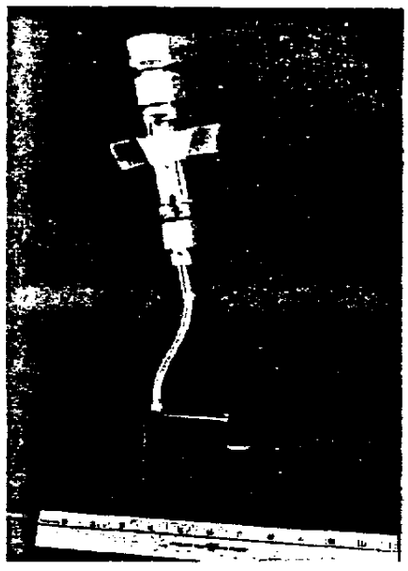

FIG. 1. Tenex cartridge and Dupont pump used in collecting personal air samples.

1). All volatile organics except vinyl chloride were collected using glass tubes 10 cm long and 1.5 cm i.d. containing 1.5 g Tenax-GC adsorbent, using DuPont P-125 pumps at a flow rate sufficient to collect 20–25 liters of air during each of the three periods of the day in the monitoring schedule (Table 2). Samples were analyzed using thermal desorption and purging by helium into a liquid-nitrogen-cooled nickel capillary cryogenic trap, followed by high resolution glass column gas chromatography–mass spectrometry (GC–MS) techniques (Krost *et al.*, 1982). Identities of sample constituents were established by comparing their mass spectra with those in the National Bureau of Standard (NBS) reference libraries. Concentrations of the target compounds were determined by loading an external standard (hexafluorobenzene or perfluorotoluene) at a known concentration on each sample cartridge before analysis. The absolute peak height of the chemical to be measured was then compared to the peak height or area of the standard, using selected characteristic ions in the mass spectra. These heights or areas are proportional to the number of moles of each substance. The proportionality constant, called the relative molar response (RMR), is known or can be determined experimentally for any compound. The mass of the chemical on the cartridge can then be determined from the known mass of the standard, the molecular weights of each chemical, the RMR, and the height or area. The calculated mass can then be corrected for recovery efficiency. The average concentration during the time the subject wore the monitor is then the quotient of the calculated mass (corrected for recovery efficiency) divided by the measured volume of air pulled across the

cartridge, provided that this volume does not exceed the breakthrough volume of the target chemical. Most of the target chemicals had breakthrough volumes well above the 20- 25-liter typical sampling volume. Concentrations of those chemicals whose sample volumes occassionally exceeded their breakthrough volumes were calculated by dividing the mass by the breakthrough volume rather than the sampling volume. This procedure gives an estimate of the mean concentration during the latter part of the sampling period (i.e., the time required to sample the breakthrough volume).

Vinyl chloride was collected using a permeable membrane (dimethylsilicone rubber) badge attached to the subject's lapel. The activated charcoal element was desorbed by carbon disulfide and analyzed using gas chromatography–electron capture detection techniques.

*Breath.* Breath samples were collected on the second and third day of each trip using a specially designed spirometer (Fig. 2). The subject inhaled pure air from Tedlar Bag A while exhaling into Bag B. Roughly 45 liters of exhaled breath were pumped across duplicate Tenax cartridges, using MSA pumps with gas meters to measure the volume. The breath samples were then analyzed by the same methods as the air samples. Some breath samples were taken before and after dinner, to test the contribution of food or beverages to breath concentrations.

*Water.* Samples of drinking water from each subject's home and workplace were collected by the subject. A 5-ml aliquot was transferred to a purge device (Bellar and Lichtenburg, 1974) via a glass syringe. The water was purged onto a Tenax GC trap at a flow rate of 40 ml/min. The compounds were then desorbed onto an analytical column (1.8 × 2.0 mm 0.2% carbowax 1500 on 60/80 Carbopack C). Both a Hall Electrolytic Conductivity Detector and flame ionization detector were operated simultaneously to detect the halogenated and aromatic compounds.

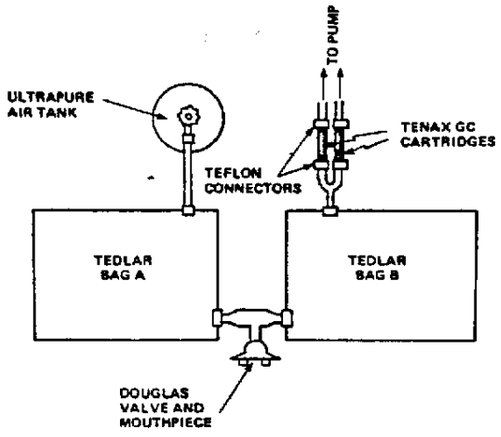


FIG. 2. Schematic diagram of the spirometer.

*Food.* Because no validated protocols exist for collecting, preparing, storing, and shipping food items from the home, only samples collected from community grocery stores were analyzed. The objective was to determine whether exposures through food were sufficiently important to require the collection of individual food samples— and the concomitant validation of protocols—in the large-scale study to follow. About 40 food items were collected from a community grocery on four separate occasions—two in New Jersey and two in North Carolina. All foods were selected and prepared according to U.S. Food and Drug Administration (FDA) Total Diet Study Adult Market Basket specifications (Entz *et al.*, 1982). Four composites (dairy, meats, fatty foods, and beverages) from each of the four sampling trips were analyzed for volatiles at the FDA laboratory in Washington, D.C. using FDA automated head space equipment and protocols. Portions of each individual food item used in the composites were held in reserve for additional sampling to determine the source of elevated concentrations in the composite.

## QUALITY ASSURANCE

The primary laboratory for the air, breath, and water analyses was Research Triangle Institute (RTI); and for the food analyses, FDA. All analyses except those for food were repeated at independent laboratories to estimate the uncertainty of the data. From each batch of 30–50 Tenax cartridges, about 10% were stored at the laboratory (lab blanks) and another 10% were shipped to the field but not exposed (field blanks). These cartridges were then analyzed at the same time as the exposed samples to determine background levels on the Tenax batch and also any contamination that may have occurred during transportation to or from the field.

Another 10% of the cartridges were spiked with known amounts of each of the target compounds. Again both laboratory and field spikes were prepared and analyzed with the field samples to determine the loss of the compounds with time and travel.

Replicate samples were also obtained for 100% of the breath samples and 10% of the air and water samples. Each sample train was internally audited before, during and after sampling in each geographic area. External audits were also performed by a team from EPA's Environmental Monitoring Systems Laboratory in Research Triangle Park, North Carolina. Flow rates were checked with a bubble meter and battery charges on personal monitors were verified. A chain-of-custody record was kept for each sample.

All quality control procedures, including preparation of blank and spiked laboratory and field samples and duplicate samples for a total of 70 air, water, and breath samples, are documented in the TEAM Study quality assurance (QA) report (Sparacino *et al.*, 1982b).

*Air.* Equipment problems at the designated QA laboratory, the Environmental Monitoring Systems Laboratory at Research Triangle Park, NC (EMSL-RTP), prevented completion of the planned number of 10 QA samples. Four samples were eventually analyzed, but these had been stored longer than the recommended upper limit of 4 weeks. Reasonable agreement was obtained, but more

samples analyzed in a more timely fashion would be required to estimate interlaboratory precision. Contamination of the Tenax by benzene during preparation, storage, shipment or analysis was evident on many air and breath blanks and spikes; thus no quantitative results for benzene in air or breath are presented. Duplicate air analysis for three prevalent target chemicals resulted in typical coefficients of variation of 25–50% (Table 3).

The QA laboratory for the vinyl chloride analyses was REAL, Inc. of New Orleans, La. All 24 field QA samples were below the limit of detection, although spiked laboratory and field samples indicated that the analysis method was capable of detecting levels above 10 $\mu g/m^3$.

*Breath.* The QA laboratory was IIT Research Institute of Chicago, Ill. Thirteen paired QA breath samples agreed to within 60–70% for chloroform and tetrachloroethylene. Duplicate analyses for three prevalent chemicals agreed to within 25–40% (Table 3). Percentage recoveries ranged from 80 to 100%, with the exceptions of chloroform (~65%) and ethylene dichloride (~40–60%) (Table 4).

