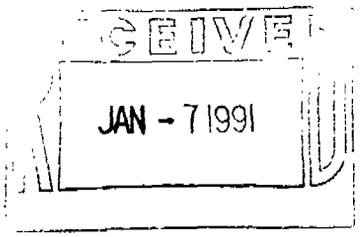
CHEMICAL MANUFACTURERS ASSOCIATION



January 3, 1991

TO: Vinylidene Chloride Producers Group

RE: Lance Wallace Study

Lance Wallace recently sent me the two enclosed published reports. I was expecting some unpublished data from him; nevertheless, this is what I received. The TEAM Study report is quite large and I did not photocopy the document other than the title page. Wallace himself is unsure of the source of vinylidene chloride in his study; however, he is confident it is not a sampling and/or analytical error. I will be in touch with Zeb Bell about our next step.

Sincerely,

Jon Busch

Jon Busch
Manager, Vinylidene Chloride Panel

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SL 063785

United States Environmental Protection Agency

Office of Acid Deposition, Environmental Monitoring and Quality Assurance Washington DC 20460

EPA/600/6-87/002b June 1987

Research and Development

EPA

The Total Exposure Assessment Methodology (TEAM) Study:

Elizabeth and Bayonne, New Jersey, Devils Lake, North Dakota and Greensboro, North Carolina: Volume II. Part 2

EPA/600/6-87/002b
June 1987

TOTAL EXPOSURE ASSESSMENT METHODOLOGY (TEAM) STUDY: ELIZABETH AND BAYONNE, NEW JERSEY, DEVILS LAKE, NORTH DAKOTA AND GREENSBORO, NORTH CAROLINA

VOL. II (SECTION 8 AND REFERENCES)

FINAL REPORT

PART II

by

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U.S. ENVIRONMENTAL PROTECTION AGENCY
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CONTENTS

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MONITORING INDIVIDUAL EXPOSURE. MEASUREMENTS OF VOLATILE ORGANIC COMPOUNDS IN BREATHING-ZONE AIR, DRINKING WATER, AND EXHALED BREATH

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Methods for determining individual exposure to volatile organic compounds (VOC) during normal daily activities were field tested on university student volunteers in Texas and North Carolina. The equipment tested included a personal monitor employing Tenax GC® to collect organic vapors for later analysis by GC-MS, and a specially designed spirometer for collecting samples of expired human breath on duplicate Tenax cartridges. The personal monitor and spirometer proved feasible for collecting abundant quantitative data on most of the 15 target organics. Air exposures to many VOC varied widely, sometimes over three orders of magnitude, among students on the same campus who had been monitored over the same time period and day. A log-linear relationship between breathing-zone air exposures and concentrations in exhaled breath was suggested for three chemicals: tetrachloroethylene, 1,1,1-trichloroethane, and vinylidene chloride. Air was the main route of exposure for all target compounds except the two trihalomethanes (chloroform and bromodichloromethane), which were transmitted mainly through water. Estimated total daily intake through air and water of the target organics ranged from 0.3 to 12.6 mg, with 1,1,1-trichloroethane at the highest concentrations in both geographic areas.

Introduction

Few studies (Pellizzari *et al.*, 1979; Zweidinger *et al.*, 1980) have attempted to measure individual human exposure to organic substances simultaneously with measurements of body burden. Yet a knowledge of exposure and body burden is crucial in arriving at decisions of great economic consequence concerning the regulation of these substances. The present study is a pilot effort to evaluate the methods required to determine individual human exposure and body burden for a number of volatile organic compounds (VOC).

Study objectives

The main objective of the study was to field test the following methods for measuring human exposure to VOC:

- A personal air-quality monitor to sample breathing-zone air;
- A specially designed spirometer to sample exhaled breath;
- Analytical protocols for measuring VOC in air, tap water, and breath.

A second objective was to compare levels of VOC in breathing-zone air and drinking water with levels of the same compounds in human breath (Table 1).

Selection of sites

Two areas were selected for study: a petrochemical manufacturing center in Texas and a nonindustrial community in North Carolina. Volunteers from local universities were sought.

Beaumont, TX, was selected to represent the petrochemical area. Lamar University is bordered on the north and south by oil storage tank farms, and on the northwest by the urban area of Beaumont. For 9 months of the year, prevailing winds from the south cross over

Table 1. Target chemicals in Lamar University and University of North Carolina studies.

	Chemical	Air and Breath	Drinking Water
1.	Benzene	X	X
2.	Chloroform	X	X
3.	1,2-Dichloroethane	X	X
4.	1,1,1-Trichloroethane	X	X
5.	Trichloroethylene	X	X
6.	Tetrachloroethylene	X	X
7.	Bromodichloromethane	X	X
8.	Chlorobenzene	X	X
9.	Vinylidene chloride	X	X
10.	1,1-dichloropropane	X	
11.	1,2-dichloropropane	X	
12.	Dibromochloromethane	X	
13.	Ethylene dibromide	X	
14.	Dichlorobenzene (*m*- or *p*-isomer)	X	
15.	*o*-dichlorobenzene	X	

major refineries and petrochemical plants before reaching the university.

Chapel Hill, NC, was selected to represent the nonindustrial area. Students at the University of North Carolina (UNC) formed the study population.

Selection of subjects

At both universities, student volunteers were selected only if they were not currently enrolled in a course involving direct contact with organic chemicals, not employed in occupations involving exposure to organic chemicals, and not engaged in hobbies involving potential exposure to organic chemicals.

A questionnaire developed by the University of Miami Medical School was administered to each student to determine factors that might be related to exposure, such as residence on or off campus, dietary habits, hobbies, parents' occupations, and so on. The questionnaire had been approved by the human rights committee at the University of Miami Medical School.

In all, 17 students were selected: 11 at Lamar University (five sampled on March 4, 1980, and six on the following day); and six at UNC (three students sampled on June 10, 1980, and three on the following day). Each participant signed a consent form and received a small incentive when sampling was completed.

Sampling and Analysis

Sample collection—Lamar University

Each morning air monitors and water sample vials (3 per person) were distributed to each of the Lamar students to be tested that day. Participants carried the monitors for a 5–9-h period while they attended classes, ate lunch, commuted, or carried out other normal daily activities. They filled a water sample vial each time they drank. At the end of the day, air monitors and tap water samples were returned and breath samples were collected.

A personal sampler employing Tenax GC® polymer to collect organic compounds was used to collect all air samples in the study. The sampler consisted of an MSA Model C-200 pump and an attached Tenax cartridge.

Breath samples were collected on Tenax GC cartridges via a specially designed spirometer, as shown in (Fig. 1). Air flow from the pure-air tank was allowed to fill the 50-L Bag A. When the bag was about half full, a clamp and plug were removed from the mouthpiece, the subject's nose was clipped closed, and the subject began to breathe through the mouthpiece from Bag A into Bag B. After a few minutes, the transfer of the exhaled breath to the Tenax cartridge was started using the Nutech sampler pump at a flow of approximately 7 L/min. (The flow was adjusted to approximate the individual subject's respiration rate.) The subject was asked to breathe until the air passing through Bag B was estimated to be about 75 L. Then the subject was asked to stop, Bag B was clamped closed near the mouthpiece, and the remainder of the contents of Bag B was sampled. The Tenax cartridges were removed and stored in culture tubes.

Sample collection—University of North Carolina

During June, 1980, tap water, breath, and air samples were collected at UNC. The criteria and methods of sampling were the same as for Lamar University. Six students participated as subjects.

