study were:

Table 1:

	Volatile Organic Compounds (VOCs) and Carbonyls (Cbyls)*		Trace Metals (TMs)	
	Compounds	Alternate Names		
1	Chloroethene	Vinyl Chloride	Beryllium	Be
2	1,3-Butadiene	Vinylethylene	Chromium	Cr
3	Acrylonitrile	Vinyl Cyanide	Manganese	Mn
4	Dichloromethane	Methylene Chloride	Nickel	Ni
5	Trichloromethane	Chloroform	Arsenic	As
6	1,2-Dichloroethane	Ethylene Dichloride	Selenium	Se
7	Benzene	Cyclohexatriene	Cadmium	Cd
8	Tetrachloromethane	Carbon Tetrachloride	Lead	Pb
9	Trichloroethene	Trichloroethylene	Hexavalent Chromium	$Cr(6^+)$
10	Toluene	Methylbenzene	**Measured Concentration Units** VOCs and Cbyls $\mu g/m^3$ - micrograms/cubic metre TMs ng/m^3 - nanograms/cubic metre	
11	1,2-Dibromoethane	Ethylene Dibromide		
12	Tetrachloroethene	Perchloroethylene		
13	Formaldehyde	Methanal		
14	Acetaldehyde	Ethanal		

The personal air quality samples were screened for more contaminants than those listed above. Different sampling and analytical methodologies and different laboratories were used throughout the study. The Atmospheric Research and Special Programs (ARSP) Section of the Air Resources Branch was responsible for this study (from conception to final reporting) and carried out the field work, sampling and a large portion of the VOC analytical work. The other analytical organic laboratory involved with the VOCs was the Organic Air Group under the Air and Biomaterials Analyses Section (ABA) of the Laboratory Services Branch. Currently, both laboratories routinely screen each sample for

39 different VOCs. Although information for only formaldehyde and acetaldehyde was requested, the Pollution Measurement Division of Environment Canada reported concentration levels for an additional 14 Cbyls. The Inorganic Air Group of the ABA Section of the Laboratory Services Branch reported concentration levels for the 8 Tms requested and in co-operation with the ARSP Section, undertook additional sampling and analytical development work for airborne hexavalent chromium (Cr^{6+}).

Carbonyls are also volatile organic compounds but due to the different sampling and analytical methodologies and laboratories involved with this study, carbonyls are treated as a separate group of compounds throughout this report.

The Windsor Air Toxics risk assessment focused on 10 target airborne contaminants chosen for two reasons: concerns over the impact of emissions from specific sources contributing to the air quality of the Windsor urban airshed and concerns about human health risks. The ten target airborne contaminants were

Hexavalent Chromium
Benzene
1,3-Butadiene
Polycyclic Aromatic Hydrocarbons (PAHs; including Benzo(a)pyrene)
1,4-Dichlorobenzene
Carbon Tetrachloride
Formaldehyde
Cadmium
Dioxins and Furans
Mercury

This report will examine airborne concentrations of hexavalent chromium, 1,3-butadiene, benzene, carbon tetrachloride, formaldehyde and cadmium as related to personal air quality. We hoped that this report will lead to a better understanding of exposure estimates in order that abatement strategies can be more effectively addressed according to the risks presented.

For each phase of this study, volunteers were recruited from the Windsor area. The volunteers were energetic, enthusiastic and knowledgeable of environmental matters. They readily opened their homes and lives to the Ministry's field personnel and this should be commended.

(For the reader's information and from a personal air quality perspective, measurements of the classical gaseous contaminants such as carbon monoxide, oxides of nitrogen, sulphur dioxide and ozone were not undertaken during this study as the instrumentation was not available. With respect to the other contaminants, if the volunteer could not wear the sampler unit, sampling was usually carried out at a height of 1.5 metre to approximate the person's "breathing zone" air.)

2.0 Phase 1

During the planning for this phase, we limited our sampling frame to volunteers in the management and professional fields (reference to Figure 2). We realize that this is not a representative sampling frame. However, as a pilot study, this was sufficient to examine the concept of building exposure profiles from microenvironmental and personal air quality monitoring. These data would be used to assess individual exposures, determine trends and to make comparisons with many of the TEAM and other similar studies (for example those reported during the 1990 Indoor Air Conference held in Toronto).

2.1 Field Program

Following the programs and the knowledge obtained from many other studies of this nature and our own Toronto 1990 Personal Exposure Pilot (PEP) study[6], the particulars of this phase were:

- The sampling days in 1991 were: June 11, 17, 23, 29 and July 5, 11 and 17
- Two volunteers were needed for each sampling day and each must:
    * - be a non-smoker (although smoking may be present in their homes, vehicles and work environments),
    * - work in downtown Windsor and live in either east or west Windsor, and
    * - on the sampling days, not wear any perfumes or other fragrances
- Sampling: The objective was to characterize each volunteer's day with respect to 3 classes of airborne contaminants and if feasible, compare concentration levels measured within the person's "breathing zone", indoors, and outdoors. Microenvironmental area monitors were used by the volunteers in their homes and offices and personal monitors were used during any commutes to and from work.

For VOCs:

Since the ambient monitoring usually started at 0700 hrs on the specified sampling days, the volunteer started his/her sampling on their commute from home to the office. Their sampling period ended 24 hours later as outlined below:

* - The office commute: a personal monitor unit was worn by the volunteer during their commute and the air sample was collected within the inhalation zone of the volunteer. Once at the office, the commute sample was stored in a cool, dark environment. An accurate time/transit log was kept during this period.
* - At the office: an indoor VOC sample was started in the volunteer's office or an office nearby. This sample was run throughout the routine work day and then removed and stored in a cool, dark environment.
* - The home commute: similar procedure was followed as with the office commute with the sample being removed and stored at the end of the commute and the sampler prepared to acquire an evening sample.
* - The evening sample: this sample was to characterize the normal activities followed in the home during the dinner and early evening. The activities ranged from cooking a meal, ordering-in pizza, going to a movie, to a quiet evening watching TV; but an accurate time-log will be required.
* - The night-time sample: was collected starting at 11pm and ending around 7am (the same time period as the ambient sampler). The sample was collected in the bedroom or nearby... again trying to characterize the volunteer's environment... In the morning, the final sample was removed and stored in a cool, dark environment... and all stored samples were delivered, picked up or sent to the field

coordinator for this study as soon as possible.

* - The ambient sample: was to be acquired adjacent to and just outside the volunteers' homes. The sampler unit was set up to collect three consecutive 8-hour samples starting at 7am on the designated sampling day.

For Carbonyls and Trace Metals:

- If possible, starting at 7am on each sampling day, 24-hour carbonyl and trace metal sampling were to be carried out indoors and outdoors at the volunteers' homes and offices. These samplers ran concurrently with the VOC samplers and if possible, all samplers were located in the same area (namely the most utilized room indoors - usually the family room or the living room, and in the volunteers' backyards).

In summary, an estimated 90 to 100 VOC samples, and 30 to 40 carbonyl and trace metal samples were collected for analyses for Phase 1.

2.2 The Results

2.2.1 Questionnaire

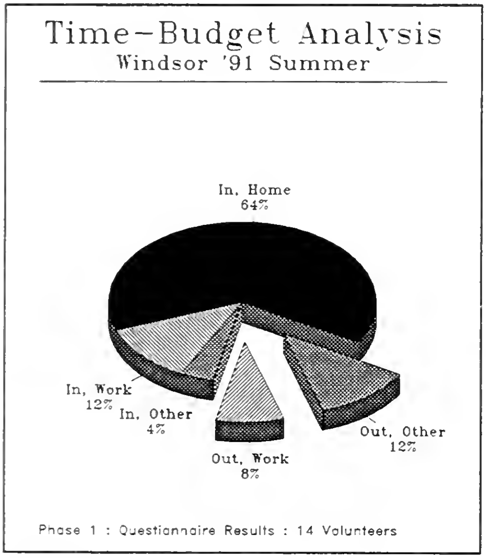


Figure 5

All 14 volunteers answered an 8-page questionnaire with two sections: microenvironmental characterization and a 24-hour recall/time activity log.

From analysis of the 24-hour recall/time activity questions, each volunteer, on the average, spent 15 hours indoors at home, 3 hours indoors at work, 1 hour indoors doing other things, 2 hours outdoors at work and 3 hours outdoors at other things. Apart from the 10-minute car drive in light traffic, the volunteers' 24-hour time-budget is shown in Figure 5.

Usually, the volunteers spent most of their working day indoors. Their occupations ranged from a student to an environmental consultant to an executive director. All were knowledgeable of environmental issues and the average age was mid to late 30's. All were non-smokers but smoking was permitted in 5 of the homes with the living room and family room being the most active smoking areas. Only 3 homes had used pesticides during the past 6 months; no one used moth balls; and yet the majority used room deodorizers and air fresheners throughout their homes on a regular basis. The ambient temperatures during the study ranged from 16 to 25°C and most homes had central air conditioning. All water was supplied by the municipality: all volunteers drank this water; took one 10-minute shower per day on the average, and washed their clothes in warm water. The majority of homes had gasoline or gasoline-powered lawnmowers and/or automobiles and some pesticides and/or lawn and gardening chemicals stored in a structure adjacent to or as part of their homes (such as a shed, garage, etc.). Most homes had cleaning supplies such as bleaches, detergents and various solvents and waxes stored in the usual places such as the kitchen, utility room and the bathroom in their homes and odours from these compounds sometimes came from these rooms.

2.2.2 Volatile Organic Compounds and Carbonyls

A variety of volatile organic compounds were detected in the many samples collected within and outside the volunteers' homes and offices, and as they commuted to and from work. Depending on the location, the sampling period ranged from 15 minutes (a commuting sample) to 24 hours (an outdoor home sample). The sampling rate was usually held between 30 and 200 mls/min (millilitres per minute) and as a result, each set of samples usually had a different sample air volume (usually in the range of 11 to 20 litres) which resulted in the method detection limit for each compound being different for each sample set; as an example, the method detection level for benzene detected in samples acquired outdoors at home was 0.3 μg/m^3 whereas for commuting, it was 0.5 μg/m^3.

Table 2:

Volatile Organic Compounds and Carbonyls*	Indoors		Commute	Outdoors	
	Home	Office		Home	Office
Dichloromethane	5.1(10)	1.6(5)	1.1(8)	1.3(6)	1.1(6)
Trichloromethane	3.5(6)	nd	0.3(1)	0.5(3)	0.5(4)
1,2-Dichloroethane	nd	nd	nd	nd	nd
Benzene	3.5(14)	4.7(10)	15.7(18)	3.8(18)	3.6(21)
Tetrachloromethane	2.6(5)	2.7(3)	4.4(9)	0.9(3)	0.7(3)
Trichloroethene	1.0(3)	1.9(5)	0.2(1)	nd	nd
Toluene	33.5(14)	16.5(10)	38.1(18)	9.4(18)	8.6(21)
Tetrachloroethene	2.3(6)	1.5(4)	1.8(9)	0.4(5)	0.3(3)
Formaldehyde *	34.5(12)	34.8(5)	na	5.0(13)	5.0(7)
Acetaldehyde *	25.7(12)	15.0(5)	na	3.4(13)	3.4(7)
Total # of Samples[n]	14,12	10,5	18,0	18,13	21,7

In the above, the average concentrations (μg/m^3) and number of samples in which the compound was positively detected (shown in brackets) are listed. For example, the average dichloromethane concentration detected in 10 of 14 samples collected indoors at home was 5.1 μg/m^3.
* Carbonyl Compounds nd : not detected na : not acquired
[n] "a,b" : total number of VOC and carbonyl samples respectively

Each sample was scanned for 22 different VOCs ranging from propane to 1,2-dichlorobenzene of which only 8 were the designated target compounds. For these compounds, the results are summarized in Table 2. Since it is almost meaningless to undertake any statistical treatment with less than 20 data points per compound and people are primarily interested in the maximum concentrations to which they are exposed, this table was designed for discussion of samples in which higher concentrations (above applicable MDLs; i.e. no non-detects) were measured. For example in Table 2, tetrachloroethene was detected in measurable amounts in only 6 of 14 samples taken indoors at home and of these 6 samples, the average airborne concentration was 2.3 $\mu g/m^3$; whereas an average concentration of 1.5 $\mu g/m^3$ was determined from 4 of 10 samples acquired indoors at the office; 1.8 $\mu g/m^3$ from 9 of 18 samples acquired during commuting; 0.4 $\mu g/m^3$ from 5 of 18 samples acquired outdoors at home; and 0.3 $\mu g/m^3$ from 3 of 21 samples acquired outdoors at the office. It must be remember that these averages are biased high but hopefully this approach will give the reader some insight as to the average maximum dosages incurred in each of these locations. From a statistical point of view and for comparisons with other research groups, additional work must be done on the data sets with respect to non-detects and the data sets should be larger. This point will be addressed in Section 4.0.