*Water (purge and trap).* Twenty QA samples of drinking water were analyzed by the Environmental Monitoring Systems Laboratory at Cincinnati, Ohio. QA analyses agreed with the primary lab analyses both qualitatively and quantitatively with average errors of ±30%.

## RESULTS

### *Occurrence and Concentration of Target Chemicals*

The broad-spectrum analyses identified over 200 chemicals, of which 100 were $C_6$ to $C_{15}$ hydrocarbon isomers. One hundred twenty other chemicals were identified in the 8 air samples, 12 breath samples, and 1 water sample collected in New Jersey (Table 5). Of these, 38 appeared in all three media, 23 in breath only, 19 in air only, and 12 in water only. The average number of chemicals identified in nine personal air samples from both locations was 149 (±36); in two water samples was 116 (±24); and in 13 breath samples was 101 (±18).

Median levels and ranges of the target chemicals in air, breath, and drinking water are provided for the New Jersey subjects (Table 6) and the North Carolina

TABLE 3
COEFFICIENTS OF VARIATION OF DUPLICATE AIR AND BREATH SAMPLES FOR THREE PREVALENT TARGET CHEMICALS

| Compound | Breath | | Air | |
|---|---|---|---|---|
| | $N^a$ | CV[b] | $N$ | CV |
| Chloroform | 46 | 42 | 14 | 52 |
| 1,1,1-Trichloroethylene | 38 | 38 | 17 | 34 |
| Tetrachloroethylene | 50 | 28 | 17 | 26 |

[a] Number of duplicate pairs.

[b] Calculated by $\frac{1}{N}\sum_i \frac{\text{SD}(D_i)}{\text{Mean}(D_i)} \times 100$, where $D_i$ is the $i$th set of duplicates.

TABLE 4
MEAN PERCENTAGE RECOVERIES OF STANDARDS FROM LAB AND FIELD CONTROLS FOR BREATH: NEW JERSEY SUBJECTS

| Compound | Field controls | | | | Lab controls | | | |
|---|---|---|---|---|---|---|---|---|
| | *N* | Mean | SD | CV | *N* | Mean | SD | CV |
| Benzene | 7 | 88 | 43 | 49 | 8 | 106 | 33 | 31 |
| Chloroform | 9 | 66 | 40 | 61 | 12 | 63 | 22 | 34 |
| 1,2-Dichloroethane | 11 | 42 | 12 | 29 | 12 | 59 | 16 | 27 |
| Tetrachloroethylene | 11 | 82 | 26 | 31 | 12 | 81 | 16 | 20 |
| Chlorobenzene | 11 | 98 | 42 | 43 | 12 | 78 | 22 | 29 |

TABLE 5
SUMMARY OF THE FREQUENCY OF OCCURRENCE OF CHEMICALS BY MEDIUM BASED ON RESULTS OF THE TOTAL EXPOSURE ASSESSMENT METHODOLOGY (TEAM) STUDY CONDUCTED IN NEW JERSEY

| Chemical | Frequency of occurrence[a] | | |
|---|---|---|---|
| | Air (*N* = 8) | Breath (*N* = 12) | Water (*N* = 1) |
| Carbon dioxide | 8 | 12 | 1 |
| Dichlorodifluoromethane | 7 | 12 | 0 |
| Xenon | 6 | 8 | 1 |
| Isobutane | 5 | 0 | 0 |
| *n*-Butane | 4 | 2 | 0 |
| Isopentane | 6 | 4 | 0 |
| Fluorotrichloromethane | 8 | 12 | 1 |
| Acetone | 8 | 11 | 1 |
| *n*-Pentane | 4 | 5 | 1 |
| Methylene chloride | 8 | 10 | 1 |
| Freon 113 | 3 | 3 | 1 |
| Methyl ethyl ketone | 3 | 5 | 1 |
| 3-Methylpentane | 5 | 6 | 1 |
| *n*-Hexane | 8 | 9 | 1 |
| Ethyl acetate | 5 | 7 | 0 |
| 1,1,1-Trichloroethane | 8 | 12 | 1 |
| Benzene | 8 | 12 | 1 |
| Cyclohexane | 4 | 8 | 0 |
| 3-Methylhexane | 6 | 6 | 1 |
| Trichloroethylene | 8 | 10 | 1 |
| *n*-Heptane | 8 | 10 | 1 |
| Methyl Isobutyl ketone | 1 | 0 | 0 |
| Toluene | 8 | 12 | 1 |
| Tetrachloroethylene | 8 | 12 | 1 |
| *n*-Octane | 6 | 7 | 1 |
| Hexamethylcyclotrisiloxane | 5 | 9 | 1 |
| Ethylbenzene | 8 | 12 | 1 |
| Styrene | 7 | 9 | 1 |
| *o*-Xylene | 4 | 5 | 0 |
| *n*-Nonane | 8 | 6 | 1 |
| Isopropylbenzene | 7 | 8 | 0 |
| Benzaldehyde | 6 | 6 | 1 |

TABLE 5—*Continued*

| Chemical | Frequency of occurrence[a] | | |
|---|---|---|---|
| | Air ($N$ = 8) | Breath ($N$ = 12) | Water ($N$ = 1) |
| *n*-Propylbenzene | 7 | 6 | 1 |
| *n*-Decane | 8 | 4 | 1 |
| Octamethylcyclotetrasiloxane | 6 | 6 | 1 |
| $C_{15}$-decahydronaphthalene (tent.) | 1 | 0 | 0 |
| *n*-Undecane | 7 | 8 | 1 |
| Naphthalene | 8 | 8 | 1 |
| Siloxane | 4 | 10 | 0 |
| *n*-Dodecane | 7 | 6 | 0 |
| 2-Methylnaphthalene | 6 | 0 | 0 |
| 1-Methylnaphthalene | 6 | 1 | 0 |
| *n*-Tridecane | 6 | 5 | 0 |
| Biphenyl | 4 | 0 | 0 |
| 2,2,4-Trimethylpenta-1,3-diol-isobutyrate | 1 | 0 | 0 |
| *n*-Tetradecane | 7 | 5 | 1 |
| 2,6-Di-*t*-butyl-4-methylphenol | 1 | 1 | 1 |
| *n*-Pentadecane | 5 | 2 | 1 |
| Phthalate | 3 | 1 | 0 |
| 2,2,4-Trimethylpenta-1,3-diol-di-isobutyrate | 8 | 9 | 0 |
| 2-Methyl-1,3-butadiene | 0 | 1 | 0 |
| 1,1,2-Trifluoro-1,2,2-trichloroethane | 2 | 4 | 0 |
| 2,5-Dimethylfuran | 0 | 7 | 0 |
| 2-Vinylfuran | 0 | 1 | 0 |
| 1,1-Diethoxyethane | 0 | 1 | 0 |
| *N,N*-dimethylacetamide | 0 | 8 | 0 |
| Phenol | 0 | 9 | 1 |
| Phenyl-*n*-propyl ether (tent.) | 0 | 1 | 0 |
| Acetophenone | 4 | 5 | 1 |
| Ethyl benzoate | 0 | 1 | 0 |
| 2-Heptane | 0 | 1 | 0 |
| Carbonyl sulphide | 1 | 0 | 0 |
| Isoprene | 1 | 1 | 0 |
| Carbon disulfide | 1 | 0 | 0 |
| Cyclopentene | 1 | 0 | 0 |
| 1,1-Dichloroethane | 1 | 0 | 1 |
| 2-Methylpentane | 3 | 3 | 1 |
| Chloroform | 2 | 7 | 1 |
| Carbon tetrachloride | 4 | 6 | 1 |
| 2-Methylhexane | 4 | 4 | 1 |
| 2,3-Dimethylpentane | 3 | 0 | 0 |
| *o*-Dichlorobenzene | 1 | 1 | 0 |
| Decahydronaphthalene | 1 | 0 | 0 |
| Δ-Tridecane | 1 | 0 | 0 |
| Methylcyclopentane | 1 | 4 | 0 |
| Methylcyclohexane | 1 | 2 | 0 |
| 4-Methyl-2-pentanone | 2 | 0 | 0 |
| 2,2,4-Trimethylpenta-1,3-diol-1-isobutyrate | 3 | 4 | 0 |
| 2,6-Di-*t*-butyl-*p*-benzoquinone | 1 | 0 | 1 |
| 1,2-Dichloro-1,1,1,2-tetrafluoroethane | 0 | 2 | 0 |
| Tetramethylsilane | 1 | 4 | 1 |