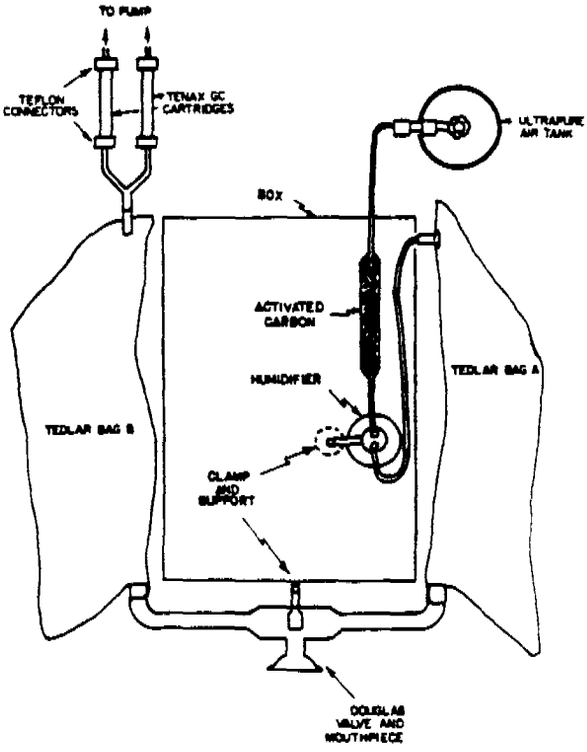

Fig. 1. Schematic diagram of the spirometer.

Table 2 Percent recovery of selected test substances in air and breath control samples (Lamar University study).

Compound	Air			Breath	
	Observed (ng/cart.) $\bar{X}$ ± S.D. (C.V.)	Actual (ng/cart.)	Percent	Observed (ng/cart.) $\bar{X}$ ± S.D. (C.V.)	Percent
Benzene	570 ± 177 (31)	528	108 ± 33	643 ± 265 (41)	122 ± 50
Chloroform	270 ± 91 (33)	200	135 ± 45	219 ± 74 (34)	109 ± 37
1,2-Dichloroethane	750 ± 285 (38)	581	129 ± 49	707 ± 243 (34)	122 ± 41
1,1,1-Trichloroethane	505 ± 175 (35)	368	137 ± 47	501 ± 115 (23)	136 ± 31
Trichloroethylene	606 ± 155 (26)	605	100 ± 26	615 ± 140 (23)	102 ± 23
Tetrachloroethylene	694 ± 142 (21)	536	129 ± 26	572 ± 171 (30)	107 ± 32
Bromodichloromethane	286 ± 90 (32)	227	126 ± 40	249 ± 68 (27)	110 ± 30
Chlorobenzene	255 ± 49 (19)	219	116 ± 22	218 ± 90 (41)	99 ± 41
m-Dichlorobenzene	567 ± 174 (31)	490	116 ± 35	499 ± 124 (25)	102 ± 25

Analysis procedures

Air and breath. Analysis of the Tenax cartridges was performed by a thermal desorption GC-MS procedure described fully in previous publications (Pellizzari, 1977; Pellizzari, 1979).

Water. Tap water samples were analyzed by a purge and trap method (Bellar and Lichtenberg, 1974). Both a Hall Electrolytic Conductivity Detector and a flame ionization detector were operated simultaneously to detect both the halogenated compounds and benzene. Standards, blanks, and controls were interspersed throughout the analysis period. The standards were prepared fresh daily and transferred to smaller containers which were stored in the refrigerator until used.

Two tap water samples were selected to be purged onto Tenax GC cartridges for broad spectrum analysis by GC-MS. The selection was determined by the number and amount of compounds detected by the purge and trap analysis.

Quality control

The blanks and controls were prepared 1 day prior to the sampling trips. Lab blanks and controls remained refrigerated in the laboratory during the trip; field blanks and controls were transported to and from the field alongside the samples at ambient temperatures. The air controls were spiked with the following seven compounds via a permeation system: chloroform, 1,2-dichloroethane, 1,1,1-trichloroethane, carbon tetrachloride, trichloroethylene, bromodichloromethane, and benzene.

The breath blanks were run on the spirometer with the mouthpiece plugged and the pure air forced through the valves from Bag A to Bag B and pumped through a blank Tenax cartridge. The controls were collected in the same manner except each cartridge was spiked with about 500 ng of each of the compounds listed above.

Water blanks were prepared from deionized water. Controls were spiked to give a concentration of 10 ng/mL of each of the following nine compounds: chloroform, 1,2-dichloroethane, 1,1,1-trichloroethane, carbon tetrachloride, trichloroethylene, tetrachloroethylene, chlorobenzene, *o*-dichlorobenzene, and bromodichloromethane.

Results

Quality control results

Air and breath. Percent recoveries for the air and breath analyses generally ranged between 95% and 140% (Tables 2 and 3). Coefficients of variance decreased considerably for 1,1,1-trichloroethane and trichloroethylene between the Lamar and UNC visits, but were unchanged for the other chemicals.

Water. The results of the quality control sample analyses are presented in Tables 4 and 5. The peaks for trichloro-

Table 3. Percent recovery of selected test substances in air and breath control samples (University of North Carolina study).

Compound	Air			Breath	
	Observed (ng) $\bar{X}$ ± S.D. (C.V.)	Actual (ng)	Percent	Observed (ng) $\bar{X}$ ± S.D. (C.V.)	Percent
Benzene	450 ± 77 (17)	530	85 ± 14	501 ± 291 (58)	94 ± 55
Chloroform	208 ± 59 (28)	200	104 ± 29	–	–
1,2-Dichloroethane	548 ± 236 (43)	567	97 ± 42	644 ± 74 (11)	113 ± 13
1,1,1-Trichloroethane	600 ± 31 (5)	455	132 ± 7	456 ± 143 (31)	100 ± 31
Trichloroethylene	889 ± 56 (6)	742	119 ± 7	828 ± 41 (5)	111 ± 6
Tetrachloroethylene	852 ± 276 (32)	556	153 ± 50	–	–
Bromodichloromethane	292 ± 98 (33)	225	130 ± 43	–	–
Carbon tetrachloride	508 ± 39 (8)	343	148 ± 11	484 ± 145 (30)	141 ± 42

Table 4. Quantities of target compounds recovered in tap water blanks and control for Lamar University study (ng/mL).

Sample	CF[a]	DE	MCF	CT	BCM	TCE	PERC	CB
Water blank (T_0)	1.2 ± 2	–[b]	–	–	0.5	–	–	–
Field blank	0.3 ± 0.1	–	–	–	–	–	–	–
Lab blank	3.0 ± 4	–	–	–	7.6	–	–	–
Field control	9.4 ± 4 (94)[c]	8.7 ± 0.5 (87)	3.9 ± 2 (37)	–	5.5 (55)	NQ	2.4 ± 0.2 (26)	7.5 ± 0.2 (76)
Lab control	11 ± 4 (109)	9.3 ± 1 (93)	4.6 ± 0.7 (46)	3.4 ± 0.1 (34)	5.8 ± 0.1 (58)	NQ	2.6 ± 0.1 (25)	7.5 ± 1 (75)

[a]CF = chloroform, DE = 1,2-dichloroethane; MCF = 1,1,1-trichloroethane; CT = carbon tetrachloride; BCM = bromodichloromethane; TCE = trichloroethylene or 1,1,2-trichloroethane; PERC = tetrachloroethylene; CB = chlorobenzene.
[b]– indicates not detected.
[c]Mean ± S.D. (percent recovered).

ethylene and 1,1,2-trichloroethane overlap, so it was not possible to determine whether one or both compounds were present, nor to quantitate either compound.