As noted in Table 2, benzene and toluene were detected in measurable concentrations in all samples. On the average, the commuting benzene concentrations were 3 to 4 times higher than those measured indoors or outdoors at the home or office. The commuting toluene concentrations were, on the average, twice as high as those measured indoors and 4 times as high as those measured outdoors. The only other target VOCs detected in measurable concentrations in a number of different samples were dichloromethane, tetrachloroethene and tetrachloromethane. For these compounds, concentrations were detected in a larger percentage of indoor samples as compared to the outdoor samples and the detected indoor values were higher by a factor of 3 to 5 than those measured outdoors.

For carbonyls, the sampling rate and sampling period (24-hours) were held constant at all locations resulting in the same air volumes being sampled ($\approx$ 1.4 m^3). As a result, the method detection limit for the target compounds was also held constant throughout the study: namely 0.1 $\mu g/m^3$ for both formaldehyde and acetaldehyde. The 16 carbonyls reported by Environment Canada ranged from formaldehyde through methyl ethyl ketone to 2,5-dimethylbenzaldehyde. As noted in Table 2, formaldehyde and acetaldehyde were detected in measurable concentrations in all samples and the indoor concentrations were usually 5 to 7 times higher than those measured outdoors.

2.2.3 Trace Metals

Airborne trace metal concentrations were determined by low-volume (Lo-Vol) sampling methodology used indoors and outdoors at the volunteers' homes and offices throughout this study period. At each site, air was sampled at 25 l/min (litres per minute) and after 24 hours, 36 m^3 of air had passed through a Whatman 41 filter on which trace metals were collected. The filters were digested for 16 hours in weak (5%) nitric acid and submitted for analyses using ICP-MS (inductively coupled plasma - mass spectrometry) instrumentation. Following this procedure, the method detection limit for the target trace metals was lowered by a factor of 10 to 100 over the conventional methodologies such as Hi-Volume sampling followed by atomic absorption analysis.

Trace metal samples were collected indoors and outdoors at the volunteers' homes and offices in the east, central and western sectors of the city. Apart from beryllium and selenium, measurable concentrations for all the target trace metals were detected in every collected sample. These results together with the method detection limits for the individual trace metals are included in Table 3.

Table 3:

Trace Metals		MDLs	Indoors			Outdoors		
			East	Central	West	East	Central	West
Beryllium	Be	0.25	nd	nd	nd	nd	nd	nd
Chromium	Cr	0.25	0.7	0.6	0.9	0.7	1.2	1.3
Manganese	Mn	0.10	5.8	4.2	11.8	16.1	27.4	37.5
Nickel	Ni	0.25	0.9	1.0	1.2	2.1	3.0	2.4
Arsenic	As	0.25	0.8	0.5	1.2	1.1	1.3	1.6
Selenium	Se	2.50	nd	nd	nd	nd	nd	nd
Cadmium	Cd	0.10	0.4	0.9	1.1	0.5	2.6	1.5
Lead	Pb	0.05	7.2	7.7	10.1	11.7	16.7	18.9
Number of samples			6	6	6	6	7	6

Average Concentrations: Units are ng/m^3 (nanograms per cubic metre)
MDLs : Method Detection Limits nd : not detected

For this phase, the total average trace metal concentrations indoors were approximately 40% of those outdoors with manganese and lead depicting the largest differences (Figure 6). Manganese is associated with steel manufacture (ferroalloys), iron ores, slag piles and gasolines (as MMT - Methylcyclopentadienyl Manganese Tricarbonyl; an octane enhancer). Lead is ubiquitous throughout Ontario area since it was a component of all gasolines. Ontario has phased out leaded gasolines but some still exists in US gasolines.

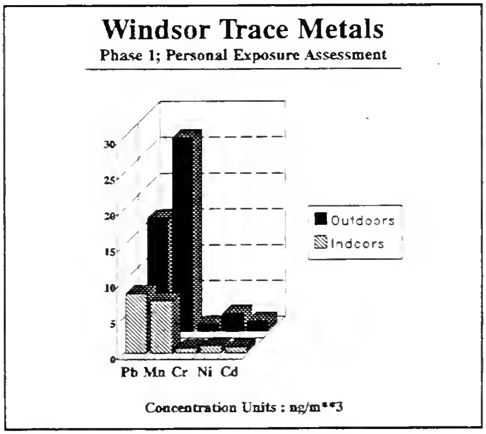


Figure 6

For trace metals, the dynamics of the sampling methodology approximated that of the human body; namely, the sampling rate and the body's inhalation rate were of the same magnitude (20 to 25 litres per minute) and the particulate size fraction of less than or equal to 10 microns (10μm) aerodynamic equivalent diameter was sampled[*] and this size fraction is of the greatest health concern since these particles can primarily deposit in the conducting airways and the gas-exchange areas of the human respiratory system. (C.N.Davis[7] and F.J.Miller et al.[8])

[*] This is true under calm weather conditions, and is directly applicable to indoor air quality studies. As Matthews et al.[9] pointed out from residential indoor velocity distribution data, more than 70% of all velocities were less than 10 cm/sec (i.e. <0.36km/hr).

2.3 Exposure Profiles

High contaminant concentrations may be detected in various microenvironments but if the individual does not spend any appreciable time in that microenvironment, his/her exposure, defined as the product of concentration and time, to a specific contaminant or group of contaminants may be very small. This point is brought out in Figure 7. For all the volatile organic compounds (up to a maximum of 39 different compounds[*]) detected in the many samples taken during this study, the highest concentrations were measured during the commuting periods, with comparable concentrations being measured indoors at the office and home and the lowest outdoors. When time is considered, exposure in the home accounted for over 70% of the total exposure profile for that individual.

Exposure profiles for the 17 carbonyl compounds[**] and the 8 trace metals[***] also depicted this same feature; namely the maximum exposure comes from indoors at home. (Figure 8). Although the outdoor trace metal concentrations were more than twice as high as those measured indoors, the outdoor exposure to these metals was only half of that reported indoors; the reason being the volunteers only spent 9% of their time outdoors.

[*] The VOCs were: propane, chloromethane, 2-methylpropane, chloroethene, 1,3-butadiene, butane, 2-methylbutane, pentane, isoprene, 1,1-dichloroethene, dichloromethane, allyl chloride, hexane, trichloromethane, 1,2-dichloroethane, 1,1,1-trichloroethane, benzene, tetrachloromethane, trichloroethene, heptane, toluene, octane, tetrachloroethene, chlorobenzene, ethylbenzene, m&p-xylenes, styrene, o-xylene, 1,1,2,2-tetrachloroethane, nonane, 1,3,5-trimethylbenzene, 1,2,4-trimethylbenzene, 1,4-dichlorobenzene, decane, 1,2-dichlorobenzene, undecane, 1,2,4-trichlorobenzene, dodecane, and tridecane.

[**] The Carbonyls were: formaldehyde, acetaldehyde, acrolein, acetone, propionaldehyde, crotonaldehyde, methyl ethyl ketone, benzaldehyde, isovaleraldehyde, 2-pentanone, valeraldehyde, o-tolualdehyde, m-tolualdehyde, p-tolualdehyde, methyl isobutyl ketone, hexanal, and 2,5-dimethylbenzaldehyde.

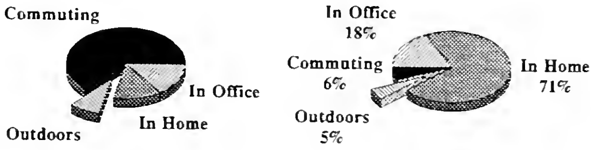
[***] The Trace Metals were: beryllium, chromium, manganese, nickel, arsenic, selenium, cadmium, and lead.

Please refer to Table 12

For the determination of airborne concentrations in Figures 7 and 8, the average of the total contaminant concentrations of each sample acquired within each microenvironment was calculated. Zero was substituted for the non-detects in each sample.

Exposure is the product of the average airborne concentrations measured in an environment and the average time a person spends in that environment.

Windsor 1991 Summer Study
Volatile Organic Compounds



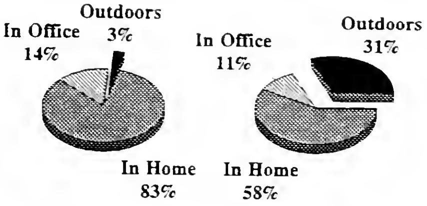
Airborne Concentrations

Exposure Profiles

Based on Arithmetic Means

Figure 7

Total Integrated Exposure Profiles
Windsor '91 Summer Study



Carbonyls

Trace Metals

All 14 Volunteers

Figure 8

3.0 Phase 2

As mentioned earlier, this phase was designed in support of Phase 1 and it was hoped that some difference(s) could be noted in the data sets as it was anticipated that winter-time airborne concentrations would be less than those reported during the summer study. This study ran for 10 weeks between February 11 and April 14, 1992 and for the most part, the same volunteers participated.

3.1 Field Program

- A 3-day mid-week monitoring schedule for 10 weeks commencing February 11th at 0700hrs and ending April 16th at 0700hrs was followed.
- For outdoor VOC measurements, a total of approximately 75 samples were collected in the downtown area of Windsor and at the volunteers' homes in east and west Windsor.
- For microenvironmental VOC measurements, a total of approximately 60 samples were acquired at work, at home and at other indoor locations.
- For personal air quality VOC measurements, the sampler units were worn mainly during the 2 daily home/office commutes. Approximately 35 samples were acquired by this type of monitoring.
- For carbonyl and trace metal monitoring, concurrent indoor and outdoor measurements were taken at the office and at the volunteers' homes and approximately 50 samples were collected.

3.2 The Results

3.2.1 Questionnaire

The questionnaire was updated from that of Phase 1 to a 14-page document divided into 3 sections: a brief description of the volunteer's lifestyle, characterization of the volunteer's work, home and commuting microenvironments, and a 24-hour recall/daily log. Ten men and 7 women responded. From analysis of the 24-hour recall/time activity section, each volunteer, on the average, spent 12.1 hours indoors at home, 6.6 hours indoors at work, 2.4 hours indoors for other activities, 0.5 hours outdoors for work and 1.5 hours outdoors for other activities. Apart from the 53 minute commute in light to moderate traffic, the volunteers' 24-hour time-budget is depicted in Figure 9 which can be compared with Figure 5 of Phase 1.

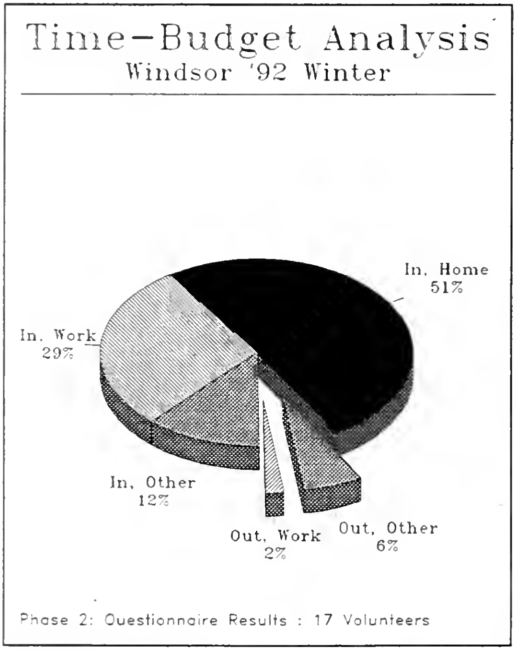


Figure 9

Additional information revealed that this group of volunteers, on the average, visited a gas station 44 times last year and each time, spent 8 minutes pumping their own gas; were exposed to environmental tobacco smoke an average of 6 hours at home and 5 hours in the office per day; were absent from work due to illness 2.9 days last year; and live in a central-air conditioned natural gas heated 1500 ft^2 home with 1.5 bathrooms, municipality supplied water and another 2.5 people. None were asthmatic but 6 had some allergies.

The occupations of these volunteers ranged from the student, teacher, college professor, engineer, school bus driver*, waitress*, public health inspector*, executive director, to the environmental officer; all "indoor" occupations. Again, all were knowledgeable of environmental issues and the average age was mid to late 30's.

(* No samples were acquired at the workplaces of the school bus driver, the waitress and the public health inspector.)