TABLE 5—*Continued*

| Chemical | Frequency of occurrence[a] | | |
|---|---|---|---|
| | Air ($N$ = 8) | Breath ($N$ = 12) | Water ($N$ = 1) |
| *n*-Butanol | 0 | 3 | 1 |
| Chlorobenzene | 0 | 3 | 1 |
| 2,2,4-Trimethylpenta-1,3-diol-1-di-isobutyrate | 0 | 1 | 1 |
| 2-Butanol (tent.) | 1 | 0 | 1 |
| Indan | 1 | 0 | 0 |
| Tripropylene alycol (tent.) | 1 | 0 | 0 |
| *n*-Butyl-*n*-butanoate (tent.) | 1 | 0 | 0 |
| Diphenyl ether | 1 | 0 | 0 |
| Diethyl phthalate | 1 | 2 | 1 |
| Ethyl acetone | 0 | 1 | 0 |
| Isopropanol | 2 | 7 | 0 |
| Thiapentane | 0 | 1 | 0 |
| Chlorodifluoromethane | 0 | 1 | 0 |
| Cyclopentane | 0 | 1 | 0 |
| 3-Methyl-2-pentanone | 0 | 1 | 0 |
| Phenyl *n*-propyl ether | 0 | 1 | 0 |
| 1,2-Dichloro-1,1,2,2-tetrafluoroethane | 1 | 1 | 0 |
| Benzoic acid | 0 | 1 | 0 |
| Methylcyclobutane | 1 | 0 | 0 |
| 1-Butanol | 1 | 0 | 0 |
| Benzene-$d_6$ | 0 | 1 | 0 |
| Cyclohexane-$d_{10}$ | 0 | 1 | 0 |
| Bromodichloromethane | 0 | 0 | 1 |
| 2-Hexane | 0 | 1 | 0 |
| Isopropoxyethanol | 0 | 1 | 0 |
| 2-Methylfuran | 0 | 1 | 0 |
| 2-Undecane | 0 | 1 | 0 |
| *n*-Pentanal | 0 | 1 | 0 |
| Vinylidine chloride | 0 | 0 | 1 |
| Silane | 0 | 0 | 1 |
| 3-Methylheptane | 0 | 0 | 1 |
| Dibromochloromethane | 0 | 0 | 1 |
| 2,3-Dimethylpentanal (tent.) | 0 | 0 | 1 |
| Bromoform | 0 | 0 | 1 |
| Benzonitrile | 0 | 0 | 1 |
| *n*-Octanol | 0 | 0 | 1 |
| 2-Ethyl-1-hexanol | 0 | 0 | 1 |
| *n*-Nonanal | 0 | 0 | 1 |
| *n*-Dodecanal (tent.) | 0 | 0 | 1 |
| 2,6-Di-*t*-butyl-bromomethylphenol | 0 | 0 | 1 |

[a] In summarizing the frequency of occurrence, those chemicals which were detected twice in the same sample but at different elution temperatures are assigned a frequency of occurrence of 1 for that sample. $N$ = total number of samples.

TABLE 6
SUMMARY STATISTICS BY MEDIUM FOR NINE NEW JERSEY SUBJECTS

| Medium | Compound | No. of samples[a] | No. below limit of detection[b] | No. at trace[c] | Median | Range |
|---|---|---|---|---|---|---|
| Air ($\mu g/m^3$) | Vinyl chloride | 106 | 106 | 0 | 1.1 | 0.63 – 2.84 |
| | Vinylidene chloride | No data | | | | |
| | Chloroform | 165 | 31 | 2 | 2.1 | 0.03 – 129.00 |
| | 1,2-Dichloroethane | 163 | 41 | 88 | 0.65 | 0.10 – 10.20 |
| | 1,1,1-Trichloroethane | 165 | 0 | 1 | 9.1 | 0.72 – 708.00 |
| | Carbon tetrachloride | 165 | 2 | 95 | 1.0 | 0.19 – 736.00 |
| | Bromodichloromethane | 164 | 136 | 16 | 0.44 | 0.10 – 13.40 |
| | Trichloroethylene | 164 | 1 | 38 | 2.8 | 0.43 – 127.00 |
| | 1,1,2-Trichloroethane | 161 | 151 | 7 | 0.35 | 0.14 – 34.70 |
| | Tetrachloroethylene | 163 | 1 | 14 | 7.2 | 0.57 – 250.00 |
| | Chlorobenzene | 160 | 45 | 64 | 0.61 | 0.05 – 26.50 |
| | Benzene[d] | 162 | 13 | 0 | —[d] | —[d] |
| | Dichlorobenzene(s) | No data | | | | |
| Breath ($\mu g/m^3$) | Vinyl chloride | No data | | | | |
| | Vinylidene chloride | 14 | 14 | 0 | | |
| | Chloroform | 49 | 7 | 2 | 3.5 | 0.09 – 53.00 |
| | 1,2-Dichloroethane | 49 | 38 | 11 | 0.1 | 0.12 – 0.69 |
| | 1,1,1-Trichloroethane | 48 | 1 | 8 | 4.8 | 0.12 – 85.00 |
| | Carbon tetrachloride | 49 | 22 | 22 | 0.3 | 0.10 – 46.50 |
| | Bromodichloromethane | 49 | 49 | 0 | 0.17 | 0.17 – 0.20 |
| | Trichloroethylene | 49 | 6 | 24 | 0.7 | 0.10 – 24.50 |
| | 1,1,2-Trichloroethane | 49 | 44 | 4 | 0.2 | 0.07 – 5.13 |
| | Tetrachloroethylene | 49 | 0 | 7 | 10.5 | 0.64 – 202.00 |
| | Chlorobenzene | 49 | 22 | 21 | 0.2 | 0.07 – 8.15 |
| | Benzene[d] | 47 | 8 | 0 | —[d] | —[d] |
| | Dichlorobenzene(s) | 18 | 18 | 0 | 0.1 | 0.10 – 0.10 |
| Water[e] (home) (ng/ml) | Vinyl chloride | No data | | | | |
| | Vinylidene chloride | No data | | | | |
| | Chloroform | 75 | 0 | 0 | 128.0 | 11.0 – 225.00 |
| | 1,2-Dichloroethane | 75 | 75 | 0 | 0.02 | 0.005 – 0.05 |
| | 1,1,1-Trichloroethane | 75 | 41 | 2 | 0.02 | 0.02 – 3.50 |
| | Carbon tetrachloride[f] | 13 | 1 | 3 | 0.05 | 0.01 – 0.34 |
| | Bromodichloromethane | 75 | 0 | 0 | 18.0 | 4.40 – 42.00 |
| | Trichloroethylene | 75 | 40 | 3 | 0.02 | 0.02 – 5.40 |
| | 1,1,2-Trichloroethane[f] | 13 | 13 | 0 | 0.01 | 0.01 – 0.01 |
| | Tetrachloroethylene | 75 | 36 | 7 | 0.07 | 0.02 – 6.50 |
| | Chlorobenzene | 75 | 75 | 0 | 0.03 | 0.02 – 0.02 |
| | Benzene[d] | 75 | 69 | 0 | —[d] | —[d] |
| | Dichlorobenzene(s) | No data | | | | |
| Water[e] (work) (ng/ml) | Vinyl chloride | No data | | | | |
| | Vinylidene chloride | No data | | | | |
| | Chloroform | 45 | 1 | 0 | 127.0 | 0.02 – 230.00 |
| | 1,2-Dichloroethane | 45 | 45 | 0 | 0.02 | 0.02 – 0.02 |
| | 1,1,1-Trichloroethane | 45 | 22 | 3 | 0.07 | 0.02 – 1.60 |
| | Carbon tetrachloride | No data | | | | |
| | Bromodichloromethane | 45 | 1 | 0 | 13.0 | 0.02 – 37.00 |