The percent recoveries given in Table 4 indicate that results for drinking water control samples in the Lamar study varied widely, from 25% for tetrachloroethylene to >100% for chloroform. Adjustments in the analytical protocol led to the greatly improved percent recoveries observed at Chapel Hill three months later (Table 5). Mean recoveries ranged between 92% and 118% for the seven spiked compounds. The precision (i.e., relative standard deviation, or coefficient of variation) ranged from 4% to 12% for the UNC study.

In addition to the quality control samples, three blind quality assurance samples were prepared for water. These samples were encoded prior to submission to the analyst. The results, presented in Table 6, indicate good recoveries for chloroform and chlorobenzene; moderate recoveries for carbon tetrachloride; but only 50% recovery of tetrachloroethylene. Recoveries of 1,1,1-trichloroethane, on the other hand, were consistently 40%–50% greater than the spiked value.

Field results

Air. Of 15 target compounds, six were found in all 17 samples, and four others in more than one-half of the samples (Tables 7 and 8). Six of these 10 compounds showed high variability, ranging over 2–3 orders of magnitude. Geometric means for one compound (1,1,1-trichloroethane) exceeded 50 $\mu g/m^3$ in each student group. Geometric means for seven other compounds generally fell between 1 and 10 $\mu g/m^3$ for each group. The mean concentrations showed no significant difference between the two student groups for any compound, as determined by a *t*-test.

Breath. Five compounds were found in all 17 samples, and two others were found in more than 50% of the samples (Tables 9 and 10). Five of these seven compounds showed high variability. Geometric means for these seven compounds ranged from about 1 to 15 $\mu g/m^3$.

Water. UNC tap water showed consistently higher mean chloroform values (220 ng/mL) than the Lamar University sources (150 ng/mL) (Tables 11 and 12). Tetrachloroethylene values were also higher in the UNC water supplies. Bromodichloromethane values were similar in the two water supplies (20 ng/mL at Lamar; 17 ng/mL at UNC). Total trihalomethanes exceeded the recommended interim drinking water standard of 100 ng/mL in all 38 water samples from the two areas. (A substantial portion of surface supplies from around the nation exceeded this value in the late 1970's.)

All of the tap water samples contained chloroform and bromodichloromethane. Some samples contained small amounts of tetrachloroethylene and chlorobenzene. No benzene, carbon tetrachloride, 1,2-dichloroethane, vinylidene chloride, or 1,1,1-trichloroethane was detected.

Summary statistics

The frequency of detection, arithmetic mean, standard deviation, and range of each target compound in air, breath, and water are displayed in Tables 13–16. Each statistic is computed using the actual or estimated values for all participants except where missing data occur. The percent detected indicates the percentage of measurements greater than the minimum limit of detection (LOD). The median and the arithmetic mean are provided as measures of central tendency. The mean is calculated using the following conventions: the quan-

Table 5. Quantities of target compounds recovered in tap water blanks and controls for UNC study (ng/mL).

Sample	CF[a]	DE	MCF	BCM	TCF	PERC	CB
Field blank	T[b]	–	–	–	–	–	–
Lab blank	1.3 ± 0.5	–	–	–	–	–	–
Field control	11 ± 1.4 (98)[c]	10 ± 0.9 (100)	12 ± 1 (118)	10 ± 1 (102)	11 ± 0 (108)	12.5 ± 0.2 (125)	10 ± 0.5 (102)
Lab control	9.8 ± 0.3 (88)	9.2 ± 0.1 (92)	10.8 ± 0.1 (107)	9.5 ± 0 (95)	10.4 ± 0.2 (104)	12 ± 1 (107)	10 ± 0.5 (100)

[a]See Table 4 for codes.
[b]T = trace.
[c]Mean ± S.D. (percent recovered).

Table 6. Results of water blind study.[a]

Compound	Blank		Spike −1			Spike −2		
	Spike (ng/mL)	Found (ng/mL)	Spike (ng/mL)	Found (ng/mL)	Recovery (%)	Spike (ng/mL)	Found (ng/mL)	Recovery (%)
Benzene	0	ND[b]	0	ND		0	ND	
Chloroform	0	ND	15.5	15.6	100	1.5	1.7	116
1,2-Dichloroethane	0	ND	6	ND		0	ND	
1,1,1-Trichloroethane	0	ND	14.1	20	142	134	202	151
Carbon tetrachloride	0	ND	16.7	13.4	80	ND	ND	
Bromodichloromethane	0	ND	0	ND		0	ND	
Trichloroethylene and/or	0	ND	0	ND		0	0.02	
1,1,2-Trichloroethane	0	ND	0			0	ND	
Tetrachloroethylene	0	ND	17.0	9.2	54	0	ND	
Chlorobenzene	0	ND	11.6	12.4	107	0	ND	

[a]Samples prepared with known levels of the compounds as indicated and encoded prior to submission for analysis.
[b]Not detected.

Table 7 Estimated levels of selected vapor-phase organics in ambient air associated with human participants (Lamar University student study) ($\mu g/m^3$).

Compound	Participant No.											LOD[a]	QL[b]
	30001	30002	30003	30004	30005	30011	30012	30013	30014	30015	30016		
Benzene	9.5	2.5	11	2.9	3.6	4.8	5.8	8.3	3.2	5.3	386	0.08	0.40
Chloroform	1.4	1.5	3.8	8.3	5.2	4.0	4.8	6.0	3.2	1.9	4.8	0.08	0.40
Vinylidene chloride	416	1.4	76	1.0	1.1	–	7.0	5.7	2.1	4.6	–	0.12	0.60
1,1-Dichloroethane	1.8	–	0.93	–	–	–	–	–	–	–	–	0.12	0.60
1,2-Dichloroethane	11	0.49	–	0.32	0.52	1.0	0.94	0.95	0.72	0.71	13	0.12	0.60
1,1,1-Trichloroethane	592	22	1,069	8.5	8.3	31	62	72	12	67	40	0.16	0.80
Trichloroethylene	19	7.5	26	1.6	0.90	3.8	2.0	63	0.99	2.4	3.7	0.16	0.80
1,2-Dichloropropane	–	–	–	–	–	–	–	–	–	–	–	0.20	1.00
Tetrachloroethylene	174	161	7.2	5.4	5.6	5.0	30	718	4.5	172	9.3	0.24	1.20
Bromodichloromethane	1.6	1.5	–	3.2	1.0	–	1.1	3.7	0.84	–	–	0.24	1.20
Dibromochloromethane	–	–	–	–	–	–	–	–	–	–	–	0.24	1.20
Ethylene dibromide	–	–	–	–	–	–	–	–	–	–	–	0.28	1.40
Chlorobenzene	–	–	–	–	0.47	–	–	–	–	–	2.1	0.16	0.80
Dichlorobenzene isomer	8.4	73	8.0	6.9	2.5	6.4	3.0	23	1.8	4.3	33	0.20	1.00
o-Dichlorobenzene	–	–	–	2.4	0.38	–	0.20	–	–	–	–	0.20	1.00

[a]Limit of detection (LOD) was defined as S/N = 4 for *m/z* ion selected for quantification, all values in $\mu g/m^3$.
[b]Quantifiable limit (QL) was defined as 5 × LOD or S/N = 20, all values in $\mu g/m^3$.