3.2.2 Volatile Organic Compounds and Carbonyls

For the home and office, microenvironmental (area) samplers were used for the determination of airborne VOC concentrations whereas for the commuting, personal samplers were used. Sixty-two samples were acquired indoors at home and the office, 73 outdoors at home and the office, and 33 commuting. These data are presented in Table 4 but as with Table 2, the data only pertain to the samples in which the target compounds were detected in measurable amounts. (Chloroethene and 1,3-butadiene results were not reported in Table 1 as the analytical system was not calibrated for these 2 compounds during Phase 1.) Again, from a statistical point of view and for comparison with other research groups, additional work must be done on these data sets with respect to the non-detects. This point will be addressed in Section 4.0.

Nevertheless, if one examines only the samples in which the target compounds were positively identified and quantified, it was interesting to note that only toluene was detected at measurable quantities in all samples and that chloroethene (vinyl chloride) was never detected. Benzene was detected in all but 1 sample. Average benzene concentrations indoors and outdoors at the office and home were essentially the same but the concentrations were 5 to 7 times greater during the commutes. A similar trend was also noted for toluene.

Twenty-eight and 29 carbonyl samples were taken indoors and outdoor respectively. Formaldehyde and acetaldehyde were detected at measurable concentrations in all samples. On the average, 1.3 to 2.5 $\mu g/m^3$ of formaldehyde and acetaldehyde were measured outdoors whereas indoors, the average concentrations were in the range of 4 to 27 $\mu g/m^3$ (up to 10 times greater).

Table 4:

Volatile Organic Compounds and Carbonyls*	Indoors		Commute	Outdoors	
	Home	Office		Home	Office
Chloroethene	nd	nd	nd	nd	nd
1,3-Butadiene	0.6(7)	0.3(6)	1.9(18)	nd	0.4(3)
Dichloromethane	6.3(14)	3.6(12)	7.4(10)	0.9(17)	1.4(11)
Trichloromethane	5.6(11)	4.1(8)	25.9(5)	3.2(4)	2.8(6)
1,2-Dichloroethane	nd	1.4(2)	10.4(1)	nd	nd
Benzene	2.7(21)	2.7(31)	15.1(32)	2.0(53)	3.1(20)
Tetrachloromethane	4.2(7)	4.0(5)	18.1(10)	3.8(14)	4.8(14)
Trichloroethene	1.7(7)	1.1(14)	6.1(8)	1.5(12)	0.6(8)
Toluene	17.1(21)	9.5(31)	51.3(33)	5.2(53)	7.4(20)
Tetrachloroethene	21.0(10)	3.0(23)	4.9(12)	1.1(15)	2.3(15)
Formaldehyde *	27.2(19)	8.1(9)	na	1.8(22)	2.5(7)
Acetaldehyde *	18.7(19)	4.1(9)	na	1.3(22)	1.9(7)
Total # of Samples[a]	21,19	31,9	33,0	53,22	20,7

In the above, the average concentrations ($\mu g/m^3$) and number of samples in which the compound was positively detected are listed. For example, the average dichloromethane concentration detected in 14 of the 21 samples collected indoors at home was 6.3 $\mu g/m^3$.

Concentration Units : $\mu g/m^3$ * Carbonyl Compounds   nd : not detected   na : not acquired

[a] "a,b" : total number of VOC and carbonyl samples respectively

3.2.3 Trace Metals:

Twenty-seven outdoor and 19 indoor (10 at home and 9 at the office) trace metal samples were also acquired during this phase and the results are presented in Table 5 which, in turn, are directly comparable with those reported in Table 3 (Phase 1) (In both Tables and apart from beryllium and selenium, the target trace metals were detected in measurable amounts in all collected samples.) It was found that the overall average indoor concentrations for these trace metals remained essentially the same throughout both phases (approximately 20 ng/m^3 total), whereas the outdoor concentrations had diminished by 30% ($\approx$35 ng/m^3 for Phase 2 as compared to $\approx$50 ng/m^3 for Phase 1). The decrease in outdoor concentrations can be explained if one considers the time of year and the ground cover during these 2 phases. Phase 1 was carried out in the summer and there was considerable amount of re-entrainment and dust in the air. Phase 2 was carried out during late winter or early spring. Some snow was on the ground and the ground was usually wet or moist. It was cool and very little dust was in the air.

Table 5:

Trace Metals	MDLs	Indoors		Outdoors	Outdoor Daily Averages		
		Home	Office		Tues	Wed	Thurs
Beryllium Be	0.25	nd	nd	nd	nd	nd	nd
Chromium Cr	0.25	4.3	1.4	2.0	1.8	2.5	1.8
Manganese Mn	0.10	4.9	7.0	18.0	18.9	17.0	18.8
Nickel Ni	0.25	1.5	1.0	1.9	1.3	1.9	1.6
Arsenic As	0.25	0.7	0.9	1.3	1.1	1.1	1.6
Selenium Se	2.50	nd	nd	nd	nd	nd	nd
Cadmium Cd	0.10	0.7	0.9	1.1	1.1	1.3	0.7
Lead Pb	0.05	9.4	9.2	11.5	11.1	10.7	10.6
Number of samples		10	9	27	9	10	8

Average Concentrations: Units : ng/m^3 (nanograms per cubic metre)
MDLs : Method Detection Limits nd : not detected

During Phase 2, the trace metal samples were only acquired during mid-week, but very little difference was apparent in the outdoor concentrations on each of the three days.

As with the first phase, the major airborne trace metal contaminants were manganese and lead. Outdoor concentrations of manganese were approximately 3 times higher than those reported indoors whereas lead concentrations were only slightly higher outdoors.

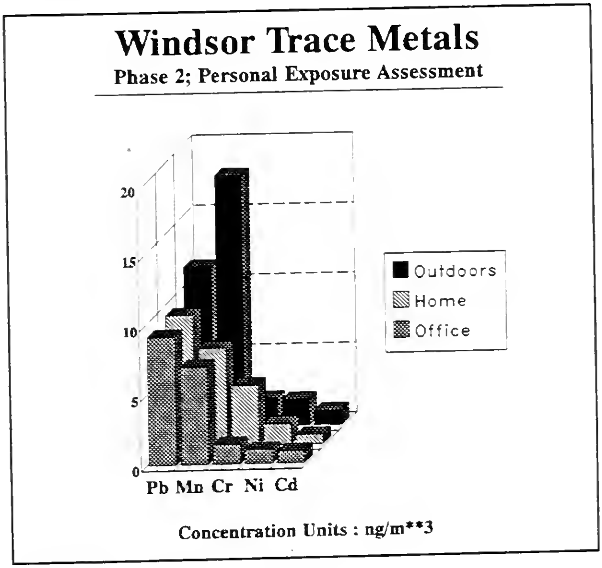


Figure 10

3.3 Exposure Profiles:

Considering the total average airborne concentrations of each compound class and the average amount of time that each volunteer spent in each microenvironment, the following table and figures of relative total integrated exposures were prepared for the volunteers. (For additional information regarding each compound class, please refer to Section 2.3.)

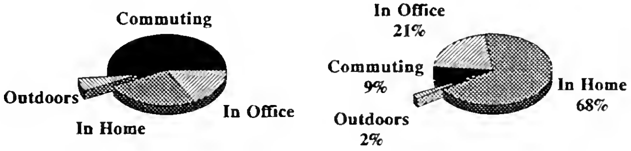
Table **6**:

Microenvironment	Avg. Time Spent	VOCs		Cbyls		TMs	
		Conc.	Exp.	Conc.	Exp.	Conc.	Exp.
Commuting	0.9hr	502	452	na	na	na	na
Indoors, Office	6.6hr	171	1129	44	290	21	139
Indoors, Home	14.5hr	247	3582	107	1552	22	319
Outdoors	2hr	58	116	8	16	38	76
Exp. : Exposure = Time X Conc.(Concentration) / na : not acquired							

It must be stressed that Table 6 and Figures 11 and 12 are <u>relative</u> measurements to highlight the volunteers' exposures in various microenvironments. As noted in Figure 11, the highest VOC concentrations were measured during commuting but the volunteers only spent an average of 0.9 hours in this microenvironment. This resulted in a relative total integrated exposure (for all reported VOC concentrations up to a maximum of 39 different compounds - see Section 2.3) of only 9% for commuting. Another interesting note was that although similar VOC concentrations were measured in the office and home, exposure in the home accounted for over two-thirds of the total integrated exposure due mainly to the relative time spent in these two microenvironments. This same resulting profile was also noted during Phase 1 (ref. Figure 7). For the carbonyls, over 12 times as much was detected indoors at home as compared to the outdoors (up to a maximum of 16 different compounds). Upon consideration of the time spent in the home, office and outdoors, the total integrated carbonyl exposure ratio for these 3 settings is approximately 100:20:1. For the 8 target trace metals, although almost twice as much was measured outdoors as compared to indoors at home or the office (ref Table 6), the outdoor total integrated exposure only accounted for 14% of the total - half of what was reported during the summer time (ref Figure 8). During the winter/early spring, the volunteers (on the average) spent 8% of their time outdoors and the outdoor trace metal concentrations were down by almost 30% over the summertime (35.8 ng/m^3 versus 49.2 ng/m^3 for the average total concentrations of the target trace metals - Tables 3 and 5).

Figures 11 and 12 are directly comparable to Figures 7 and 8 and once again, the fact that people receive their greatest exposure indoors at home is brought forth. Their least exposure is from the outdoors; especially for VOCs and Cbyls. However, one should not lose sight of the fact that even though indoor exposures may dominate for most substances, in certain cases this is only due to the fact that most of the day is spent indoors. For example, a major source of airborne trace metals may be due to infiltration of air polluted by outdoor emission sources.

Windsor 1992 Winter Study
Volatile Organic Compounds



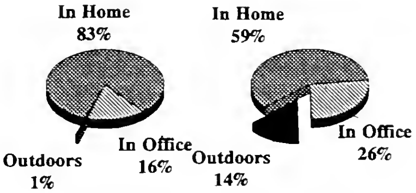
Airborne Concentrations

Exposure Profiles

Based on Arithmetic Means

Figure 11

Total Integrated Exposure Profiles
Windsor '92 Winter Study



Carbonyls

Trace Metals

All 17 Volunteers

Figure 12

4.0 Statistical Summary for Phases One and Two

A considerable amount of data was collected during these two phases but owing to the variable and sometimes low air sample volumes, many non-detects for the target compounds were reported. To prepare these data for use by other research groups, the non-detects must be considered. If a compound was detected at measurable concentrations in more than 20% of the samples, one-half of its method detection limit was substituted for the non-detects and the summary statistics were calculated on the data set. The results of this back-fill technique for the indoor and outdoor microenvironmental airborne concentration data are presented in the following tables.

During Phases 1 and 2, up to 127 and 112 VOC, 45 and 49 Cbyl, and 47 and 46 TM samples were acquired indoors and outdoors respectively. For all target VOCs (except chloroethene) and Cbyls, indoor concentration levels were much higher than those measured outdoors. The two carbonyls (formaldehyde and acetaldehyde) and the more common VOCs (such as toluene, benzene, and perchloroethylene) were 7 and 3 or 4 times higher respectively indoors than outdoors. (Chloroethene was never detected in any of the samples.)

The outdoor VOC data of Table 8 are in close agreement with the data reported from 3 permanent ambient network sites in downtown Windsor[10]. For example, between January 1988 to December 1991, the average concentrations reported for benzene, formaldehyde and methylene chloride were 3.0, 1.9 and 1.4 $\mu g/m^3$ respectively.

For the trace metals, it appears that the manganese airborne concentrations were, on the average, over three times higher outdoors as compared to indoors. For the other trace metals (except for beryllium and selenium), although they were detected in all samples, the data set was too small to state with definable degrees of confidence if the outdoor concentrations were higher than those measured indoors. For example, it appeared that for chromium, the indoor concentrations were higher than the outdoors. The average airborne chromium concentration detected indoors was 2.5 ng/m^3 whereas outdoors, it was 1.6 ng/m^3. However when one considers the 40 paired samples (concurrent indoors and outdoors) and the standard deviation associated with each set, this difference was not significant at the 95% confidence level.