TABLE 6—*Continued*

| Medium | Compound | No. of samples[a] | No. below limit of detection[b] | No. at trace[c] | Median | Range |
|---|---|---|---|---|---|---|
| | Trichloroethylene | 45 | 19 | 3 | 0.11 | 0.02–3.50 |
| | 1,1,2-Trichloroethane | No data | | | | |
| | Tetrachloroethylene | 45 | 17 | 6 | 0.07 | 0.02–6.50 |
| | Chlorobenzene | 45 | 45 | 0 | 0.03 | 0.03–0.03 |
| | Benzene[d] | 45 | 41 | 0 | —[d] | —[d] |
| | Dichlorobenzene(s) | No data | | | | |

[a] Maximum number of individuals = 9; multiple observations per individual. Duplicates averaged.
[b] For duplicates, both had to be below the LOD to be counted.
[c] For duplicates, at least one had to be at trace and the other at trace or below to be counted.
[d] Due to difficulties in chemical analysis, data were not analyzed.
[e] By purge and trap method.
[f] By Master Analytical Scheme analysis.

subjects (Table 7). Results for the food composites collected in each community are summarized (Table 8).

*Air.* Ten of eleven target compounds were present in air; only vinyl chloride was never found, perhaps because its limit of detection (LOD) was >20 times the LOD of the other chemicals. Six of the ten were found in more than 75% of both the New Jersey samples (Fig. 3) and the North Carolina samples. Typical geometric means were 1–10 $\mu g/m^3$ in both locations. However, the range was often large; maximum concentrations exceeded 100 $\mu g/m^3$ for five chemicals in personal air samples from the New Jersey participants (Fig. 4) and for two chemicals in the North Carolina samples.

*Breath.* Nine of twelve target compounds were found in breath samples from each group of participants. Six of these chemicals were present in more than 50% of the breath samples from New Jersey (Fig. 3) and North Carolina. Again the geometric means were in the 1–10 $\mu g/m^3$ range, with the exception of chloroform in breath samples of the North Carolina group, which exceeded 30 $\mu g/m^3$.

*Water.* Municipal surface water sources were used by all subjects but one, who used bottled water. Two chemicals were predominant in drinking water samples: chloroform and bromodichloromethane. Median levels of chloroform exceeded 100 $\mu g$/liter in both groups; median levels of bromodichloromethane were in the 15–20 $\mu g$/liter range. No other chemicals attained median concentrations as high as 1 $\mu g$/liter. Summer concentrations of each trihalomethane were ~five times the fall levels (Fig. 5).

*Food.* Of the eight target compounds, chloroform and bromodichloromethane were found in most beverage composites and in a dairy composite; 1,1,1-trichloroethane and trichloroethylene were found in several fatty food composites. Further investigation of the individual food items comprising the fatty food composite showed that the source of the trichloroethylene was margarine (Fig. 6). Beverages are likely to be an important route of exposure of chloroform and bromodichloromethane. However, the solid food samples appeared to have little

TABLE 7
SUMMARY STATISTICS BY MEDIUM FOR THREE NORTH CAROLINA SUBJECTS

| Medium | Compound | No. of samples[a] | No. below limit of detection[b] | No. at trace[c] | Median | Range |
|---|---|---|---|---|---|---|
| Air ($\mu g/m^3$) | Vinyl chloride | 32 | 32 | 0 | | 0.70 – 2.26 |
| | Vinylidene chloride | No data | | | | |
| | Chloroform | 59 | 9 | 0 | 3.4 | 0.09 – 17.60 |
| | 1,2-Dichloroethane | 60 | 31 | 27 | | 0.10 – 1.58 |
| | 1,1,1-Trichloroethane | 61 | 4 | 2 | 4.5 | 0.13 – 236.00 |
| | Carbon tetrachloride | 61 | 7 | 45 | | 0.16 – 4.66 |
| | Bromodichloromethane | 60 | 48 | 7 | | 0.10 – 3.66 |
| | Trichloroethylene | 60 | 14 | 28 | 0.66 | 0.09 – 5.54 |
| | 1,1,2-Trichloroethane | 60 | 59 | 0 | | 0.14 – 0.94 |
| | Tetrachloroethylene | 61 | 4 | 13 | 2.9 | 0.29 – 125.00 |
| | Chlorobenzene | 60 | 47 | 7 | | 0.05 – 3.66 |
| | Benzene[d] | 56 | 12 | 0 | | |
| | *m* + *p*-Dichlorobenzene | No data | | | | |
| Breath ($\mu g/m^3$) | Vinyl chloride | No data | | | | |
| | Vinylidene chloride | 5 | 4 | 1 | | 1.25 – 6.25 |
| | Chloroform | 17 | 1 | 0 | 50 | 0.11 – 685.00 |
| | 1,2-Dichloroethane | 17 | 16 | 1 | | 0.12 – 0.50 |
| | 1,1,1-Trichloroethane | 17 | 0 | 8 | 0.61 | 0.29 – 7.65 |
| | Carbon tetrachloride | 17 | 17 | 0 | | 0.10 – 0.30 |
| | Bromodichloromethane | 17 | 17 | 0 | | 0.14 – 2.20 |
| | Trichloroethylene | 17 | 8 | 9 | | 0.13 – 2.02 |
| | 1,1,2-Trichloroethane | 17 | 17 | 0 | | 0.21 – 0.20 |
| | Tetrachloroethylene | 17 | 0 | 3 | 4.2 | 1.19 – 60.00 |
| | Chlorobenzene | 17 | 13 | 2 | | 0.09 – 3.00 |
| | Benzene[d] | 17 | 5 | 0 | —[d] | —[d] |
| | *m* + *p*-Dichlorobenzene | 5 | 1 | 4 | | 0.09 – 0.76 |
| Water[e] (home) (ng/ml) | Vinyl chloride | No data | | | | |
| | Vinylidene chloride | No data | | | | |
| | Chloroform | 30 | 0 | 0 | 120 | 75.0 – 191.0 |
| | 1,2-Dichloroethane | 30 | 29 | 0 | | 0.02 – 0.19 |
| | 1,1,1-Trichloroethane | 30 | 23 | 0 | | 0.02 – 1.90 |
| | Carbon tetrachloride | No data | | | | |
| | Bromodichloromethane | 30 | 0 | 0 | 16 | 12.0 – 20.0 |
| | Trichloroethylene | 30 | 18 | 0 | | 0.02 – 1.18 |
| | 1,1,2-Trichloroethane | No data | | | | |
| | Tetrachloroethylene | 30 | 21 | 2 | | 0.02 – 0.44 |
| | Chlorobenzene | 30 | 28 | 0 | | 0.03 – 3.10 |
| | Benzene | 15 | 15 | 0 | | 0.04 – 0.04 |
| | *m* + *p*-Dichlorobenzene | No data | | | | |
| Water[e] (work) (ng/ml) | Vinyl chloride | No data | | | | |
| | Vinylidene chloride | No data | | | | |
| | Chloroform | 18 | 1 | 0 | 110 | 0.02 – 148.00 |
| | 1,2-Dichloroethane | 18 | 17 | 0 | | 0.02 – 0.13 |
| | 1,1,1-Trichloroethane | 18 | 16 | 0 | | 0.02 – 0.80 |
| | Carbon tetrachloride | No data | | | | |
| | Bromodichloromethane | 18 | 1 | 0 | 14 | 0.02 – 20.00 |
| | Trichloroethylene | 18 | 13 | 0 | | 0.02 – 1.48 |

TABLE 7—*Continued*

| Medium | Compound | No. of samples[a] | No. below limit of detection[b] | No. at trace[c] | Median | Range |
|---|---|---|---|---|---|---|
| | 1,1,2-Trichloroethane | No data | | | | |
| | Tetrachloroethylene | 18 | 12 | 2 | | 0.02–0.43 |
| | Chlorobenzene | 18 | 18 | 0 | | 0.25–0.25 |
| | Benzene | 9 | 8 | 0 | | 0.04–24.00 |

[a] Duplicates have been averaged.
[b] For duplicates, both measures had to be below the LOD in order to be counted.
[c] For duplicates, at least one measure had to be at trace and the other at trace or below, in order to be counted.
[d] Due to methodological difficulties in chemical analysis, statistical analysis was not performed.
[e] By purge and trap method.

potential for exposure, with the possible exception of trichloroethylene in margarine.