Table 8. Estimated levels of vapor-phase organics in ambient air for several human subjects (University of North Carolina at Chapel Hill study) ($\mu g/m^3$).

Compound	Participant Number					
	40001	40002	40003	40011	40012	40013
Benzene	14	7.5	3.8	3.2	4.2	3.0
Chloroform	7.8	5.1	3.7	3.2	17	2.2
Vinylidene chloride	14	27	9.8	3.5	5.7	7.0
1,1-Dichloroethane	–[a]	–	–	–	–	–
1,2-Dichloroethane	–	–	1.1	0.42	0.45	0.63
1,1,1-Trichloroethane	165	194	93	14	70	57
Trichloroethylene	9.7	2.2	10.8	4.6	2.2	183
1,2-Dichloropropane	–	–	–	–	–	–
Tetrachloroethylene	2.5	2.6	2.1	1.2	4.3	127
Bromodichloromethane	–	–	–	–	4.3	–
Dibromochloromethane	–	–	–	–	–	–
Ethylene dibromide	–	–	–	–	–	–
Chlorobenzene	–	–	–	0.17	0.18	–
Dichlorobenzene isomer	35	0.58	0.46	0.29	15	0.63
o-Dichlorobenzene	1.5	0.32	–	–	0.27	0.14

[a]– indicates not detected.

Table 9 Estimated levels of selected vapor phase organics in breath (Lamar University student study) ($\mu g/m^3$).

Compound	Participant No. 30001	30002	30003	30004	30005	30011	30012	30013	30014	30015	30016	LOD	QL
Benzene	2.9 ± 1.1	1.4 ± 0.2	0.7 ± 0.0	1.71 ± 0.28	0.99 ± 0.33	1.8 ± 0.13	2.2	1.7 ± 0.15	1.1 ± 0.15	1.9 ± 0.20	1 3 ± 0.52	0.11	0.55
Chloroform	T[a]	T	T	T	T	T	2.48	T	T	T	T	0.11	0.55
Vinylidene chloride	15 ± 2.8	0.08	26 ± 8.0	0.08	2.9	0.08	0.08	0.5 T	5.8 ± 1.6	3.8 ± 1.2	0.08	0.16	0.82
1,1-Dichloroethane	–[b]	–	–	–	–	–	–	–	–	–	–	0.16	0.82
1,2-Dichloroethane	–	–	–	–	–	–	–	T	–	T	–	0.16	0.82
1,1,1-Trichloroethane	161 ± 16	0.66 ± 0.16	93 ± 21	T	T	T	2.5	T	1.7 ± 0.46	6.5 ± 0.75	T	0.22	1.10
Trichloroethylene	–	1.11 ± 0.04	T	T	–	T	T	1.45 ± 0.10	T	1.07 ± 0.04	T	0.2	1.10
1,2-Dichloropropane	–	–	–	–	–	–	–	–	–	–	–	0.27	1.37
Tetrachloroethylene	69 ± 5 4	96 ± 0.20	98 ± 1.0	13 ± 1.5	13 ± 0.71	T	24	161 ± 31	1.0	176 ± 0.91	T	0.33	1.65
Bromodichloromethane	–	–	–	–	–	–	–	–	–	–	–	0.33	1.65
Dibromochloromethane	–	–	–	–	–	–	–	–	–	–	–	0.33	1.65
Ethylene dibromide	–	–	–	–	–	–	–	–	–	–	–	0.38	1.92
Chlorobenzene	–	–	–	–	–	–	–	–	–	–	–	0.22	1.10
Dichlorobenzene isomer	T	31 ± 2.5	T	T	T	T	1.3	20 ± 6.2	6.1	23 ± 3.0	T	0.27	1.37
o-Dichlorobenzene	–	–	–	–	–	–	–	–	–	–	–	0.27	1.37

[a]T = trace amount.
[b]– indicates not detected.

tifiable limit (QL) is defined as 5 × LOD; values of compounds not detected are estimated as 0.5 LOD; and trace levels are estimated as 0.5 (QL + LOD). In general, the sample distributions for water show much less variability and skewness than for air and breath.

Discussion

The concentrations of some chemicals reached levels of 100–1000 $\mu g/m^3$ in air and 100–200 $\mu g/m^3$ in human breath. Although the air levels are far below the workplace standards of the Occupational Safety and Health Administration, their chronic effects are unknown and could be of significant public health concern.

The great variability exhibited by seven of the 10 most prevalent compounds indicates that it would have been erroneous to characterize either student group as a geographical cohort with uniform exposures. If validated by future studies, this conclusion would have important implications for epidemiological studies, which have often traditionally assigned similar exposure histories to residents of a given region.

Table 10. Estimated levels of vapor phase organics in breath of human subjects (University of North Carolina at Chapel Hill study) ($\mu g/m^3$).

Compound	Participant Number 40001	40002	40003	40011	40012	40013
Benzene	1.0 ± 0.05	1.4 ± 0.23	1.4 ± 0.18	1.1 ± 0	NC[a]	1.5 ± 0.41
Chloroform	2.8 ± 1.5	3.0 ± 0.16	5.1 ± 2.8	1.8 ± 0.28	NC	1.7 0.41
Vinylidene chloride	4.5 ± 0.39	14 ± 1.3	5.5 ± 1.3	3.9 ± 0.09	7.7 ± 0.05	7.9 ± 0.65
1,1-Dichloroethane	–[b]	–	–	–	–	–
1,2-Dichloroethane	–	–	–	–	0.37	0.48
1,1,1-Trichloroethane	23 ± 3.6	48 ± 11	19 ± 5.7	6.1 ± 0.04	8.5 ± 1.8	13 ± 0.34
Trichloroethylene	1.1 ± 0.12	0.55 ± 0.19	1.2 ± 0.36	0.65 ± .05	0.49 ± 0.11	32 ± 0.70
1,2-Dichloropropane	–	–	–	–	–	–
Tetrachloroethylene	3.4 ± 0.44	3.3 ± 0.19	4.3 ± 0.76	8.8 ± 1.1	7.5 ± 0.68	48 ± 5.5
Bromodichloromethane	–	–	–	–	–	–
Dibromochloromethane	–	–	–	–	–	–
Ethylene dibromide	–	–	–	–	–	–
Chlorobenzene	–	–	0.27	–	0.11[c]	–
Dichlorobenzene Isomer	0.54 ± .03	4.5 ± 0	2.2 ± 0.56	0.92 ± 0	5.3 ± 0.71	1.1 ± 0.36
o-Dichlorobenzene	–	–	–	–	–	–

[a]NC = missing values.
[b]– indicates not detected.
[c]Given value is below the limit of detection.

Table 11. Quantities of target compounds found in tap water (Lamar University) (ng/mL).