It must be reiterated that the majority of these samples were acquired through the use of microenvironmental area (exposure) monitors and as C.E. Rodes[6] stated for gases and aerosols, the "Ratios of concentration measurements from personal exposure monitors to those made by microenvironmental area monitors can be typically 3 to 10 times for an occupational setting and 1.2 to 3.3 for a residential setting." The significance of this statement is that for a "True" inhalation concentration, the compound means of Tables 7 and 8 should be multiplied by these ratios resulting in higher concentrations presented to the person in his/her breathing zone. As a further consequence, the office, home and commuting exposure profiles (Figures 8, 9, 12 and 13) should also be increased proportionally for a more realistic representation of the person's actual exposure profile. Furthermore these statements infer that ***the total integrated personal exposures to outdoor (ambient) airborne contaminants may be considered as being so small as to be insignificant when one considers the impact(s) from all of the other microenvironments in which one spends his or her life.***

Table 7... Personal Air Quality (Phases 1 and 2)
Microenvironmental Summary (Indoors at Home, Office and Commuting)

VOCs and Carbonyls [c]	**# Samples**	**Max**	**Min**	**# Detects**	**Mean**[1]
Chloroethene	85	nd	nd	0	
1,3-Butadiene	85	6.3	nd	31	0.7
Dichloromethane	127	52.4	nd	58	2.7
Trichloromethane	127	74.0	nd	31	2.9
1,2-Dichloroethane	127	10.4	nd	4	
Benzene	127	84.1	nd	126	7.9
Tetrachloromethane	127	70.6	nd	31	4.5
Trichloroethene	127	14.2	nd	38	1.2
Toluene	127	149.9	1.1	127	28.9
Tetrachloroethene	127	110.3	nd	87	3.5
Formaldehyde *	45	107.2	2.5	45	26.1
Acetaldehyde *	45	61.9	1.7	45	17.2
Trace Metals					
Beryllium	47	nd	nd	0	
Chromium	47	41.0	nd	46	2.5
Manganese	47	30.1	0.9	47	6.2
Nickel	47	9.3	0.3	47	1.2
Arsenic	47	2.6	nd	44	0.8
Selenium	47	3.3	nd	8	
Cadmium	47	4.5	0.1	47	0.8
Lead	47	47.1	0.7	47	9.0

[1] The arithmetic means were only computed if the substance was detected in more than 20% of the samples. One-half of the appropriate method detection limits were substituted for the non-detects for this calculation.

* Carbonyls - Analyses done by Environment Canada. nd : not detected

[c] Concentration Units: **VOCs and Carbonyls - $\mu g/m^3$, Trace Metals - ng/m^3**

Table 8... Personal Air Quality (Phases 1 and 2)
Ambient (Outdoor) Data Summary (Windsor Airshed - Residential and Commercial)

VOCs and Carbonyls [c]	**# Samples**	**Max**	**Min**	**# Detects**	**Mean**[1]
Chloroethene	112	nd	nd	0	
1,3-Butadiene	112	0.5	nd	3	
Dichloromethane	112	10.6	nd	37	0.9
Trichloromethane	112	5.6	nd	11	
1,2-Dichloroethane	112	nd	nd	0	
Benzene	112	14.7	nd	107	2.7
Tetrachloromethane	112	12.8	nd	31	2.8
Trichloroethene	112	10.5	nd	20	
Toluene	112	26.0	0.7	112	6.9
Tetrachloroethene	112	8.5	nd	40	0.9
Formaldehyde *	49	9.7	0.3	49	3.3
Acetaldehyde *	49	7.9	0.2	49	2.3
Trace Metals					
Beryllium	46	nd	nd	0	
Chromium	46	7.3	nd	41	1.6
Manganese	46	77.5	3.3	46	21.6
Nickel	46	8.7	0.4	46	2.1
Arsenic	46	3.3	0.4	46	1.3
Selenium	46	5.2	nd	14	1.9
Cadmium	46	9.2	0.1	46	1.3
Lead	46	29.2	2.9	46	13.0

[1] The arithmetic means were only computed if the substance was detected in more than 20% of the samples. One-half of the appropriate method detection limits were substituted for the non-detects for this calculation.

* Carbonyls - Analyses done by Environment Canada. nd : not detected

[c] Concentration Units: **VOCs and Carbonyls - $\mu g/m^3$, Trace Metals - ng/m^3**

5.0 Phase 3:

Phase 3 was carried out during the summer of '92 and its main objective was to characterize as many microenvironments as possible in which people find themselves during a routine day. This phase ran for six weeks starting mid-July to the end of August. During this time, VOC and Cbyl sampling was performed indoors at different places such as a hotel (smoking and non-smoking rooms), taxis, cars, buses and couriers; a fruit market and a tavern; indoors and outdoors at 6 asthmatic homes; inside a bingo hall; outdoor measurements downwind of two landfills; and the general urban ambient Windsor airshed. Some trace metal sampling was also carried out but the majority was in support of the hexavalent chromium study (Cr^{6+}) - this will be presented as a separate entity in the next section. Furthermore, additional microenvironmental sampling was conducted in Toronto and these settings included new offices, garages and laboratories, a cafeteria, a retirement home, a gymnasium, an indoor swimming pool and a "SBS" (sick building syndrome) building. The results of the Toronto study are probably readily transferrable to the Windsor setting and are therefore included in this report.

5.1 Windsor Airshed

Although microenvironmental indoor air quality sampling was the main objective of this phase, concurrent ambient (outdoor) sampling at many of these sites was also conducted. These data are presented in Table 9 which in turn, may be directly compared to Table 8 (Phases 1 and 2 ambient results).

Table 9... Ambient Air Quality (Phase 3 - Windsor)

VOCs and Cbyls	# Samples	Max	Min	# Detects	Mean[1]
Chloroethene	18	nd	nd	0	
1,3-Butadiene	18	1.2	nd	2	
Dichloromethane	18	71.9	nd	9	7.1
Trichloromethane	18	10.0	nd	4	1.8
1,2-Dichloroethane	18	nd	nd	0	
Benzene	18	7.8	0.2	18	2.0
Tetrachloromethane	18	5.5	nd	7	3.1
Trichloroethene	18	nd	nd	0	
Toluene	18	44.3	0.6	18	9.3
Tetrachloroethene	18	10.6	nd	7	1.5
Formaldehyde *	6	15.2	0.4	6	5.7
Acetaldehyde *	6	9.2	0.5	6	3.7

[1] The arithmetic means were only computed if the substance was detected in more than 20% of the samples. One-half of the method detection limits were substituted for the non-detects for this calculation.

* Carbonyls; nd : not detected; Concentration units are $\mu g/m^3$ (micrograms per cubic metre)

Table 9 ctd... Ambient Air Quality (Phase 3 - Windsor)

Concentration Units : ng/m³

Trace Metals	# Samples	Max	Min	# Detects	Mean[1]
Beryllium	6	nd	nd	0	
Chromium	6	7.7	2.4	6	4.8
Manganese	6	36.5	5.4	6	21.9
Nickel	6	7.2	1.1	6	3.0
Arsenic	6	5.4	0.4	6	2.5
Selenium	6	2.6	0.5	6	1.2
Cadmium	6	1.1	0.2	6	0.7
Lead	6	30.5	5.4	6	16.0

With the exception of dichloromethane, the ambient concentrations for all three groups of compounds were similar to those reported earlier. The dichloromethane mean of 7.1 μg/m^3 was derived mainly from the one valid ambient result of 71.9 μg/m^3. If this value were to be removed from the data set, the arithmetic mean would then be more in agreement with the 0.9 μg/m^3 reported in Table 8. However the 71.9 μg/m^3 concentration value was deemed to be valid and should not be removed. Dichloromethane (methylene chloride) has many uses, among them: paint remover, chemical extraction and cleaning solvent, a blowing agent, and use in refrigeration.

5.2 Homes of Asthmatics

The GAGE Research Institute, Department of Medicine and the Department of Chemical Engineering and Applied Chemistry of the University of Toronto is currently conducting an environmental health study among asthmatics in Windsor. The long term objective of this study is to examine relationships between environmental variables and the well-being of a population of asthmatics in Windsor. A pilot study was conducted during 1992-93 to determine the feasibility and to establish the apparatus for performing the more definitive study. This study was based on a group of 40 asthmatics aged 12 years or older, each of whom was observed for a period of 4 weeks. As part of this study, the Air Resources Branch received permission to enter a limited number of homes and conduct air quality measurements.

Table 10 ... The Homes of Asthmatics - Indoors (Phase 3)

VOCs and Cbyls	**# Samples**	**Max**	**Min**	**# Detects**	**Mean[1]**
Chloroethene	26	nd	nd	0	
1,3-Butadiene	26	0.9	nd	1	
Dichloromethane	26	56.1	nd	17	7.7
Trichloromethane	26	17.9	nd	15	5.0
1,2-Dichloroethane	26	nd	nd	0	
Benzene	26	5.7	0.2	26	2.2
Tetrachloromethane	26	13.0	nd	9	3.8
Trichloroethene	26	3.2	nd	2	
Toluene	26	110.5	0.8	26	26.2
Tetrachloroethene	26	18.8	nd	19	4.0
Formaldehyde *	6	66.6	6.6	6	33.4
Acetaldehyde *	6	44.1	4.5	6	19.5
Trace Metals					
Beryllium	6	nd	nd	0	
Chromium	6	6.6	1.5	6	3.0
Manganese	6	18.4	2.8	6	9.9
Nickel	6	1.8	0.7	6	1.2
Arsenic	6	4.3	0.4	6	1.6
Selenium	6	1.4	nd	5	0.6
Cadmium	6	1.8	0.2	6	0.7
Lead	6	17.8	4.1	6	11.9

[1] The arithmetic means were only computed if the substance was detected in more than 20% of the samples. One-half of the method detection limits were substituted for the non-detects for this calculation.

* Carbonyls nd : not detected Units: VOCs and Cbyls - $\mu g/m^3$; Trace Metals - ng/m^3

Twenty-six indoor air quality VOC, 6 Cbyl and 6 trace metal samples were taken inside of 6 asthmatic homes.These results are presented in the Table 10 which may be directly compared to those listed in Table 7 - Indoor Microenvironmental Summary for Phase 1 and 2. Considering the arithmetic means of the six different VOCs detected in measurable amounts in both of these tables, the sum of the means were the <u>same</u>. It was thought that perhaps the homes with at least one member being asthmatic would have been cleaner with respect to VOCs than the homes of the other volunteers but the data did not support this assumption.

For the carbonyls, approximately 25% more formaldehyde was measured in the homes of the asthmatics. The highest formaldehyde concentration measured inside of one home was 66.6 $\mu g/m^3$. The major sources of this contaminant are off-gassing of wood products (plywood and particle board containing glues and adhesives) and furnishings, UFFI (urea formaldehyde foam insulation) and tobacco smoke. Upon further investigation, at least one family member in 5 of the 6 homes smoked cigarettes. Upon review of the homes investigated during all three phases of this study, the average indoor formaldehyde concentration in 12 homes where smoking was permitted was 39.4 $\mu g/m^3$ and 27.1 $\mu g/m^3$ in 22 "smoke-free" homes.

Some health problems associated with higher formaldehyde concentrations involve eye and upper respiratory tract irritations. Formaldehyde has an exposure guideline based on carcinogenic effects. As stated in the 1989 report of the Federal-Provincial advisory committee on environmental and occupational health "Exposure Guidelines for Residential Indoor Air Quality"[11], the Action and Target levels of 120 and 60$\mu g/m^3$ were set for this contaminant. As stated, *"Because of the possible carcinogenicity of formaldehyde, it would be <u>prudent</u> to reduce indoor levels as much as possible. The Action level is the lowest concentration considered feasible at the present time. However, it is recommended that in the future, and where remedial measures are taken, every effort be made to reduce concentrations to below the Target value."*

For the trace metals, very little difference was noted in the two data sets (viz. Tables 7 and 10).

5.3 Bingo Halls

It is estimated that there may be as many as 10 bingo halls in the Windsor area. A few of them are very large... often accommodating 300 to 500 people per session. Many of these bingo halls open at noon, break for an hour or so for dinner, resume operations in the early evening and often ending at midnight. This is one of the favourite pastimes for a large group of people in the Windsor area and a person may spend a substantial portion of his or her day inside these halls.