*Temporal and Occupational Effects*

Air and breath levels varied considerably from day to day and with the season (Table 9). For the nine New Jersey residents, chloroform in breath was much higher ($P < 0.01$) in July than in December, corresponding to similar differences in air and drinking water concentrations. Tetrachloroethylene and 1,1,1-trichloroethane were significantly higher in breath in July and December than in September. Air levels of carbon tetrachloride and 1,2-dichloroethane were significantly lower in December than in July. Weekday air exposures were significantly ($P < 0.01$) higher than weekend exposures for trichloroethylene, tetrachloroethylene, and 1,1,1-trichloroethane, indicating a possible source in the working or commuting environment. Time of day was a relatively unimportant variable, with only 1,1,1-trichloroethane showing a significant decrease between daytime and night-time values. Occupational exposures were evident for one individual (the sewage treatment plant worker), who had many of the highest values noted for chloroform, carbon tetrachloride, tetrachloroethylene, and trichloroethylene in air and breath. However, the mean exposures for all five workers in oil, chemical, and sewage treatment plants were not greatly different (about a factor of 2) from the exposures of the four "unexposed" New Jersey subjects.

*Total Exposures*

For the four most prevalent compounds, mean daily exposures were estimated for each subject, assuming an air intake of 10 cubic meters/day and a water intake of 1 liter/day (Table 10). (Of course, air and water intakes vary by activity level—the values selected are conservatively low for sedentary adults. Values of 20 $m^3$/day and 2 liters/day have been employed in EPA risk assessments.) Three of the four chemicals—trichloroethylene, tetrachloroethylene, and 1,1,1-trichloroethane—were transmitted almost exclusively through air. The fourth (chloroform)

TABLE 8

VOLATILE HALOCARBONS IN FOOD AND BEVERAGE COMPOSITES FROM NORTH CAROLINA AND NEW JERSEY[a]

| Sample location | Composite | Chloroform | 1,1,1-Trichloroethane | Bromodichloromethane | Carbon tetrachloride | Trichloroethylene | Tetrachloroethylene | Ethylene dibromide |
|---|---|---|---|---|---|---|---|---|
| NC | Dairy | —[b] | — | — | — | — | — | — |
| | Meats | — | — | — | — | — | — | — |
| | Fats | — | — | — | — | 920[c] | — | — |
| | Beverages | 32 | — | 1.0 | — | — | — | — |
| NC | Dairy | — | — | — | — | — | — | — |
| | Meats | — | — | — | — | — | — | — |
| | Fats | — | — | — | — | — | — | — |
| | Beverages | 12 | — | — | — | — | — | — |
| NJ | Dairy | — | — | — | — | — | — | — |
| | Meats | — | — | — | — | — | — | — |
| | Fats | — | — | — | — | 55 | — | — |
| | Beverages | 10 | — | — | — | — | — | — |
| NJ | Dairy | — | — | — | — | — | — | — |
| | Meats | — | — | — | — | — | — | — |
| | Fats | — | — | — | — | — | — | — |
| | Beverages | 6 | — | — | — | — | — | — |

[a] Not corrected for method recovery.
[b] Not detected.
[c] All values in ppb.

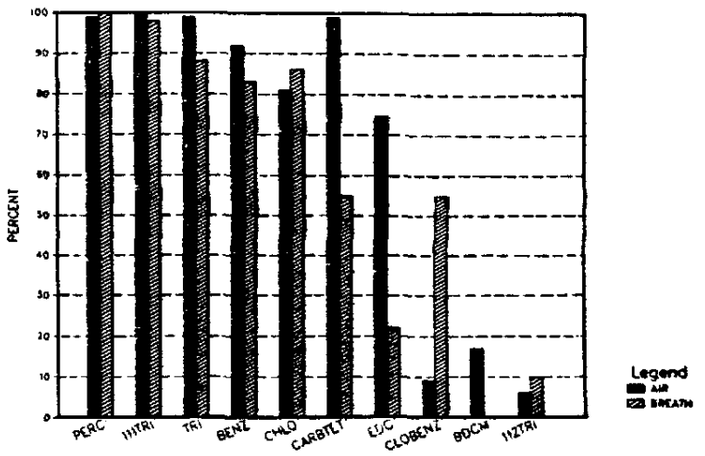


FIG. 3. Percentage frequencies of detection for target compounds (10 volatile organics) in personal air and breath samples for the nine New Jersey subjects. Key: PERC = tetrachloroethylene, 111TRI = 1,1,1-trichloroethane, TRI = trichloroethylene, BENZ = benzene, CARBTET = carbon tetrachloride, CHLO = chloroform, EDC = 1,2-dichloroethane, CLOBENZ = chlorobenzene, BDCM = bromodichloromethane, and 112TRI = 1,1,2-trichloroethane.

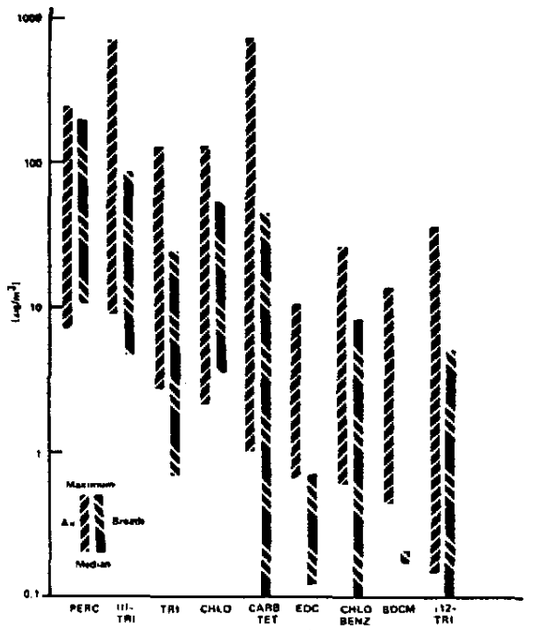




FIG. 4. Range of concentrations of nine volatile organics for New Jersey participants (165 personal air samples, 49 exhaled breath samples). For key to chemical names see caption to Fig. 3.

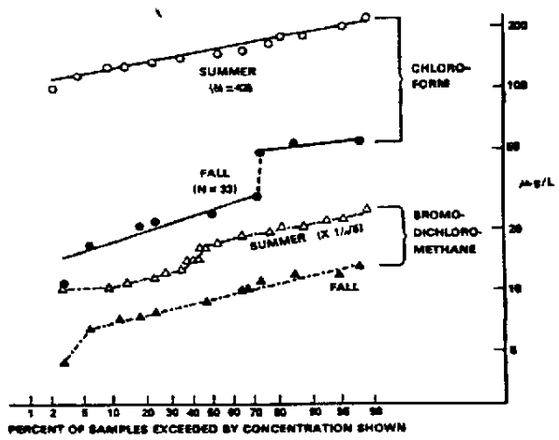


FIG. 5. Cumulative distribution of trihalomethane concentrations in drinking water, by season, for the nine New Jersey participants. Plotted on log-normal probability paper.

was transmitted mainly through water, but a significant fraction (32 ± 18%) came through the air. If the contribution of chloroform from beverages is included, the relative contribution from air would decrease. Mean exposures ranged over more than an order of magnitude for each chemical.