Number	Chloroform	1,2-Dichloroethane	1,1,1-Trichloroethane	Carbon Tetrachloride and/or Bromodimethane	Trichloroethylene and/or 1,1,2-Trichloromethane	Tetrachloroethylene	Chlorobenzene
1-30001	110	–[a]	–	16	NC[b]	–	–
1-30002	260	–	–	18	NC	–	–
2-30002	130	–	–	23	NC	–	–
1-30003	550	–	–	44	NC	T[c]	–
1-30004	160	–	–	25	NC	–	–
2-30004	99	–	–	18	NC	–	–
1-30005	140	–	–	25	NC	–	–
2-30005	120	–	–	22	NC	–	–
1-30011	120	–	–	20	NC	–	–
2-30011	120	–	–	18	NC	0.2	0.2[d]
3-30011	110	–	–	23	NC	–	–
1-30012	120	–	–	22	NC	–	–
2-30012	170	–	–	26	NC	–	–
3-30012	110	–	–	17	NC	–	–
1-30013	140	–	–	18	NC	–	–
2-30013	160	–	–	22	NC	0.1[d]	–
3-30013	130	–	–	18	NC	–	–
1-30014	160	–	–	20	NC	–	–
2-30014	130	–	–	18	NC	–	–
3-30014	110	–	–	13	NC	–	–
1-30015	110	–	–	7.4	NC	0.2[d]	0.2[d]
2-30015	140	–	–	18	NC	–	–
1-30016	120	–	–	13	NC	–	–
2-30016	120	–	–	13	NC	–	–
3-30016	120	–	–	14	NC	0.1[d]	–
LOD	1.0	0.6	0.2	0.4	1.3	1.1	0.6

[a]Not detected.
[b]NC = missing data.
[c]T = trace amount.
[d]Given value is below limit of detection.

Table 12. Quantities of target compounds found in tap water (Chapel Hill) (ng/mL).

Sample	Chloroform	1,2-Dichloroethane	1,1,1-Trichloroethane	Bromodichloromethane	Trichloroethylene	Tetrachloroethylene	Chlorobenzene
40001-1	260	ND	ND[a]	20	2.8	3.8	ND
40001-2	260	ND	ND	19	3.0	3.8	ND
40002-1	220	ND	ND	17	ND	1.8	ND
40002-3	250	ND	ND	18	ND	1.8	ND
40003-1	200	ND	ND	18	ND	1.8	1.4
40003-2	230	ND	ND	18	ND	1.8	ND
40011-1	200	ND	ND	17	ND	1.7	ND
40011-2	210	ND	ND	16	ND	1.8	ND
40011-3	220	ND	ND	17	ND	1.8	1.5
40012-1	210	ND	ND	17	ND	1.8	ND
40012-2	210	ND	ND	16	ND	1.8	ND
40013-1	180	ND	ND	15	ND	1.3	1.5
40013-2	200	ND	ND	15	1.3	1.3	ND
Mean[b]	220	–	–	17	0.6	2.0	0.4
SD	23	–	–	2	1	0.8	0.6
CV (%)	10	–	–	12	170	40	150
Median	220	–	–	17	ND	1.8	ND
LOD[c]	0.05	0.06	0.1	0.1	0.05	0.05	ND

[a]Not detected.
[b]Mean of all values (ND = ½ LOD).
[c]Limit of detection (S/N = 3).

Table 13. Summary statistics for estimated levels of selected vapor-phase organics (Lamar University).

		% Detected[a]	% at Trace	Mean[b]	Std. Dev.	Median	Range	% ≥ 10 μg/m³
Benzene	Air	100	0	40.30	118.87	5.16	2.46–386.56	18
	Breath	100	0	1.61	0.62	1.70	0.72–2.95	0
Chloroform	Air	100	0	4.00	2.13	4.04	1.39–8.33	0
	Breath	100	91	0.42	0.68	0.22	0.22–2.48	0
Vinylidene chloride	Air	82	0	46.84	124.43	2.14	0.06–416.07	18
	Breath	55	9	4.88	8.19	0.33	0.08–25.17	18
1,1-Dichloroethane	Air	18	0	0.30	0.57	0.06	0.06–1.83	0
	Breath	0	0	0.08	0.00	0.08	0.08–0.08	0
1,2-Dichloroethane	Air	91	9	2.72	4.66	0.72	0.06–12.80	18
	Breath	18	18	0.12	0.10	0.08	0.08–0.33	0
1,1,1-Trichloroethane	Air	100	0	180.35	339.47	40.00	8.27–1069.04	82
	Breath	100	45	24.37	53.14	0.66	0.44–161.50	18
Trichloroethylene	Air	100	0	11.88	18.90	3.67	0.90–63.39	27
	Breath	82	54	0.59	0.43	0.44	0.11–1.45	0
1,2-Dichloropropane	Air	0	0	0.10	0.00	0.10	0.10–0.10	0
	Breath	0	0	0.13	0.00	0.13	0.13–0.13	0
Tetrachloroethylene	Air	100	0	117.63	212.38	9.26	4.54–718.20	45
	Breath	100	18	51.36	65.61	13.25	0.66–176.32	64
Bromodichloromethane	Air	64	0	1.23	1.24	1.00	0.12–3.71	0
	Breath	0	0	0.16	0.00	0.16	0.16–0.16	0
Dibromochloromethane	Air	0	0	0.12	0.00	0.12	0.12–0.12	0
	Breath	0	0	0.16	0.00	0.16	0.16–0.16	0
Ethylene Dibromide	Air	0	0	0.14	0.00	0.14	0.14–0.14	0
	Breath	0	0	0.19	0.00	0.19	0.19–0.19	0
Chlorobenzene	Air	18	0	0.30	0.08	0.61	0.08–2.12	0
	Breath	0	0	0.11	0.00	0.11	0.11–0.11	0
Dichlorobenzene Isomer	Air	100	0	15.56	21.52	6.95	1.83–73.47	27
	Breath	100	54	7.73	11.31	0.56	0.55–30.67	27
o-Dichlorobenzene	Air	27	0	0.34	0.67	0.10	0.10–2.40	0
	Breath	0	0	0.13	0.00	0.13	0.13–0.13	0

[a] $n = 11$.
[b] All compounds measured in μg/m³.

Relative contributions of individual VOC to exposure of volunteers

Table 17 shows the relative contribution of each of 12 volatile organics to the air exposure of each of the 17 subjects. These "profiles" can be used to compare different study groups or areas with respect to their dominant pollutants. For both student groups studied, methyl chloroform is the main contributor, supplying over one-half the total intake at UNC, and more than one-third at Lamar. The relative importance of benzene, chloroform, and vinylidene chloride was also very similar for each group, ranging between 4% and 8%. However, tetrachloroethylene was far more important for the Lamar group than the UNC group (35%–7%), while trichloroethylene was relatively more important at UNC (13%–3.5%).

Breath–air relationships

For certain chemicals, a relationship between environmental levels and levels in body fluids on tissues has been established. [As an example, the Coburn equation relates carbon monoxide levels in air to carboxyhemoglobin levels in blood (Coburn *et al.*, 1965).] Such a relationship is useful because it allows body burden or dose to be estimated by measuring the environment rather than the person. For other chemicals, however, such a relationship has not been established, at least at environmental levels. Therefore a preliminary attempt was made in this study to determine whether levels in breath correlated with previous exposures in air.

It should be noted that the method of measuring breath levels involves inhaling pure air. Thus, whatever trace chemicals are exhaled are being transferred to the breath from other body compartments, particularly the blood.

The simplest assumption is that all compartments are in equilibrium with a steady-state environmental concentration. In this case, assuming a constant fraction $(1 - f)$ of the chemical is removed by metabolic processes on each "pass" through the body, the breath concentration should be directly related to the concentration in air:

$$C_B = f C_A.$$

This theoretical relationship was tested by calculating Spearman correlation coefficients between air and breath samples for each student group (Table 18). Since no significant differences were observed between the two student groups with respect to air concentrations, they were combined into a single group ($N = 17$) and

Table 14. Summary statistics for estimated levels of selected vapor phase organics (University of North Carolina at Chapel Hill study).