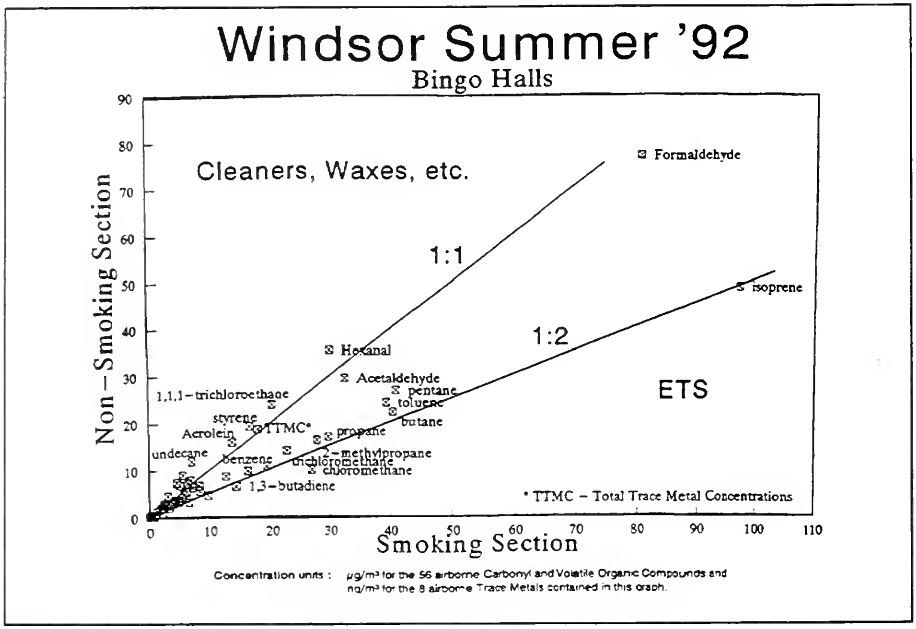
During this phase, the indoor air quality at 4 bingo halls was sampled and the data are summarized in Table 11. As can be seen from the data, the air quality is poor in comparison to the indoor air quality in the home (ref. Tables 7 and 10). Elevated benzene, toluene and carbonyl concentrations were measured in these halls. As with the previous discussion, formaldehyde concentrations were also found to be elevated and this compound has been identified with both acute and chronic health effects.

Table 11 ... Personal Air Quality (Phase 3)
All Bingo Halls - Indoors

VOCs and Cbyls	# Samples	Max	Min	# Detects	Mean[1]
Chloroethene	39	nd	nd	0	
1,3-Butadiene	39	36.9	nd	36	10.3
Dichloromethane	39	28.8	nd	31	3.6
Trichloromethane	39	41.1	nd	38	15.2
1,2-Dichloroethane	39	5.7	nd	11	1.5
Benzene	39	49.1	3.6	39	20.8
Tetrachloromethane	39	41.5	nd	9	5.5
Trichloroethene	39	36.0	nd	3	
Toluene	39	399.4	19.2	39	103.0
Tetrachloroethene	39	15.9	nd	37	6.7
Formaldehyde *	4	89.7	57.8	4	76.3
Acetaldehyde *	4	75.5	29.4	4	42.0
Trace Metals					
Beryllium	4	nd	nd	0	
Chromium	4	2.9	2.3	4	2.6
Manganese	4	11.0	4.1	4	7.2
Nickel	4	2.9	1.2	4	1.9
Arsenic	4	0.6	0.4	4	0.5
Selenium	4	0.8	0.2	4	0.5
Cadmium	4	7.3	3.0	4	4.1
Lead	4	17.5	5.0	4	11.6

[1] The arithmetic means were only computed if the substance was detected in more than 20% of the samples. One-half of the appropriate method detection limits were substituted for the non-detects for this calculation. * Carbonyls (Cbyls) nd : not detected Units: VOCs and Cbyls - $\mu g/m^3$; Trace Metals - ng/m^3

Each VOC sample was scanned for 39 different compounds, each carbonyl sample 17 compounds and each trace metal sample 8 compounds. If one examines the spectral profile obtained from these samples, an interesting picture evolves regarding the air quality in these establishments.



Concentration units : $\mu g/m^3$ for the 56 airborne Carbonyl and Volatile Organic Compounds and ng/m^3 for the 8 airborne Trace Metals contained in this graph.

Figure 14

One bingo hall was divided into smoking and non-smoking sections. The smoking section was approximately 14,800 square feet while the non-smoking section was approximately 2,300 square feet. The non-smoking section had a new ventilation system but there were no solid doors or other barriers separating the two areas.

During one 24-hour period, 1 carbonyl, 1 trace metal and 7 VOC samples were collected in the smoking section. At the same time, 1 carbonyl, 1 trace metal and 4 VOC samples were collected in the non-smoking section. A plot of the arithmetic means of these data shows the impact of environmental tobacco smoke (ETS), cleaners, waxes and other materials used throughout this hall - Figure 14.

If a line is drawn from isoprene (at co-ordinates 49,97) through the origin, the majority of the contaminants close to this line were found to be major components of ETS. From published literature[12], some of the major vapour phase components of ETS are isoprene, toluene, benzene, styrene, propane, 2-methylpropane, 1,3-butadiene, tetrachloroethene, and the xylenes ... all of which fall very close to this line. The slope of this line is at 1:2 (ratio) and this suggests that the air in the non-smoking area was twice as good as that in the smoking area and the one possible major source would be ETS.

Another line may be drawn from formaldehyde through the origin. The slope of this line is 1:1 indicating that compounds falling close to this line are common in both sections. These compounds generally arise from different building materials, carpets, various solvents, waxes and cleaning agents commonly used in any building. For example, methyl chloroform (1,1,1-trichloroethane) is a solvent used for dry cleaning, and as an aerosol propellant for pesticides and other cleaning applications. Sources of formaldehyde and acetaldehyde include ETS but also glues, resins, pesticides and fumigants, particle boards, carpets and building materials in general.

The airborne concentrations of the specific trace metals were low (Table 11) and the average total trace metal concentrations (TTMC) were in the range of 18-20 ng/m^3 in both sections, suggesting that the "smoke-eaters" were working well throughout the hall.

For the reader's information, potential sources of all the airborne contaminants measured during this study are presented in Table 12. For an indoor location, the major sources of airborne contaminants are ETS, carpets and building materials in general.

Table 12.... Sources of Airborne Contaminants

	ETS	Vehicular Exhaust	Oil & Gas Heating	Cleaners	Waxes	Pesticides Fumigants	Paints	Carpets	Building Materials
Volatile Organic Compounds									
1 Propane		■	■						
2 Chloromethane	■								
3 2-Methylpropane		■	■						
4 Chloroethene								■	■
5 1,3-Butadiene	■							■	
6 Butane		■	■						
7 2-Methylbutane		■							
8 Pentane		■							
9 Isoprene	■							■	
10 1,1-Dichloroethene								■	
11 Dichloromethane				■		■			■
12 Allyl Chloride									■
13 Hexane		■	■			■			■
14 Trichloromethane									
15 1,2-Dichloroethane		■		■		■			
16 1,1,1-Trichloroethane				■			■	■	■
17 Benzene	■	■	■	■	■		■	■	■
18 Tetrachloromethane									■
19 Trichloroethene				■					■
20 Heptane		■	■			■	■		■
21 Toluene	■	■	■	■	■	■	■	■	■
22 Octane	■	■	■	■		■	■	■	■
23 Tetrachloroethene				■				■	■
24 Chlorobenzene									■
25 Ethylbenzene	■	■	■	■	■		■	■	■
26 m,p-Xylenes	■	■	■	■	■		■	■	■
27 Styrene	■	■					■	■	■
28 o-Xylene	■	■	■	■	■		■	■	■
29 1,1,2,2-Tetrachloroethane									■
30 Nonane	■	■	■		■		■	■	■
31 1,3,5-Trimethylbenzene		■					■	■	
32 1,2,4-Trimethylbenzene		■					■	■	■
33 1,4-Dichlorobenzene				■		■			■
34 Decane	■	■	■	■	■		■	■	■
35 1,2-Dichlorobenzene				■			■		■
36 Undecane									■
37 1,2,4-Trichlorobenzene									■
38 Dodecane				■	■				■
39 Tridecane						■			■
Carbonyls									
1 Formaldehyde	■	■	■			■		■	■
2 Acetaldehyde	■	■				■	■	■	■
3 Acrolein	■	■	■						
4 Acetone	■	■		■					■
5 Propionaldehyde	■	■							
6 Crotonaldehyde	■	■							
7 MEK etc.	■	■						■	■
8 Benzaldehyde	■	■				■			■
9 Isovaleraldehyde	■								
10 2-Pentanone	■								
11 Valeraldehyde	■								
12 o-Tolualdehyde		■							
13 m-Tolualdehyde		■							
14 p-Tolualdehyde		■	■						
15 MIBK							■		■
16 Hexanal	■					■			■
17 2,5-Dimethylbenzaldehyde	■	■							
Trace Metals									
1 Beryllium									
2 Manganese	■	■	■			■			■
3 Nickel	■	■	■						■
4 Chromium	■		■						
5 Arsenic	■								
6 Selenium									
7 Cadmium	■	■	■				■		■
8 Lead	■	■					■		■

5.4 Other Microenvironments

The objective of Phase 3 was to characterize as many microenvironments as possible. As a result of a limited number of samples being collected in each, no comprehensive data interpretation could be attempted. The results of these "snapshot" samples are now presented.

Commuting:

A number of VOC samples were acquired during various commutes within the Windsor airshed. All samples were taken within the vehicle cabin using personal monitors and all were of a short duration (usually 10 to 20 minutes). These data plus those of the commutes from Phases 1 and 2 are presented in Table 13.

Upon examining this table, some interesting observations can be made from these data. Although a couple of taxi samples contained elevated concentrations of trichloroethene, in general, higher concentrations of the target compounds were reported for the couriers. The four courier samples were acquired in a garage area where some maintenance and cleaning activities were taking place. Trichloroethene and dichloromethane are degreasers and cleansers, and toluene and benzene are major components of gasoline. Only benzene and toluene were detected at measurable amounts in all Phase 3 commuting samples.

Table 13:
Commutes - Personal Air Quality

Volatile Organic Compounds	Phases 1 and 2	Phase 3			
		Car	Taxis	Buses	Couriers
1,3-Butadiene	1.9(18)	0.3(1)	0.8(4)	0.9(4)	1.8(3)
Dichloromethane	4.6(18)	0.7(1)	2.0(6)	1.5(4)	13.0(4)
Trichloromethane	21.6(6)	nd	4.0(2)	3.6(3)	nd
1,2-Dichloroethane	10.4(1)	nd	nd	nd	nd
Benzene	15.3(50)	4.0(2)	4.2(6)	5.9(5)	10.3(4)
Tetrachloromethane	11.6(19)	5.4(1)	7.5(5)	6.1(4)	6.5(1)
Trichloroethene	5.4(9)	nd	56.0(2)	nd	19.6(4)
Toluene	46.6(51)	7.7(2)	21.9(6)	23.0(5)	140.3(4)
Tetrachloroethene	3.6(21)	nd	4.8(6)	1.8(5)	16.0(4)
# of samples[n]	51	2	6	5	4

In the above, the average concentrations ($\mu g/m^3$) and number of samples in which the compound was positively detected in measurable amounts are listed.
For example, the average dichloromethane concentration detected in 18 of 51 samples collected during the commutes of Phases 1 and 2 was 18 $\mu g/m^3$. [n] total number of samples

Others: - in Windsor

Chloroethene (vinyl chloride) was not detected in any of the samples acquired throughout the entire study but some concern was expressed regarding possible ambient concentrations of this contaminant downwind of landfill sites as chloroethene is recognized as a gaseous emission from these sites. As part of Phase 3, four samples were acquired directly downwind of 2 landfill sites (one active and one dormant) in the Windsor airshed. These were 24-hour samples and the detection limit for this compound was determined to be less than 0.1 $\mu g/m^3$. Considerable care was taken in acquiring and analyzing these 4 samples but again, no chloroethene was detected.

For the smoking and non-smoking hotel rooms, very little difference could be noted in the air quality profiles. Major non-ETS sources of formaldehyde include new carpets, furnishings and wood products such as particle boards and plywood. At the market, a gasoline powered front-end loader was being operated. As a result, elevated toluene and benzene concentrations were recorded. At the tavern, elevated levels of 1,3-butadiene, benzene, and toluene were recorded; again major components of ETS. High concentrations of trichloromethane, tetrachloromethane and tetrachloroethene were also detected but these are common solvents used in drycleaning and other cleaning activities.

Table 14 .... Windsor Microenvironments

Volatile Organic Compounds and Carbonyls	Ambient	Hotel Rooms			
	Landfills	Smoking	Non-Smk	Market	Tavern
Chloroethene	nd	nd	nd	nd	nd
1,3-Butadiene	nd	1.3(6)	1.6(2)	1.4(2)	18.9(2)
Dichloromethane	1.6(2)	1.6(8)	1.5(3)	1.3(1)	2.3(2)
Trichloromethane	nd	3.6(7)	4.0(2)	nd	16.0(2)
1,2-Dichloroethane	nd	nd	nd	nd	nd
Benzene	0.9(4)	4.2(8)	5.3(5)	10.3(2)	34.5(2)
Tetrachloromethane	3.6(1)	5.4(3)	5.9(2)	nd	14.6(2)
Trichloroethene	nd	nd	nd	nd	nd
Toluene	6.3(4)	10.6(8)	12.1(5)	118.2(2)	93.7(2)
Tetrachloroethene	6.8(2)	2.8(7)	2.3(1)	3.8(1)	7.9(2)
Formaldehyde	na	31.8(2)	40.1(2)	na	na
Acetaldehyde	na	37.1(2)	19.5(2)	na	na
# of samples[n]	4	8,2	5,2	2	2

The entries are average concentrations ($\mu g/m^3$) based on the detected and measured amounts in each sample. [n] Total number of samples (VOCs, Cbyls) nd : not detected na : not acquired

In Toronto

5.5 Other Microenvironments - General

The cost of field implementation of personal air quality exposure assessment programs is very high. Since microenvironmental screening or scoping was required for a large variety of different indoor settings, the field work was brought back to Toronto.