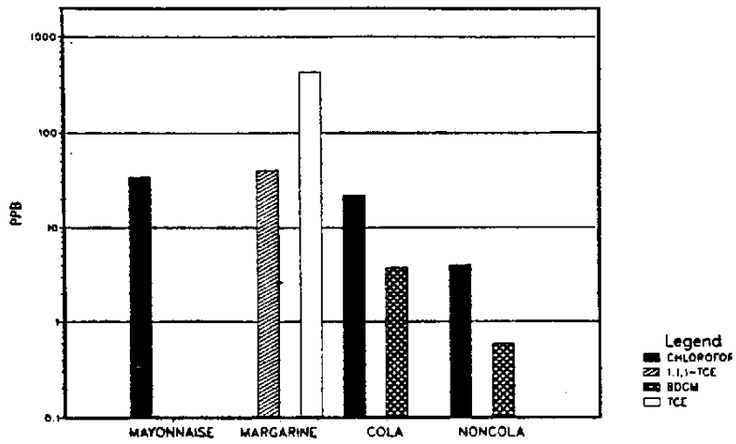


FIG. 6. Volatiles in individual fatty foods and beverages from one site in New Jersey. The only food (of 40 items surveyed) with detectable levels of trichloroethylene and 1,1,1-trichloroethane was margarine. Both chloroform and bromodichloromethane appeared to be at higher concentrations in colas than in noncola soft drinks.

TABLE 9

ADJUSTED GEOMETRIC MEANS FOR VOLATILES BY MEDIUM, TRIP, EXPOSURE, TYPE OF DAY, AND TIME OF DAY FROM NEW JERSEY DATA

| Medium | Compound | Trip (Season) | | | Occupational | | Type of day | | Time of day | | | No. of samples |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | July | Sept. | Dec. | Exp. | Unexp | WD | WE | Work | Even | Sleep | |
| Breath ($\mu g/m^3$) | Chloroform | 6.2 | 3.7 | .40 | 2.1 | 2.1 | 1.8 | 2.5 | | | | 49 |
| | | | (0.01)[a] | | (NS) | | (NS) | | | | | (9)[b] |
| | 1,1,1-Trichloroethane | 4.4 | 1.7 | 6.2 | 2.6 | 5.3 | 4.5 | 2.9 | | | | 48 |
| | | | (0.05) | | (0.10) | | (NS) | | | | | (9) |
| | Tetrachloroethylene | 10.1 | 4.0 | 8.7 | 9.8 | 4.6 | 10.0 | 4.8 | | | | 49 |
| | | | (0.05) | | (0.05) | | (0.10) | | | | | (7) |
| Air ($\mu g/m^3$) | Chloroform | 3.1 | 1.1 | 1.1 | 2.2 | 1.1 | 1.4 | 1.7 | 1.6 | 1.8 | 1.3 | 165 |
| | | | (0.01) | | (0.01) | | (NS) | | | (NS) | | (33) |
| | Carbon tetrachloride | 1.9 | 1.4 | 1.1 | 1.5 | 1.3 | 1.4 | 1.4 | 1.6 | 1.4 | 1.2 | 165 |
| | | | (0.05) | | (NS) | | (NS) | | | (NS) | | (97) |
| | 1,2-Dichloroethane | .82 | .81 | .56 | .74 | .71 | .81 | .65 | .60 | .85 | .74 | 163 |
| | | | (0.05) | | (NS) | | (0.05) | | | (0.05) | | (129) |
| | 1,1,1-Trichloroethane | 9.4 | 9.1 | 10.7 | 8.6 | 11.4 | 13.7 | 6.9 | 17.3 | 5.8 | 9.0 | 164 |
| | | | (NS) | | (0.10) | | (0.01) | | | (0.01) | | (1) |
| | Trichloroethylene | 3.9 | 3.0 | 2.7 | 3.4 | 3.0 | 4.6 | 2.2 | 3.2 | 3.2 | 3.2 | 163 |
| | | | (NS) | | (NS) | | (0.01) | | | (NS) | | (39) |
| | Tetrachloroethylene | 6.8 | 6.7 | 8.1 | 8.3 | 5.9 | 10.1 | 5.1 | 8.2 | 6.8 | 6.7 | 163 |
| | | | (NS) | | (0.05) | | (0.01) | | | (NS) | | (15) |
| | Chlorobenzene | .60 | .72 | .40 | .69 | .44 | .57 | .56 | .59 | .66 | .44 | 159 |
| | | | (0.10) | | (0.05) | | (NS) | | | (NS) | | (109) |
| Water (home) (ng/ml) | Chloroform | 148.4 | | 28.8 | | | 70.8 | 60.9 | 64.1 | 67.4 | | 75 |
| | | | (0.01) | | | | (0.01) | | (NS) | | | (0) |
| | 1,1,1-Trichloroethane | .12 | | .08 | | | .06 | .06 | .07 | .07 | | 75 |
| | | | (0.01) | | | | (NS) | | (NS) | | | (43) |
| | Bromodichloromethane | 25.5 | | 8.8 | | | 16.4 | 13.5 | 14.0 | 15.5 | | 75 |
| | | | (0.01) | | | | (0.01) | | (0.10) | | | (0) |
| | Trichloroethylene | .05 | | .09 | | | .06 | .07 | .06 | .06 | | 75 |
| | | | (0.05) | | | | (NS) | | (NS) | | | (43) |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tetrachloroethylene | .09 | (NS) | .06 | | | .07 | .08 | (NS) | .06 | .10 | (0.10) | | | | 75 | (43) |
| Water (work) (ng/ml) | Chloroform | 94.6 | (0.01) | 27.1 | | 40.0 | 68.0 | (NS) | 83.9 | 30.6 | (0.05) | | | | | 45 | (1) |
| | *1,1,1-Trichloroethane* | .15 | (NS) | .08 | | .06 | .25 | (.05) | .10 | .13 | (NS) | | | | | 45 | (25) |
| | Bromodichloromethane | 16.0 | (0.10) | 8.2 | | 10.6 | 12.5 | (NS) | 17.6 | 7.9 | (0.05) | | | | | 45 | (1) |
| | *Trichloroethylene* | .05 | (0.05) | .15 | | .08 | .09 | (NS) | .10 | .07 | (NS) | | | | | 45 | (22) |
| | Tetrachloroethylene | .07 | (NS) | .11 | | .11 | .08 | (NS) | .10 | .08 | (NS) | | | | | 45 | (23) |

[a] Significance level of the test of the difference between geometric means. NS = not significant.

[b] ( ) = Number of samples below LOD or at trace levels. (In general, data are based on only nine respondents and should not be extrapolated to larger populations.)

TABLE 10
ESTIMATED MEAN DAILY AIR EXPOSURES OF TWELVE SUBJECTS TO FOUR VOLATILE ORGANICS

| Subject | Occupation | N[b] | Mean daily air exposure, μg (%)[a] | | | |
|---|---|---|---|---|---|---|
| | | | 1,1,1-Trichloroethane | Tetrachloroethylene | Trichloroethylene | Chloroform |
| 1 | Statistician | 10 | 360 (100) | 160 (100) | 14 (100) | 25 (16) |
| 2 | Statistician | 10 | 120 (100) | 72 (100) | 12 (97) | 33 (22) |
| 3 | Statistician | 10 | 55 (99) | 72 (100) | 15 (97) | 73 (37) |
| 4 | Activities coordinator | 9 | 210 (100) | 78 (100) | 48 (99) | 82 (46) |
| 5 | Oil plant worker | 9 | 110 (100) | 78 (100) | 66 (100) | 38 (34) |
| 6 | Oil plant worker | 10 | 910 (100) | 340 (100) | 140 (100) | 53 (39) |
| 7 | Housing inspector | 4 | 720 (100) | 60 (100) | 77 (100) | 32 (17) |
| 8 | Chemical plant operator | 8 | 86 (98) | 100 (95) | 21 (87) | 61 (44) |
| 9 | Chemical plant operator | 9 | 130 (100) | 92 (100) | 120 (100) | 45 (37) |
| 10 | Police officer | 4 | 54 (100) | 24 (100) | 14 (100) | 31 (14) |
| 11 | Police officer | 8 | 1000 (100) | 450 (100) | 170 (100) | 7 (5) |
| 12 | Sewage treatment operator | 9 | 680 (100) | 610 (100) | 300 (100) | 260 (70) |
| Mean | | | 370 (99.8) | 178 (99.6) | 83 (98.3) | 62 (32) |
| Standard deviation | | | 357 (0.6) | 186 (1.4) | 87 (3.7) | 66 (18) |

[a] Percentage of total exposure provided by air only, calculated by $\frac{1}{N}\sum \frac{\text{Exposure in air} \times 100}{\text{(Exposure in air plus exposure in water)}}$

[b] Number of days sampled.