		% Detected[a]	% at Trace	Mean[b]	Std. Dev.	Median	Range	% ≥ 10 μg/m³
Benzene	Air	100	0	5.89	4.14	4.00	2.95–13.65	17
	Breath	100	0	1.29	0.22	1.38	1.00–1.51	0
Chloroform	Air	100	0	6.59	5.66	4.41	2.25–17.46	17
	Breath	10 (n = 5)	0	2.86	1.36	2.84	1.70–5.06	0
Vinylidene chloride	Air	100	0	11.21	8.66	8.40	3.53–27.29	34
	Breath	100	0	7.28	3.73	6.59	3.94–14.12	17
1,1-Dichloroethane	Air	0	0	0.06	0.00	0.06	0.06–0.06	0
	Breath	0	0	0.08	0.00	0.08	0.08–0.08	0
1,2-Dichloroethane	Air	67	0	0.45	0.39	0.43	0.06–1.09	0
	Breath	33	0	0.19	0.18	0.08	0.08–0.48	0
1,1,1-Trichloroethane	Air	100	0	99.07	68.06	81.81	14.45–193.77	100
	Breath	100	0	19.47	15.14	15.97	6.10–47.63	67
Trichloroethylene	Air	100	0	35.33	72.16	7.13	2.17–182.43	34
	Breath	100	0	5.94	12.60	0.86	0.49–31.66	17
1,2-Dichloropropane	Air	0	0	0.10	0.00	0.10	0.10–0.10	0
	Breath	0	0	0.13	0.00	0.13	0.13–0.13	0
Tetrachloroethylene	Air	100	0	23.34	50.94	2.56	1.22–127.30	17
	Breath	100	0	12.52	17.40	5.92	3.30–47.74	17
Bromodichloromethane	Air	17	0	0.83	1.73	0.12	0.12–4.36	0
	Breath	17	0	0.29	0.30	0.16	0.16–0.91	0
Dibromochloromethane	Air	0	0	0.12	0.00	0.12	0.12–0.12	0
	Breath	0	0	0.16	0.00	0.16	0.16–0.16	0
Ethylene Dibromide	Air	0	0	0.14	0.00	0.14	0.14–0.14	0
	Breath	0	0	0.19	0.00	0.19	0.19–0.19	0
Chlorobenzene	Air	33	0	0.11	0.05	0.08	0.08–0.18	0
	Breath	17	0	0.14	0.0	0.11	0.11–0.27	0
Dichlorobenzene Isomer	Air	100	0	8.66	14.14	0.61	0.29–34.96	34
	Breath	100	0	2.42	2.01	1.53	0.54–5.30	0
o-Dichlorobenzene	Air	50	0	0.40	0.55	0.18	0.10–1.52	0
	Breath	0	0	0.13	0.00	0.13	0.13–0.13	0

[a] n = 6 unless otherwise noted.
[b] All compounds are measured in μg/m³.

studied further for correlations between chemicals in air and breath (Table 19). Four of the five chemicals prevalent in the breath samples showed significant correlations with their concentrations in air; only benzene showed little correlation between breathing-level exposure and breath clearance.

Regression analyses were performed relating breath levels to air levels for those compounds with significant air–breath correlations. Logarithms were employed because of the wide range of concentrations. Nondetectable (ND) samples were assigned a value of one-half the LOD; and trace (T) samples a value halfway between the LOD and the quantifiable limit (QL).

For three chemicals, 50% or more of the variance in breath levels was explained by the preceding air exposures. The F values are all above the 99% level. A simple log-linear model appears capable of predicting breath levels to within a factor of 3 or 4, given the air exposures for the preceding 8 h. This approach yields the following regression parameters:

Table 15. Summary statistics for estimated levels of selected vapor phase organics in tap water (Lamar University student study).

	% Detected	% at Trace	Mean[a]	Standard Deviation	Median	Range
Chloroform	100	0	172.38	126.56	130.00	117.00–550.00
1,2-Dichloroethane	0	0	0.30	0	0.30	0.30–0.30
1,1,1-Trichloroethane	0	0	0.10	0	0.10	0.10–0.10
Bromodichloromethane and/or Carbon Tetrachloride	100	0	21.21	8.38	20.33	13.33–44.00
Trichloroethylene and/or 1,1,2-Trichloroethane	–	–	–	–	–	–
Tetrachloroethylene	9	9	0.95	1.33	0.55	0.55–4.95
Chlorobenzene	0	0	0.30	0	0.30	0.30–0.30

[a] All compounds are measured in ng/mL.

Table 16. Summary statistics for estimated levels of selected organics in tap water (Chapel Hill).

	% Detected	% at Trace	Mean[a,b]	Standard Deviation	Median	Range
Chloroform	100	0	220	23	220	180–260
1,2-Dichloroethane	0	0	–	–	–	ND
1,1,1-Trichloroethane	0	0	–	–	–	ND
Bromodichloromethane	100	0	17	2	17	15–20
Trichloroethylene	23	0	0.6	1	ND	ND–3.0
Tetrachloroethylene	100	0	2.0	0.8	1.8	1.3–3.8
Chlorobenzene	23	0	0.4	0.6	ND	ND–1.5

[a]All compounds are measured in ng/ml.
[b]Mean of all values (ND = 2.00).

tetrachloroethylene: $\log C_B = 0.23 \pm 0.44 + (0.72 \pm 0.13) \log C_A$,

1,1,1-trichloroethane: $\log C_B = -0.98 \pm 0.54 + (0.91 \pm 0.23) \log C_A$,

vinylidene chloride: $\log C_B = -0.24 \pm 0.67 + (0.71 \pm 0.17) \log C_A$,

where C_B = concentration in breath, C_A = concentration in air, in $\mu g/m^3$.

Figures 2–4 display this possible log-linear relationship between air exposures and breath concentrations of several compounds. If this preliminary observation is confirmed by future studies, an exposure–body-burden relationship could be established for some compounds. This would allow recent exposures to be estimated from a single noninvasive test lasting just 15 min; conversely, body burden could be estimated from a single personal monitoring sample.

Two possible problems exist in attempting to relate expired air concentrations to a previous exposure aver-

Table 17. Percent of individual air exposure supplied by selected vapor-phase organics (Both groups).

Participant	Benzene	Chloroform	Vinylidene chloride	1,1-Dichloroethane	1,2-Dichloroethane	1,1,1-Trichloroethane	Trichloroethylene	Tetrachloroethylene	Bromodichloromethane	Chlorobenzene	*m*-Dichlorobenzene	*o*-Dichlorobenzene
Lamar University												
30001	0.76	0.11	34	0.14	0.88	48	1.5	14	0.13	–	0.67	–
30002	0.86	0.51	0.48	–	0.17	8.0	2.6	59	0.52	–	27	–
30003	0.86	0.30	6.0	0.07	–	85	2.1	0.57	–	–	0.63	–
30004	7.1	20	2.4	–	0.73	21	3.9	13	7.8	–	17	5.9
30005	8.8	13	27	–	1.2	20	2.2	14	2.4	1.2	6.0	1.0
30011	8.6	7.1	–	–	1.8	55	6.8	87	–	–	11	–
30012	4.7	3.9	5.7	–	0.7	51	1.6	25	0.90	–	2.5	0.17
30013	0.93	0.67	0.67	–	0.11	8.0	7.0	80	0.40	–	2.5	–
30014	11.0	11.0	7.2	–	2.4	41	3.4	16	2.8	–	6.2	–
30015	2.0	0.7	1.7	–	0.26	25	0.9	67	–	–	1.6	–
30016	[a]	6.1	–	–	16	51	4.7	12	–	2.7	42	–
Mean	4.7	5.8	7.8	–	2.2	38	3.5	35	1.4	–	11	0.6
Standard Deviation	±3.8	±6.2	±11.0	–	±4.4	±22	±2.0	±30	±2.3	–	±12	–
UNC												
40001	5.6	3.1	5.6	–	–	66	3.9	1	–	–	14	0.6
40002	3.1	2.1	11	–	–	81	0.9	1.1	–	–	0.2	0.1
40003	3.0	3.0	7.8	–	0.88	74	8.8	1.7	–	–	0.4	0.1
40011	11	11	12	–	1.3	47	15	4.0	–	0.7	1.0	0.3
40012	2.4	9.6	3.2	–	0.23	40	1.2	2.4	2.5	0.1	8.5	0.2
40013	0.8	0.6	1.8	–	0.16	15	48	34	–	–	0.16	0.03
Mean	4.3	4.9	6.	–	0.43	54	13	7.4	0.4	0.1	4.0	0.2
Standard Deviation	±3.3	±3.9	±3.8	–	±0.49	±23	±16	±12	–	–	±5.3	±0.2