In Toronto, indoor air quality investigations took place within a government building whose occupants had complained of poor air quality (?SBS - Sick Building Syndrome), a retirement home, a government-run cafeteria, a gymnasium and at an indoor swimming pool. The results of the VOC and Cbyl sampling at these different indoor locations are given in Table 15.

Since the data set for each of these locations was small, the data presentation was prepared in the same manner as that reported in Tables 2 and 4 - indoor average VOC and Cbyl concentrations for Phases 1 and 2 respectively. It must be remembered that these are "snapshot" air quality profiles and no statistical interpretation should be performed on these data.

From a qualitative perspective, it was interesting to note the low carbonyl concentrations within the SBS building, retirement home and cafeteria. If eye or throat irritations were being reported within the SBS, carbonyls may still be a problem as the results of Table 15 are based only on 2 samples collected on one floor during one sampling day. This was a snapshot profile and should be treated as such. Only one VOC sample was acquired at the indoor swimming pool and the results showed elevated levels of trichloromethane (chloroform) - possibly as a result of the chlorination process at the pool. (Elevated chloroform concentrations have also been reported in numerous TEAM[3] and other personal air quality studies when samples were taken within the bathrooms and shower stalls of homes.) The source of toluene detected in the single sample acquired inside a gym (81$\mu g/m^3$) remains unknown.

Table 15:
Toronto Microenvironments

VOCs and Cbyls	"SBS"	Ret'mnt Home	Cafeteria	Swimming Pool	Gym
Chloroethene	nd	nd	nd	nd	nd
1,3-Butadiene	0.5(6)	0.3(9)	0.4(3)	0.6	nd
Dichloromethane	nd	2.9(9)	nd	nd	10.2
Trichloromethane	5.3(5)	10.9(6)	4.6(2)	39.9	nd
1,2-Dichloroethane	0.9(5)	1.5(10)	1.2(3)	nd	nd
Benzene	3.7(6)	3.1(14)	3.1(6)	3.6	2.1
Tetrachloromethane	nd	12.2(5)	7.5(2)	nd	7.4
Trichloroethene	1.6(2)	4.6(8)	1.5(4)	nd	8.9
Toluene	14.4(6)	33.6(14)	10.0(6)	95.0	80.8
Tetrachloroethene	10.8(6)	5.3(13)	4.3(5)	6.6	6.0
Formaldehyde [2]	14.6(2)	11.8(6)	5.7	na	0.9
Acetaldehyde [2]	5.4(2)	5.8(6)	2.7	na	0.3
Total Cbyl Conc. [1]	45.1	38.4	18.2	na	3.2
# of samples[n]	6,2	14,6	6,1	1	1,1

In the above, the entries are average concentrations ($\mu g/m^3$) for the samples in which the compound was detected in measurable amounts. For example, benzene was detected in all 6 SBS VOC samples and its average concentration was 3.7 $\mu g/m^3$.

SBS - Sick Building Syndrome building Ret'mnt - Retirement

[1] Total average carbonyl concentrations based on the reported concentrations of a possible 17 different cbyls (those of Phases 1 and 2 plus 2-pentanone; reference to Section 2.3) that could have been present in the carbonyl samples.

[2] Carbonyls (Cbyls) nd : not detected na : not acquired/applicable

[n] Maximum number of VOC and Cbyl samples respectively

5.6 Government Offices, Laboratories and Garages

The Ontario Government constructed new offices and laboratories in Toronto. Prior to moving-in, some air quality samples were taken indoors at the new offices (denoted as W. Wing Offices) and new garage facilities (denoted as the lower garage). These results were then compared to existing government locations such as the Lobby (in the same building complex), older offices (denoted as AQM - possibly 10 years old) and an older garage (denoted as the Upper Garage - possibly 5 years old). Again a very limited number of samples were acquired and the results are presented in Table 16.

The most important finding of this monitoring was that chloroethene (vinyl chloride) was detected in 3 samples taken in the W. Wing offices. These samples were taken in early September of '92 and the maximum concentration reported was 0.7 $\mu g/m^3$. The Ministry's Ambient Air Quality Criteria (AAQC)[13] for this contaminant is 1 $\mu g/m^3$. Three more samples were acquired in the same office area in early January of '93 but after analyses, no chloroethene was detected. It was surmised that the chloroethene may have been in the new indoor carpets or adhesives and glues. After 4 months, sufficient out-gassing had occurred to diminish the airborne concentration of this contaminant to below 0.1 $\mu g/m^3$, the method detection limit.

Table 16 .... Government - New Offices, Laboratories and Garages

VOCs	N. Wing Lobby	W. Wing Offices	Lower Garage	AQM(old) Offices	Upper Garage
Chloroethene	nd	0.6(3)	nd	nd	nd
1,3-Butadiene	0.2(3)	0.2(5)	1.7(2)	0.3(2)	2.3(2)
Dichloromethane	32.(4)	29.7(5)	5.6(3)	48.6(2)	3.8(2)
Trichloromethane	nd	1.9(2)	nd	nd	nd
1,2-Dichloroethane	0.5(2)	0.6(4)	7.7(2)	0.9(2)	4.7(2)
Benzene	1.7(4)	2.4(6)	7.6(4)	3.2(2)	12.1(2)
Tetrachloromethane	nd	2.8(1)	28.7(2)	10.1(2)	17.8(2)
Trichloroethene	3.1(3)	2.4(4)	9.1(2)	1.8(2)	6.1(2)
Toluene	14.6(4)	10.0(6)	33.1(4)	57.7(2)	89.3(2)
Tetrachloroethene	1.3(2)	1.5(3)	2.6(2)	1.3(2)	3.5(2)
Number of samples	4	6	4	2	2

In the above, the entries are average concentrations ($\mu g/m^3$) for the samples in which the compound was detected in measurable amounts. For example, benzene was detected in all 4 Lobby VOC samples and its average concentration was 1.7 $\mu g/m^3$. nd : not detected

If one examines the relative averages of the detected amounts for the 3 prominent VOCs listed in Table 16, an interesting air quality profile emerges for the 5 different areas in this government science and technology centre (Figure 14). Dichloromethane concentrations appear to be quite high in the lobby and offices whereas benzene and toluene appear to be high in the garages. The lobby and offices are adjacent to large analytical laboratories within this complex whereas the garages are somewhat removed. Dichloromethane is one of the most commonly used solvents in any environmental analytical laboratory; it is very volatile; and can easily permeate throughout a building complex of this nature. Benzene and toluene are major components of gasoline.

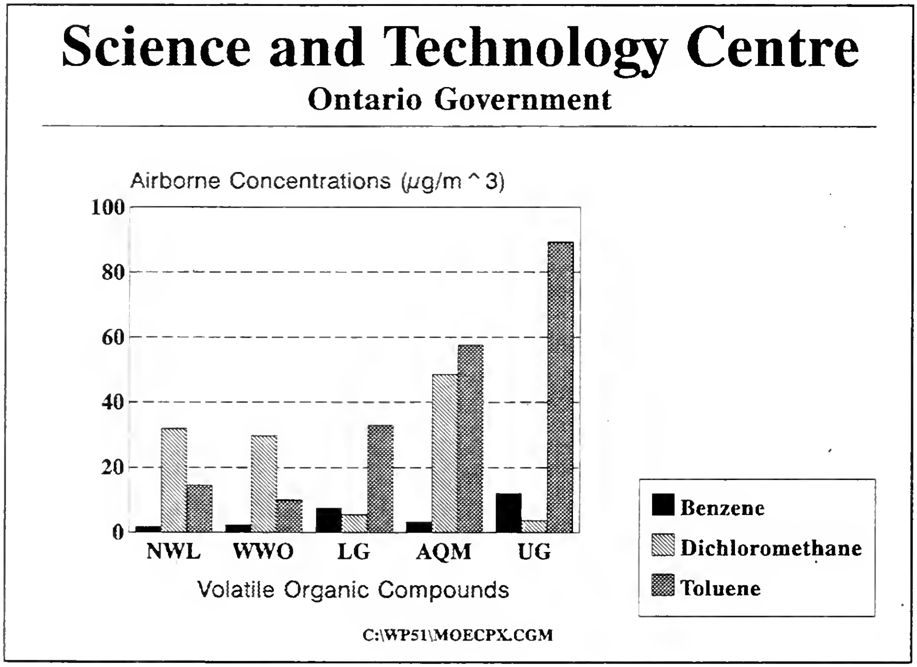


Figure 14

6.0 Statistical Summary for the Study

6.1 The Homes

Air quality samples were collected indoors at 37 different homes during this study. When the homes were divided into those that contained at least one family member that smoked and those which were "Smoke-free", and when the median concentration values for the target airborne contaminants were compared, some interesting profiles emerged.

From analyses of samples collected in the 22 "smoke-free" homes (Table 17a), higher concentrations of volatile organics (especially formaldehyde, acetaldehyde and toluene) were measured as compared to the outdoors (Table 8). For the trace metals, airborne chromium concentration levels were similar in both the home and outdoors whereas the other trace metal concentrations were lower in the homes: especially manganese at 21.6 versus 7.1 ng/m^3 and lead at 13.0 versus 7.8 ng/m^3.

From analyses of samples collected in 15 "smoking" homes (Table 17b), higher aromatic and carbonyl concentrations were detected when compared to the "smoke-free" homes. Very high levels of tetrachloroethene (perchloroethylene - a maximum of 185 μg/m^3) were detected in "smoking" homes and it was suggested that this was because "smokers" tend to have their clothes dry-cleaned more often than non-smokers.

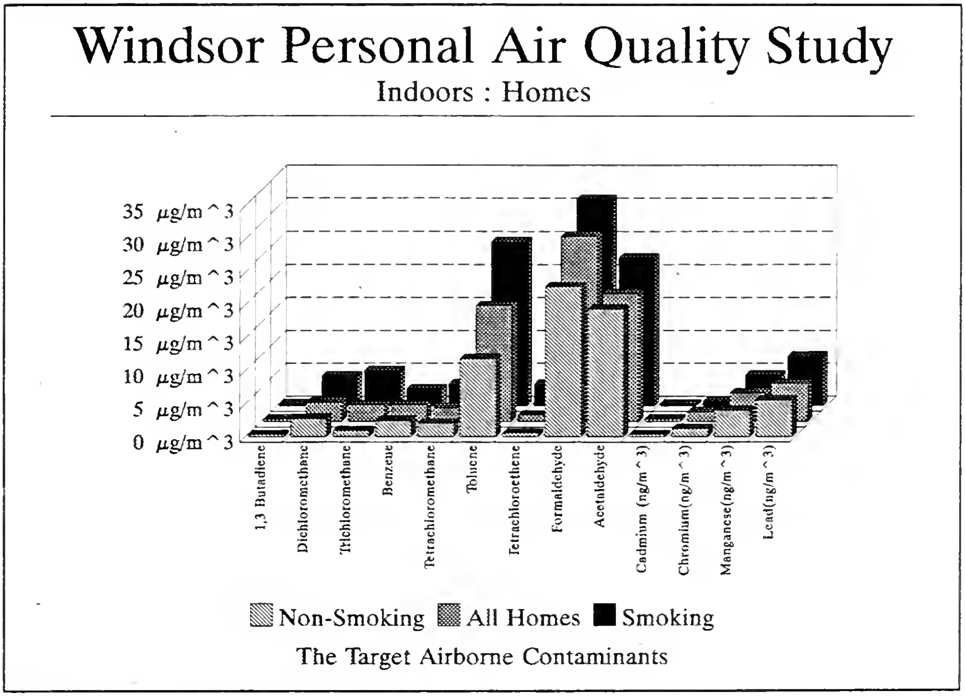


Figure 15 Median Concentration Levels

Table 17a
Microenvironmental Characterization - Indoors: Homes

Indoors	Number of Samples	Number of Detects	Number of Homes	Statistics Based on the Average Home				
Non-Smoking				Mean	Median	Max	90thP*	Min
1,3-Butadiene	29	4	22	0.4	0.4	0.9	0.5	nd**
Dichloromethane	29	20	22	6.0	2.8	50.2	11.7	nd
Trichloromethane	29	14	22	3.3	1.0	17.9	8.1	nd
Benzene	29	29	22	2.8	2.5	6.7	5.8	0.2
Tetrachloromethane	29	9	22	3.1	2.1	9.8	5.2	nd
Trichloroethene	29	8	22	0.8	0.5	3.7	1.5	nd
Toluene	29	29	22	21.2	11.9	87.8	54.8	1.8
Tetrachloroethene	29	11	22	1.8	0.6	11.7	3.8	nd
Formaldehyde	24	24	22	27.1	22.8	59.7	45.7	2.5
Acetaldehyde	24	24	22	21.7	19.4	61.9	46.5	1.7
Chromium	22	22	22	1.8	1.3	6.6	3.7	0.2
Manganese	22	22	22	7.1	4.0	30.1	16.5	1.3
Nickel	22	22	22	1.1	0.9	2.3	2.1	0.4
Arsenic	22	22	22	0.9	0.5	4.3	1.6	0.3
Cadmium	22	22	22	0.7	0.4	4.5	1.4	0.1
Lead	22	22	22	7.8	5.6	23.1	15.1	2.1