## DISCUSSION

### *Review of Previous Studies*

Although a number of investigators have measured these or similar chemicals in ambient air (Brodzinsky and Singh, 1982) or in drinking water (Boland, 1981), few have measured individual exposures in breathing-zone air and drinking water simultaneously. The first such effort occurred in March 1979 (Wallace *et al.*, 1982; Zweidinger *et al.*, 1982). Eleven college students at Lamar University in Beaumont, Texas and six students at the University of North Carolina carried personal monitors for 5–9 hr, collected drinking water samples, and gave breath, blood, and urine samples to be analyzed for 15 volatile organics. Findings included high frequencies of detection for seven chemicals in air and wide variability in exposures. Later studies were carried out for benzene in Houston and St. Louis (Zweidinger *et al.*, 1980) and for a number of volatiles in Baton Rouge/Geismar, Louisiana, in Houston, Texas, and in Greensboro, North Carolina (Pellizzari *et al.*, 1983). Field work in the large-scale follow-up to the pilot study described here has been completed on 362 volunteers in Bayonne and Elizabeth, New Jersey, 25 in Greensboro, North Carolina, and 25 in Devils Lake, North Dakota (Wallace *et al.*, 1983).

A major finding of the last two studies has been the significantly higher frequencies of detection and concentrations of these chemicals in personal air samples than in simultaneous outdoor samples. For example, 90% of personal air samples in Greensboro had detectable levels of chloroform compared to only 40% of the outdoor samples. Similar significant differences were noted for benzene, styrene, 1,1,1-trichloroethane, bromodichloromethane, trichloroethylene, *para*-dichlorobenzene, and trichlorobenzene isomers in Greensboro, Baton Rouge/Geismar, and Bayonne/Elizabeth. Thus reliance on outdoor ambient air sampling may grossly underpredict the frequency and severity of exposure to these toxic and carcinogenic compounds, which have a number of indoor and in-transit sources.

One previous study of exhaled breath (Krotozynski *et al.*, 1979) has provided valuable baseline information on concentration ranges in Chicago residents.

Two field studies of volatile organic levels in food have appeared. One (Pearson and McConnell, 1975) dealt with foodstuffs in the United Kingdom; the other (Bauer, 1981) dealt with levels in ambient air, water, food, and human tissue in West Germany. Volatile organic levels in the U.K. foodstuffs tended to agree in the aggregate with levels found in this study; however, West German levels of chloroform in drinking water were far lower, and tetrachloroethylene in food (particularly pork sausage) far higher, than the levels reported here.

### *The Present Study*

*Air.* From Table 5, we find that 46 chemicals were present in at least half of the air samples selected for broad-scale analysis; and 16 were present in all samples. Thus it is clear that these urban and suburban subjects were inhaling a complex mixture of compounds including known human carcinogens, animal car-

cinogens, mutagens, and cocarcinogens. The significance with respect to health of inhaling these compounds at low levels for long periods of time is not known.

Distributions of most compounds were closer to log normal than normal, as determined by the Kolmogorov–Smirnov modified *D*-statistic. The five compounds with the highest geometric mean concentrations for the 12 respondents were 1,1,1-trichloroethane (8.6 $\mu g/m^3$), tetrachloroethylene (6.3), trichloroethylene (2.3), chloroform (1.9), and carbon tetrachloride (1.3).

The relative concentrations in air of the three most prevalent compounds were the same for the North Carolina subjects as for the New Jersey subjects (Figs. 7 and 8). In both cases, the highest concentrations were, in descending order, 1,1,1-trichloroethane, tetrachloroethylene, and chloroform.

*Breath.* From the broad-spectrum analyses of 12 breath samples, 37 chemicals were present in at least half the samples, and 8 were present in all samples. These figures prove that many, probably most, of the chemicals being inhaled or ingested are in fact crossing the body membranes into the blood stream.

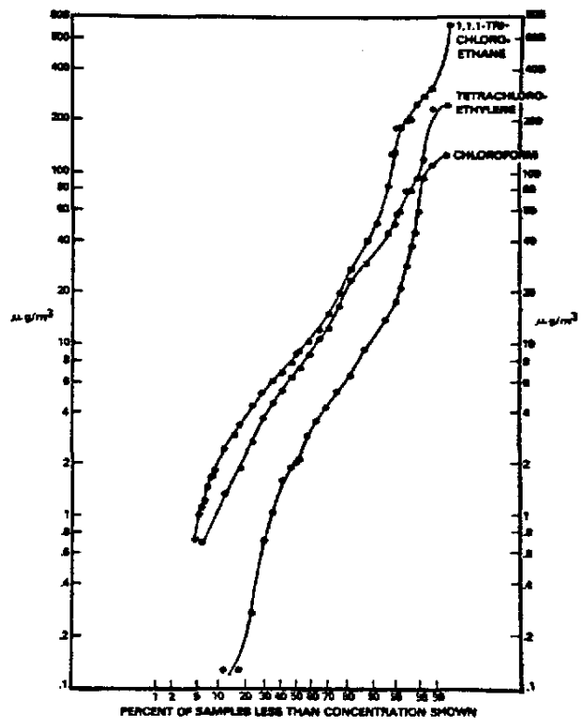


FIG. 7. Cumulative frequency distributions of three volatile organics in air in New Jersey, plotted on log-normal probability paper, of 8-hr exposures for the New Jersey residents ($N$ = 170) show 1000-fold ranges.

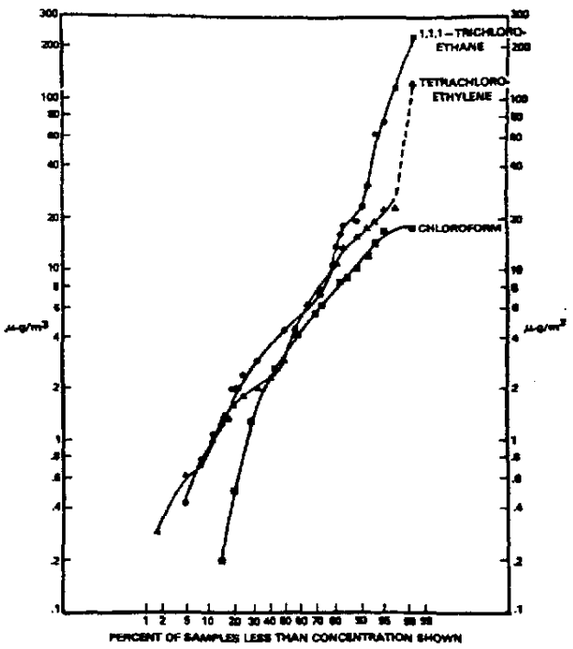


FIG. 8. The frequency distribution of three volatile organics in air in North Carolina indicates that exposures of the North Carolina residents have a similar range to those of the New Jersey residents.

Again the observed distributions of the chemicals were closer to log normal than normal, as judged by the Kolmogorov–Smirnov modified *D*-statistic.

No significant difference was observed between the breath concentrations of three chemicals measured before and after dinner. This is further indication that food was not an important source of volatile organics for the subjects tested.

The four chemicals with the highest geometric mean concentrations were tetrachloroethylene (7.9 $\mu g/m^3$), chloroform (4.5), 1,1,1-trichloroethane (2.6), and trichloroethylene (0.7).

The relative breath concentrations of the three most prevalent compounds were sharply different for the North Carolina subjects from the New Jersey subjects (Figs. 9 and 10). Chloroform, which showed the lowest concentrations of the three chemicals in air in both locations, and was also the lowest in the breath of the New Jersey subjects, was highest in the breath of the North Carolina subjects. The five highest values occurred during the second trip, which (unfortunately) was the only time that drinking water concentrations were not measured.