[a]Outlier – not included in calculations.

Table 18. Spearman correlation coefficients between air and breath for estimated levels of selected vapor phase organics (both groups).

	n		$r_{Air\text{-}Breath}$	
	UNC	Lamar	UNC	Lamar
Benzene	5	11	0.70	0.04
Chloroform	5	11	0.60	0.20
Vinylidene chloride	6	11	0.48	0.67[a]
1,1-Dichloroethane	6	11	0.00	0.00
1,2-Dichloroethane	6	11	0.44	0.07
1,1,1-Trichloroethane	6	11	0.94[b]	0.63[a]
Trichloroethylene	6	11	0.94[b]	0.41
1,2-Dichloropropane	6	11	0.00	0.00
Tetrachloroethylene	6	11	0.20	0.80[b]
Bromodichloromethane	6	11	0.20	0.00
Dibromochloromethane	6	11	0.00	0.00
Ethylene dibromide	6	11	0.00	0.00
Chlorobenzene	6	11	0.31	0.00
Dichlorobenzene isomer	6	11	0.03	0.08
o-Dichlorobenzene	6	11	0.00	0.00

[a] $p < 0.01$.
[b] $p < 0.05$.

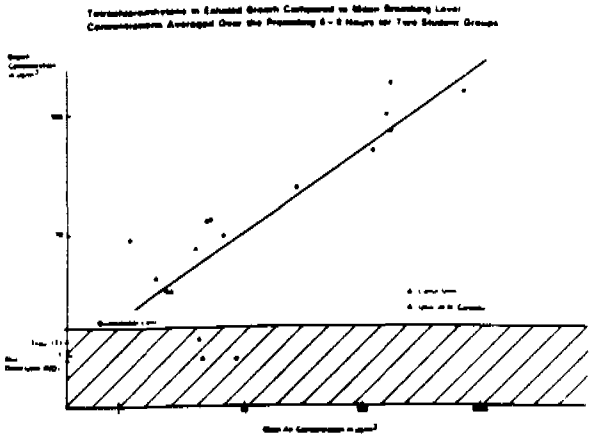

Fig. 2. Correlation between air exposures and breath concentrations for tetrachloroethylene. $R^2 = 0.68$.

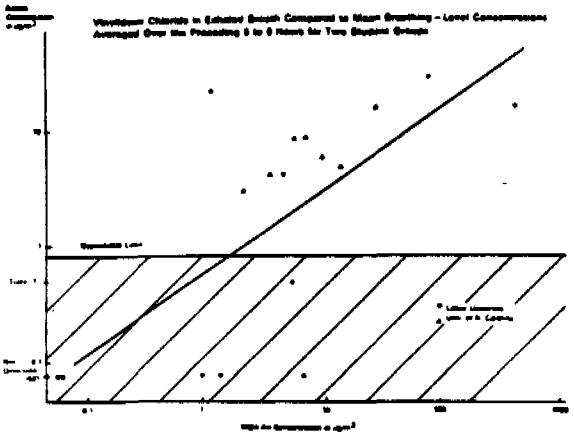

Fig. 3. Correlation between air exposures and breath concentrations for vinylidene chloride. $R^2 = 0.53$.

aged over 8 h. First, since most of these volatile chemicals have two or more distinct halflives associated with different body compartments (the shorter of which is often measured in minutes) (Andersen *et al.*, 1980) the breath level immediately following exposure is likely to reflect the most recent few minutes of the exposure. Stewart *et al.* (1970) found, for example, that not until the third hour postexposure to trichloroethylene was the concentration in expired breath able to be directly related to the time-weighted average exposure. Thus a sharp increase or decrease in exposure toward the end of the exposure period is likely to yield a breath level well above or below the value expected on the basis of the mean exposure level over 8 h.

Second, it is possible that an unusually high exposure previous to the measured exposure period would continue to show some effects on expired air concentrations measured 5–9 h later. This is unlikely to be a problem for those chemicals with short halflives, since the effect would be "washed out" during the exposure period. (For example, the halflife of 1,1,1-trichloroethane associated with the vessel-rich group is only 0.8 h) (Humbert and Fernandez, 1977). Even for chemicals with longer halflives, such as tetrachloroethylene, Hake *et al.* (1976) have stated that breath samples taken 8 h after exposure were indicative of the amount adsorbed. Also, only in the case where the previous exposure was higher than the measured exposure would there be a noticeable effect on the expired air concentration, yet for all of these subjects, their previous exposure was during the sleep period, an unlikely time for severe exposures.

Table 19. Significant Spearman correlation coefficients for volatile organic compounds observed in breathing-zone air and in exhaled breath of 17 students at Lamar University and University of North Carolina.

	Breath				
Air	Benzene	Methyl Chloroform	Tetrachloroethylene	Trichloroethylene	Vinylidene Chloride
Benzene					
Methyl chloroform		0.74			0.62
Tetrachloroethylene	0.54		0.73		
Trichloroethylene				0.53	
Vinylidene chloride		0.88			0.77
Ethylene dichloride	0.54				

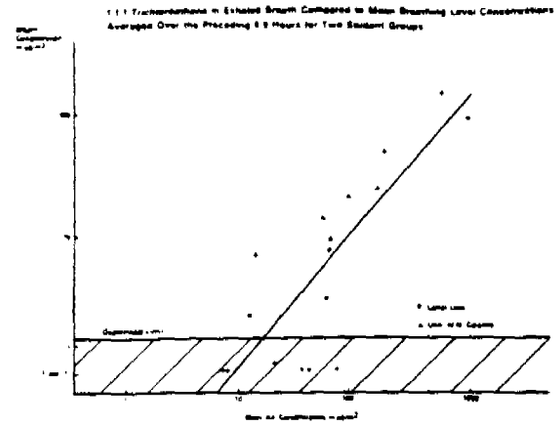

Fig. 4. Correlation between air exposures and breath concentrations for 1,1,1-trichloroethane. $R^2 = 0.68$.

Other possible confounding variables include biological variation in metabolic rates and short-term alteration of metabolic processes by medication. It should be noted that if these hypothesized variations in exposures before the beginning or toward the end of the measured exposure period were in fact occurring, the result would reduce or eliminate any correlation between exposures and breath levels; however, four significant correlations were observed.