* 90thP : 90th Percentile ; ** nd : not detected ; Concentration Units : Volatile Organics - $\mu g/m^3$ and Trace Metals - ng/m^3

Table 17b
Microenvironmental Characterization - Indoors: Homes

Indoors	Number of Samples	Number of Detects	Number of Homes	Statistics Based on the Average Home				
Smoking				Mean	Median	Max	90thP*	Min
1,3-Butadiene	30	8	14	0.5	0.4	1.3	1.0	nd**
Dichloromethane	30	24	14	12.7	4.6	58.4	39.3	nd
Trichloromethane	30	20	14	6.7	5.4	17.0	15.4	nd
Benzene	30	30	14	3.6	2.6	7.8	7.0	0.7
Tetrachloromethane	30	12	14	4.4	3.4	10.0	9.4	nd
Trichloroethene	30	8	14	1.0	0.4	3.7	3.2	0.7
Toluene	30	30	14	32.9	25.0	86.4	68.9	2.5
Tetrachloroethene	30	25	14	29.2	3.3	185.2	110.3	nd
Formaldehyde	12	12	12	39.4	31.4	107.2	66.6	6.6
Acetaldehyde	12	12	12	21.3	22.5	44.1	43.5	3.8
Chromium	15	15	15	4.4	1.7	41.0	4.7	0.1
Manganese	15	15	15	6.8	4.6	18.4	14.9	1.6
Nickel	15	15	15	1.6	1.1	9.2	1.7	0.3
Arsenic	15	15	15	0.9	0.5	2.9	2.0	0.3
Cadmium	15	15	15	0.8	0.3	2.6	1.8	0.2
Lead	15	15	15	12.6	5.7	47.0	45.8	2.4

* 90thP : 90th Percentile ; ** nd : not detected ; Concentration Units : Volatile Organics - μg/m³ and Trace Metals - ng/m³

Table 17c

Microenvironmental Characterization - Indoors: All Homes

Smoking and Non-Smoking	Number of Samples	Number of Detects	Number of Homes	Statistics Based on the Average Home				
				Mean	Median	Max	90thP*	Min
1,3-Butadiene	59	12	36	0.5	0.4	1.3	0.7	nd**
Dichloromethane	59	44	36	8.5	2.9	58.4	29.3	nd
Trichloromethane	59	34	36	4.6	2.5	17.9	13.2	nd
Benzene	59	59	36	3.1	2.5	7.8	6.4	0.2
Tetrachloromethane	59	21	36	3.6	2.1	10.0	7.7	nd
Trichloroethene	59	16	36	0.9	0.4	3.7	3.2	nd
Toluene	59	59	36	25.7	17.6	87.8	68.9	1.8
Tetrachloroethene	59	36	36	12.5	1.0	185.2	13.6	nd
Formaldehyde	36	36	36	31.2	28.1	107.2	52.5	2.5
Acetaldehyde	36	36	36	21.5	19.4	61.9	44.1	1.7
Chromium	37	37	37	2.9	1.5	41.0	4.7	0.1
Manganese	37	37	37	7.0	4.3	30.1	16.5	1.3
Nickel	37	37	37	1.3	1.0	9.2	2.1	0.3
Arsenic	37	37	37	0.9	0.5	4.3	2.0	0.3
Cadmium	37	37	37	0.7	0.4	4.5	1.7	0.1
Lead	37	37	37	9.7	5.7	47.0	19.1	2.1

* 90thP : 90th Percentile ; ** nd : not detected ; Concentration Units : Volatile Organics - $\mu g/m^3$ and Trace Metals - ng/m^3

6.2 Indoors : Offices and M/Hotels

Air samples were collected in 43 different offices and 17 different m/hotel rooms during this study. All offices were non-smoking whereas smoking was permitted (at some time) in the m/hotel rooms. In general, the air quality in the offices was better than that measured in the homes - even the "smoke-free" homes (Tables 17a and 17d). For the m/hotel rooms, the volatile organic concentrations appeared to be similar to those reported for the average home. Although only 3 carbonyl and 3 trace metal samples were collected in the m/hotel rooms, the results appeared to be similar to those reported for the average home.

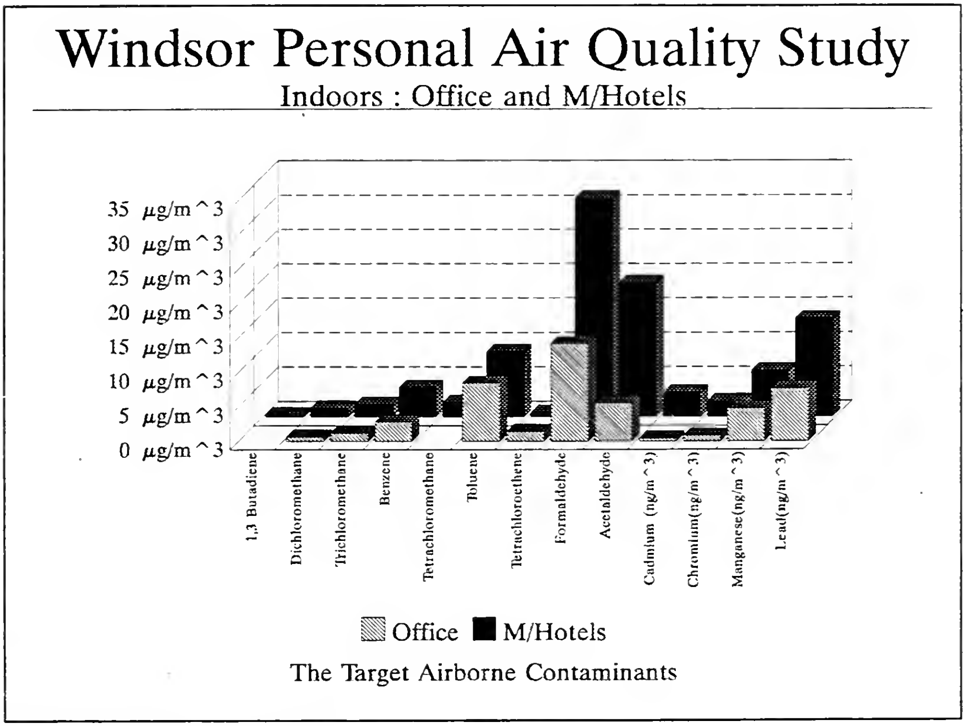


Figure 16 Median Concentration Levels

Table 17d

Microenvironmental Characterization - Indoors: Offices (all non-smoking)

Indoors	Number of Samples	Number of Detects	Number of Offices	Offices				
Non-Smoking				Mean	Median	Max	$90^{th}P^{*}$	Min
1,3-Butadiene	43	7	43			1.0		0.2
Dichloromethane	43	18	43	1.7	0.6	23.1	2.7	nd**
Trichloromethane	43	10	43	1.8	1.2	6.6	4.1	nd
1,2-Dichloroethane	43	3	43			1.5		1.1
Benzene	43	43	43	3.2	2.8	12.8	5.5	0.5
Tetrachloromethane	43	6	43			11.7		3.6
Trichloroethene	43	18	43	1.3	0.7	6.1	3.9	nd
Toluene	43	43	43	11.1	8.4	42.3	21.0	1.3
Tetrachloroethene	43	28	43	2.3	1.4	12.2	5.3	nd
Formaldehyde	18	18	18	17.6	14.1	87.0	39.9	5.9
Acetaldehyde	18	18	18	7.5	5.5	27.8	17.5	2.6
Chromium	17	17	16	1.1	0.8	3.2	2.4	nd
Manganese	17	17	17	5.5	4.7	19.1	11.4	0.9
Nickel	17	17	17	1.0	0.8	2.2	1.7	0.4
Arsenic	17	17	17	0.7	0.4	2.3	2.0	0.1
Cadmium	17	17	17	0.8	0.4	2.3	2.2	0.1
Lead	17	17	17	8.5	7.6	20.2	19.9	0.7

* $90^{th}P$: 90^{th} Percentile ; ** nd : not detected ; Concentration Units : Volatile Organics - $\mu g/m^3$ and Trace Metals - ng/m^3

Table 17e
Microenvironmental Characterization - Indoors: M/Hotels

Indoors	Number of Samples	Number of Detects	M/Hotels				
Smoking			Mean	Median	Max	90thP*	Min
1,3-Butadiene	17	8	0.9	0.4	2.5	2.5	nd
Dichloromethane	17	11	1.1	1.4	2.3	2.0	nd
Trichloromethane	17	9	2.3	1.9	5.9	5.0	nd
1,2-Dichloroethane	17	0					
Benzene	17	17	3.8	4.3	8.1	5.9	0.2
Tetrachloromethane	17	5	3.2	2.2	6.9	6.7	nd
Trichloroethene	17	0					
Toluene	17	17	9.0	9.5	18.2	17.1	0.3
Tetrachloroethene	17	8	1.7	0.7	4.1	3.5	nd
Formaldehyde	3	3	25.6		41.0		3.9
Acetaldehyde	3	3	19.7		37.0		2.7
Chromium	3	3	4.5		9.1		2.1
Manganese	3	3	7.7		12.1		4.3
Nickel	3	3	1.7		2.1		1.3
Arsenic	3	3	1.0		1.5		0.7
Cadmium	3	3	2.5		3.7		0.2
Lead	3	3	11.7		17.9		3.0

* 90thP : 90th Percentile ; ** nd : not detected ; Concentration Units : Volatile Organics - $\mu g/m^3$, Trace Metals - ng/m^3

6.3 Commuting

Throughout the study, the volunteers were asked to wear personal VOC sampler units while they were commuting to and from work. Going to work, the volunteers would turn their samplers on when they left their homes and turn them off when they arrived at work. Upon return, they would turn their samplers on when they left their work and turn them off when they arrived home. One VOC sample being collected during each trip. Following this format and regardless of the mode of transit (i.e. whether by vehicle, bicycle or by walking), 59 VOC samples were collected.

During the last phase, 15 "in-cabin" VOC samples were collected in a variety of vehicles... including private cars, courier service vehicles, buses, taxis and in two garages.

Although not surprising, vehicular emissions dominate the air quality during these periods. Gasoline is not a source of chlorinated compounds but nevertheless, the air quality profiles shown in Figure 17 demonstrate the influence of vehicles during these times. It is suggested that the low concentration levels for the chlorinated compounds arise from the interior of vehicles and from clothing... especially tetrachloroethene.

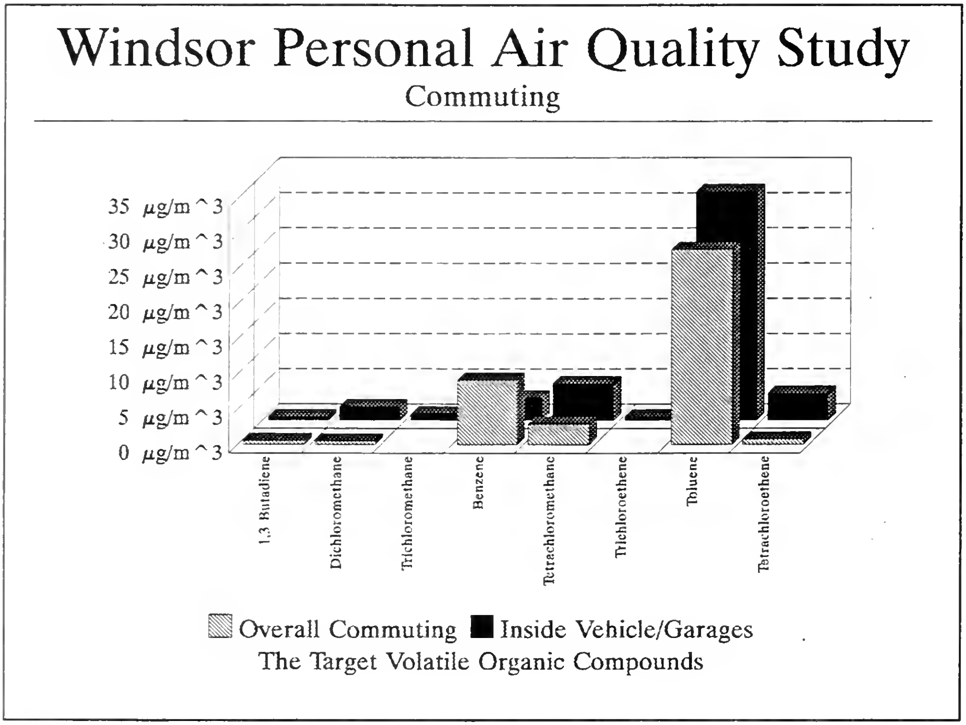


Figure 17 Median Concentration Levels

Table 17f
Microenvironmental Characterization - Commuting

Personal Samples	Number of Samples	Number of Detects	Commuting - Only VOCs				
Entire Commutes			Mean	Median	Max	90thP*	Min
1,3-Butadiene	59	18	1.1	0.6	6.3	2.4	nd
Dichloromethane	59	21	2.0	0.5	52.4	3.3	nd
Trichloromethane	59	7			74.0		4.9
Benzene	59	58	15.7	9.2	93.1	40.7	nd
Tetrachloromethane	59	21	6.6	2.9	70.6	15.2	nd
Trichloroethene	59	10			14.2		0.4
Toluene	59	59	54.4	27.7	584.2	137.7	2.5
Tetrachloroethene	59	23	2.5	0.8	13.6	8.5	nd
Vehicles & Garages							
1,3-Butadiene	15	11	1.0	0.5	3.3	2.9	nd
Dichloromethane	15	14	4.7	1.9	14.0	13.7	nd
Trichloromethane	15	5	1.8	0.9	4.8	4.7	nd
Benzene	15	15	6.4	3.2	19.5	16.6	0.2
Tetrachloromethane	15	9	5.7	5.2	11.2	10.1	nd
Trichloroethene	15	6	13.0	0.5	74.9	37.2	nd
Toluene	15	15	53.8	32.5	239.2	227.3	1.8
Tetrachloroethene	15	15	6.8	3.8	21.6	17.5	nd

* 90thP : 90th Percentile ; ** nd : not detected ; Concentration Units : Volatile Organics - $\mu g/m^3$

7.0 Hexavalent Chromium

7.1 Background

Much of the trace metal work of Phase 3 was dedicated to the determination of airborne total chromium and hexavalent chromium, Cr^{6+}. From a risk perspective, hexavalent chromium is designated as a human respiratory carcinogen by the USEPA and the American Industrial Hygiene Association and as such, is one of the highest risk target airborne contaminants under investigation for this study.

Airborne chromium primarily occurs in two valence states. Trivalent chromium, Cr^{3+}, is relatively non-toxic and an essential nutrient in human health. Conversely, hexavalent chromium is primarily man-made and has been shown to be carcinogenic to humans exposed to relatively high-levels in the workplace.

A threshold limit value (TLV) is a time-weighted average concentration for a normal 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect. TLVs have been established for a number of airborne contaminants and have been adopted in 1981 by the American Conference of Governmental Industrial Hygienists. For Cr^{6+}, the TLV is set at $50\mu g/m^3$, but concern has been expressed to assess the potential for cancer in environments where the concentrations are very much lower, namely at the 1 ng/m^3 concentration level found in the ambient environment. The MOEE Ambient Air Quality Criterion[14] and Point of Impingement Limit for chromium based on total chromium is under review but currently set at $1.5\mu g/m^3$ and $5\mu g/m^3$ respectively.

Under normal environmental conditions, Cr^{6+} is less stable than Cr^{3+} but will convert to Cr^{3+} in the presence of inorganic and organic reducing agents and gases. The average half-life for Cr^{6+} was determined to be 13 hours in chamber studies that were designed to closely approximate the ambient environment.

Since Cr^{6+} is man-made and does not reside very long in the atmosphere, it was originally thought to be a small fraction of the total airborne chromium. From ambient studies, Cr^{6+} has been found to be less than 1% in remote areas but between 10 and 40% of the total chromium in the vicinity of chromium sources; such as chrome plating plants, foundries and scrap yards. From a study conducted by Sheehan, Ricks et al.[14] , "the average percentage of Cr^{6+} in airborne chromium was 25% for 77 co-located samples collected at 19 outdoors sites." Although it was thought that very little chromium would be detected indoors, this same group found that "the average percentage Cr^{6+} in total airborne chromium was 21% for 60 samples collected indoors at 17 sites."

From analyses of 790 MOEE 24-hour Hi-Vol filters collected at 14 different sites within the Windsor airshed during 1990[15], the range of average concentrations for total chromium was between 5 and 19 ng/m^3 with a maximum of 140 ng/m^3. Based on the work by Sheehan and Ricks et al, the anticipated airborne concentrations of Cr^{6+} in the Windsor airshed was expected to be 1 to 5 ng/m^3 for both the outdoor and indoor environments. These figures are in agreement with the published work of Falerios et al[16] in which they state that their data "indicate that background levels of Cr^{6+} of perhaps 1 to 4 ng/m^3 exist in urban air as a result of a variety of anthropogenic sources."

Following the sampling and analytical methodology outlined by Sheehan et al.[14], a field program for the determination of airborne Cr^{6+} at concentrations as low as 1 ng/m^3 was carried out in the Windsor airshed. The attainment of good data at these very low concentrations demanded a great deal of new research and development work.

7.2 Sampling and Analytical Methodology

Since this methodology is new and was first implemented by the Ministry during this study, a brief description is warranted.

During sampling, airborne Cr^{6+} was trapped in solution using a two-stage Greenberg-Schmidt impinger train similar to the setup in Figure 18. The air was drawn through the impingers at 13 to 15 litres per minute for 24 hours. To preserve Cr^{6+}, the first impinger contained a solution of 350 ml of sodium carbonate and sodium hypocarbonate with a pH of 10.3 and 10.6 respectively. The second impinger was empty and guarded the pump against possible backsurge from the first impinger.

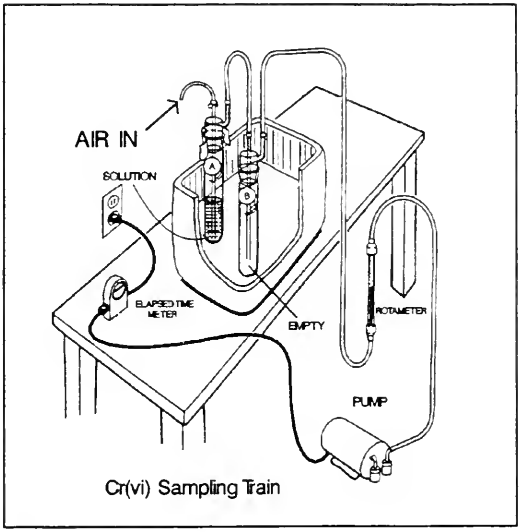


Figure 18

For field applications, 2 impinger trains were used at each site. The first train was as described above, whereas the second was an identical system with a spike of 0.5 parts per billion (PPB) placed in the solution. The spike was 5 mls of a 100 PPB standard solution of $K_2Cr_2O_7$ and this was used to verify collection recovery efficiency.

After collection, each sample was made up to the original impinger volume and a portion of the sample was filtered through a 0.2 μm pore size syringe filter prior to analysis. The sample was preconcentrated by passing 9 ml of the filtered sample through a resin based Dionex AG4A anionic exchange guard cartridge. The Cr^{6+} was then separated from the Cr^{3+} and other metals and eluted off the column using a distilled water eluent. The Cr^{6+} concentration was then determined using postcolumn colorimetry with 1,5-diphenylcarbohydrazide (DPC).

7.3 Results

A very limited number of samples were collected during this phase as the development and field work were very labour intensive. From our sample analysis, Cr^{6+} concentrations were typically in the range of 0.5 to 6 ng/m^3 .... in agreement with other investigators working in this field[14,16] (Table 18).

Since this is a new methodology, work will continue on this project.

Table 18
Windsor - Airborne Chromium

Date	Location	Total Cr (Hi-Vol)[1]	Cr^{6+}
16-17/3	Station 12007 Wright & Water Streets	8	1.4
15-16/6			2.7
16-17/6			2.9
17-18/6			5.7
18-19/3	Station 12008 467 University Avenue West	6	4.1
20-21/4			1.8
15-16/6			1.5
16-17/6			1.9
17-18/6			2.0
20-21/4	Station 12013 Filtration Plant 3665 Wyandotte Street East	11	1.5
15-16/6			0.5
16-17/6			0.2
17-18/6			0.3
18-19/3	Station 12016 College/South St.	8	1.0
17-18/3	Station 12038 2885 Howard Avenue	16	3.0
22-23/4			0.8
21-22/4	Various Residences (Indoors)	na	1.1
21-22/4			1.0
21-22/4			1.5

Concentration units are nanograms per cubic metre (ng/m^3)

[1] Annual mean concentrations as determined from Hi-Vol sampling in 1991 (53-58 samples per station)

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Peer-reviewed by:

- G. Grosse and J. Janse of the Southwestern Regional office of the MOEE
- I. Broder of the GAGE Institute, University of Toronto
- L. Smith of the Public Health Branch of the Ministry of Health

9.0 References

1 Risk Analysis: A Guide to Principles and Methods for Analyzing Health and Environmental Effects; J.J. Cohrssen and V.T. Covello (1989) **ISBN 0-934213-20-8 NTIS PB89-137772**

and

A Framework for Risk Characterization of Environmental Pollutants; D.P. Naugle et. al.: **Journal of the Air and Waste Management Association** October 1991

2 Human Exposure to Environmental Pollutants; W.R. Ott et al.; **Proceedings of the 81st Annual Meeting of the Air Pollution Control Association**, June 1988

3 The Total Exposure Assessment Methodology (TEAM) Study; Lance A. Wallace et al., Office of Research and Development - USEPA **EPA/600/6-87 Series/002a** 1987

4 Assessing Human Exposure to Airborne Pollutants; P.J. Lioy et al.; **Environmental Science Technology 25: 1360** (1991)

5 The Significance and Characteristics of the Personal Activity Cloud on Exposure Assessment Measurements for Indoor Contaminants; C.E. Rodes et al.; **Indoor Air, 2 123-145** (1991)

6 The 1990 Toronto Personal Exposure Pilot (PEP) Study; R.W. Bell et al.; Ontario Ministry of the Environment and Energy; **ARB-207-90; ISBN 0-7729-7962-6**

7 The Entry of Aerosols into Sampling Tubes and Heads; C.N. Davis et al.; **British Journal of Applied Physics, Str 2, Vol 1** (1968)

8 Size Considerations for Establishing a Standard for Inhalable Particles; F.J. Miller et al.; **Journal of the Air Pollution Control Association, Vol 29, No 6, June** 1979

9 Air Velocities Inside Domestic Environments: An Important Parameter in the Study of Indoor Air Quality and Climate; Matthews et al.; **Environment International 15 545-550**, 1989

10 Personal Communications - Special Studies and Research Management; **ARB** 1993

11 Exposure Guidelines for Residential Indoor Air Quality, The Federal-Provincial Advisory Committee on Environmental and Occupational Health; Environmental Health Directorate, Health Protection Branch, Health and Welfare Canada, **ISBN 0-662-17882-3** July 1989

12 The Chemistry of Environmental Tobacco Smoke; M. Eisenberg et al.; 1992; **ISBN 0-87371-444-X**

13 The Environmental Assessment Act as revised by **RSO 1990 - RSO 1980,c. 140, s.2**

14 Field Evaluation of a Sampling and Analytical Method for Environmental Levels of Airborne Hexavalent Chromium; P. Sheehan et al.; **Am. Ind. Hyg. Assoc. J. 53: 57-68**; January 1992

15 Air Quality in Ontario 1991; AQM Section, ARB **ISSN 0840-9366 PIBS 2251E-01**

16 Airborne Concentrations of Trivalent and Hexavalent Chromium from Contaminated Soils at Unpaved and Partially Paved Commercial/Industrial Sites; M. Falerios et al.; **J. Air Waste Manage. Assoc. 42: 40-48**; January 1992.