Breath–air ratios

Table 20 compares the breath-to-air ratios of the concentrations of seven VOC for each of the 17 student volunteers. Breath–air ratios among the two student groups are similar for benzene (30%), vinylidene chloride (80%), and trichloroethylene (20%). For three other compounds, however, (1,1,1-trichloroethane, tetrachloroethylene, and dichlorobenzene isomer), the UNC mean breath–air ratios are several times higher than those of Lamar. Moreover, the UNC breath–air ratio is higher than 100% for two of these compounds (tetrachloroethylene and dichlorobenzene isomer). This anomaly is most likely due to the high variance associated with the sampling and analytical protocol, as well as the small number of subjects. In the case of chloroform, the considerable difference between UNC and Lamar breath levels is likely to be the result of the higher chloroform levels in UNC drinking water.

Estimated total daily intake

Drinking water was an important contributor to total intake (air and water) for only two of the seven compounds measured in tap water samples (Table 21). Assuming daily intakes of 10 m^3 of air and 1 L of drinking water, the water accounted for 79% of the chloroform intake and 76% of the bromodichloromethane in-

Table 20. Breath/air ratios[a] for selected volatile organics for student volunteers from two geographical areas.

Participant Number	Benzene	Chloroform	Vinylidene Chloride	1,1,1-Trichloroethane	Trichloroethylene	Tetrachloroethylene	*m*-Dichlorobenzene
Lamar University							
1	0.3	0.2	0.04	0.3	0.01[c]	0.4	0.1[b]
2	0.6	0.2[b]	0.06[c]	0.03	0.2	0.6	0.4
3	0.07	0.1[b]	0.3	0.09	0.03[b]	1.4	0.1[b]
4	0.6	0.04[b]	0.08[c]	0.07[b]	0.4[b]	2.4	0.1[b]
5	0.3	0.06[b]	2.5	0.07[b]	0.1[c]	2.4	0.3[b]
6	0.4	0.08[b]	–	0.02[b]	0.2[b]	0.2[b]	0.1[b]
7	0.4	0.5	0.01[c]	0.04	0.3[b]	0.8	0.4
8	0.2	0.05[b]	0.09[b]	0.01[b]	0.02	0.2	0.8
9	0.3	0.1[b]	2.7	0.1	0.7[b]	0.2	3.3
10	0.4	0.2[b]	0.8	0.1	0.4	1.0	5.4
11	–	0.07[b]	–	0.02[b]	0.2[b]	0.1[b]	0.03[b]
UNC							
1	0.07	0.4	0.3	0.1	0.1	1.4	0.02[b]
2	0.2	0.6	0.5	0.2	0.2	1.2	7.8
3	0.4	1.4	0.6	0.2	0.1	2.1	4.7
4	0.3	0.6	1.1	0.4	0.1	7.2	3.1[b]
5	–	–	1.4	0.1	0.2	1.7	3.5
6	0.5	0.8	1.1	0.2	0.2	0.4	1.7[b]
Arithmetic Mean (± Standard Deviation)							
Lamar University	0.31 ± 0.18	0.15 ± 0.14	0.74 ± 1.1	0.08 ± 0.07	0.23 ± 0.21	0.88 ± 0.83	1.0 ± 1.7
UNC	0.30 ± 0.17	0.72 ± 0.38	0.83 ± 0.42	0.23 ± 0.11	0.17 ± 0.06	2.4 ± 2.5	3.5 ± 2.6
Combined	0.31 ± 0.17	0.33 ± 0.35	0.78 ± 0.86	0.13 ± 0.11	0.21 ± 0.17	1.4 ± 1.7	1.9 ± 2.4

[a]Calculated using $T = \frac{1}{2}$ (LOD + QL); ND = ½ LOD.
[b]Breath value = trace or below quantifiable limit.
[c]Breath value below limit of detection.

Table 21. Estimated daily intake[a] of selected compounds from water compared to air (μg/day).

Subject	Chloroform			Bromodichloromethane			Tetrachloroethylene		
	Air	Water	Percent Intake from Air	Air	Water	Percent Intake from Air	Air	Water	Percent Intake from Air
1	13.9	185	7	16.3	17	49	1750	ND[c]	100
2	15.2	130	10	15.2	23	40	1620	ND	100
3	28 3	550	5	ND[b]	44	3	72.1	T	95
4	83.3	130	39	32.1	22	59	54.1	ND	98
5	52.2	130	29	10.0	24	29	56.5	ND	98
6	40.4	117	26	ND	20	6	49.8	0.07	100
7	48.4	133	27	11.4	22	34	301	ND	100
8	60.2	143	29	37.1	19	66	7180	0.03	100
9	31.7	133	19	8.4	17	33	45.4	ND	98
10	18.6	125	13	ND	13	9	1720	0.01	100
11	48.2	120	29	ND	13	9	92.6	0.03	100
12	78.1	255	23	ND	20	6	24.8	3.8	86
13	50.9	235	18	ND	18	7	26.5	1.8	94
14	37.4	215	15	ND	18	7	20.6	1.8	92
15	31.9	210	13	ND	17	7	12.2	1.8	87
16	175	210	45	43.6	16	73	43.2	1.8	96
17	22.5	190	11	ND	15	8	1270	1.3	100

[a]Assuming 10 m³/day respiration rate and 1 L/day ingestion rate.
[b]ND = < 1.2 μg/10m³.
[c]ND = < 1.1 μg/L.

take. By contrast, drinking water contributed only 7% of the combined (air + water) intake of tetrachloroethylene for the UNC students, and even less for the Lamar students.

Each student's estimated daily intake of all the target compounds from air and drinking water is listed in Table 22. The air values range from 0.3 to 12.4 mg/day, with a geometric mean of 1.6 mg/day and a geometric standard deviation of 3.5. The corresponding geometric mean for the water intake was 0.2 mg/day.

Table 22. Estimated daily intake[a] of 10 volatile organic compounds through air and water for 17 subjects.

Subject	Air μg/day	Water	Total	Percent from Air
30001	12,400	200	12,600	98
30002	2,700	150	2,850	95
30003	12,000	600	12,600	95
30004	400	150	550	73
30005	300	150	450	67
30011	550	140	690	80
30012	1,250	160	1,410	89
30013	9,000	160	9,160	98
30014	300	150	450	67
30015	2,600	140	2,740	95
30016	1,140	130	1,270	90
40001	2,470	280	2,750	90
40002	2,390	260	2,650	90
40003	1,250	240	1,490	84
40011	300	240	540	56
40012	1,240	230	1,470	84
40013	3,800	210	4,010	95

[a]Assuming 10 m³/day and 1 L/day intake rates for air and water.

Summary and Conclusions

This report documents the first field effort of a continuing exposure monitoring program at the United States Environmental Protection Agency. Sampling equipment and analytical protocols were tested on 17 subjects at two universities. The sampling equipment (personal monitors and a specially designed spirometer) and the analytical protocols worked well for the air, breath, and tap water samples.

These results indicate that the concept of making simultaneous direct measurements of individual human exposure to a significant number of volatile organic compounds is feasible. This first effort has resulted in several interesting findings, particularly the wide variability of exposures among a homogenous group of subjects, and the apparent relationship between inhaled and exhaled concentrations of several compounds. These findings could not have been made using standard approaches of ambient monitoring.

Additional studies (Pellizzari *et al.*, 1980; Pellizzari *et al.*, 1981) have been undertaken to extend the personal monitoring approach discussed here to a statistically valid sample of several hundred people in an industrial community.

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