Spearman correlation coefficients were calculated for all possible pairs of the chemicals in air and in breath for the New Jersey subjects. The three strongest correlations for both air and breath were between trichloroethylene, tetrachlo-

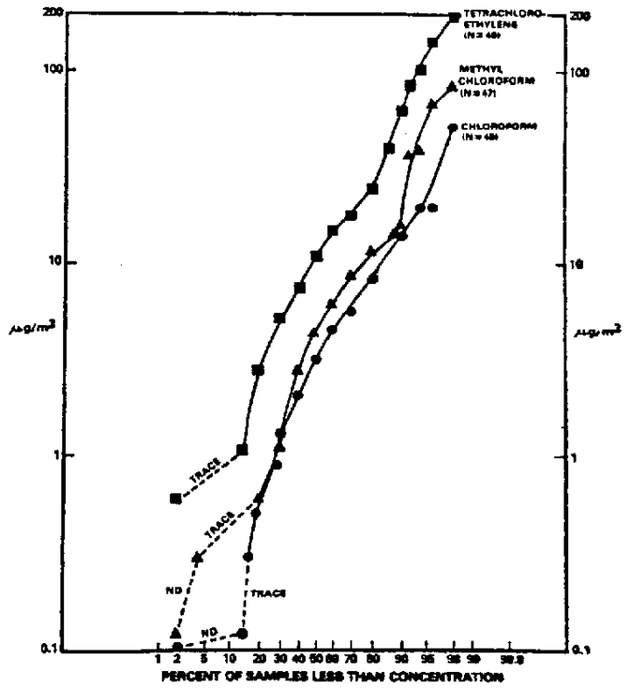


FIG. 9. Concentration levels of three volatile organics in exhaled breath in New Jersey paralleled the air exposures.

roethylene, and 1,1,1-trichloroethane (Table 11). These correlations suggest a common source for at least a portion of the subject's exposures to these solvents. The lack of significant correlations between chloroform and the other chemicals in air or in breath is further indication of the essentially dissimilar exposure pathways for chloroform compared to the other three prevalent volatile organics.

*Water.* The subjects' tap water, drawn from municipal surface water supplies, contained only two of the target chemicals in significant amounts: chloroform and bromodichloromethane, each of which contributed at least 75% of the subjects' total exposure to each chemical. Although several other halocarbons were present in more than half of the samples, their contribution to the subjects' total exposure was nearly always less than 1%.

*Food.* Chloroform and bromodichloromethane in beverages such as soft drinks may supply a significant fraction of the daily intake of these chemicals. The solid foods tested did not appear to contribute importantly to intake of any halocarbon. However, only four samples were tested for each of four food composites, so no general conclusions can be reached.

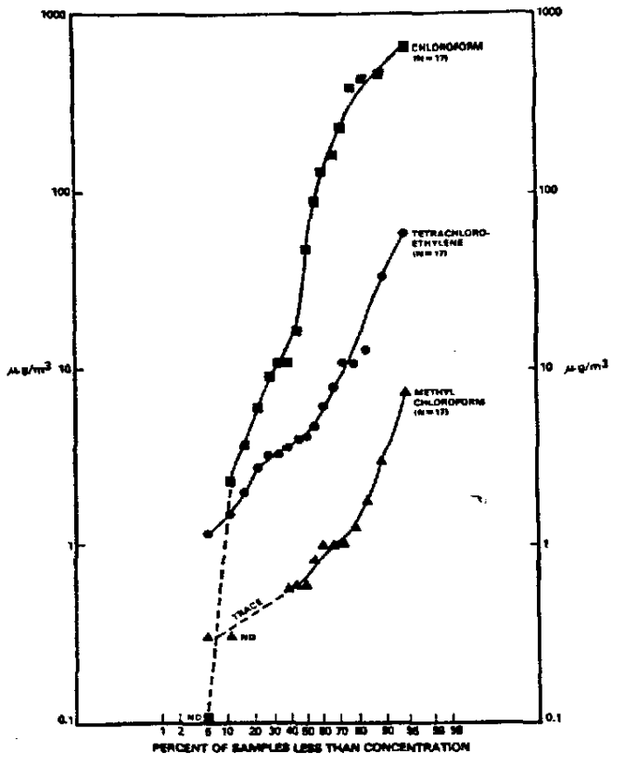


FIG. 10. Concentration levels of three volatile organics in exhaled breath in North Carolina showed high chloroform levels.

TABLE 11

*SIGNIFICANT ($P < 0.01$) SPEARMAN CORRELATIONS OF VOLATILE ORGANICS IN PERSONAL AIR AND BREATH OF NINE NEW JERSEY SUBJECTS*

| | | Breath ($N = 49$) | | Air ($N = 160$) | |
|---|---|---|---|---|---|
| Pollutant 1 | Pollutant 2 | *r* | *P* | *r* | *P* |
| Trichloroethylene | Tetrachloroethylene | .69 | 0.0001 | .68 | 0.0001 |
| Trichloroethylene | 1,1,1-Trichloroethane | .63 | 0.0001 | .60 | 0.0001 |
| Tetrachloroethylene | 1,1,1-Trichloroethane | .60 | 0.0001 | .58 | 0.0001 |
| Tetrachloroethylene | Carbon tetrachloride | .44 | 0.002 | — | NS |
| Trichloroethylene | Chlorobenzene | .41 | 0.004 | — | NS |
| Chloroform | Chlorobenzene | .41 | 0.004 | — | NS |
| Carbon tetrachloride | Trichloroethylene | .37 | 0.009 | .25 | 0.002 |
| Chloroform | Carbon tetrachloride | — | NS | .43 | 0.0001 |

## CONCLUSIONS

The following conclusions are based on several hundred environmental samples collected over a period of time from only 12 persons, and should not be extrapolated to larger populations.

(1) Monitoring individual air and water exposures and breath concentrations for a number of volatile organic compounds simultaneously proved feasible (provided careful attention is paid to sources of contamination, particularly benzene) and gave useful information on the concentrations encountered in normal daily activities.

(2) Six of the target compounds were found in more than half of the air and breath samples, but seldom or never in food or water. Two compounds were transmitted primarily through drinking water or beverages. None was transmitted primarily through food. Two target compounds (vinyl chloride and 1,1-2-trichloroethane) were virtually never found.

(3) Median concentrations in air and breath were usually in the 1–10 $\mu g/m^3$ range, but air concentrations were highly variable, with maxima exceeding 100 $\mu g/m^3$ for five chemicals. On the other hand, little day-to-day or person-to-person variability within a given geographic area was noted for trihalomethanes in drinking water, but a strong seasonal component was present, with summer values much greater than winter values. Beverages appeared to be an important route of exposure for chloroform and bromodichloromethane.

(4) Mean daily intakes of the four most prevalent chemicals were conservatively estimated to range from about 50 to 1000 $\mu g$/day for 1,1,1-trichloroethane, 25 to 600 $\mu g$/day for tetrachloroethylene, 10 to 300 $\mu g$/day for trichloroethylene, and 140 to 370 $\mu g$/day for chloroform.

## ACKNOWLEDGMENTS

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# Toxic chemical levels higher indoors than out

To the surprise of Environmental Protection Agency scientists, a five-year study has revealed that people are exposed to far greater concentrations of common toxic organic chemicals indoors than they are outdoors, even in cities where plants manufacture or use these chemicals. This finding, which has been confirmed by European studies, has vast implications for the way toxic pollutants are measured and regulated.

The study found that air is the main exposure route for the most commonly found 11 volatile organic chemicals. But contrary to general belief, people living in areas teeming with petrochemical, paint, or plastics processing plants are not subjected to greater exposures than are people living in less industrialized, or even rural, areas. The scientists reached this conclusion after studying 355 people in the highly industrialized cities of Bayonne and Elizabeth, N.J., 25 people in the lightly industrialized city of Greensboro, N.C., and another 25 in rural Devils Lake, N.D.

Using personal and stationary outdoor air monitors, the investigators found median indoor levels to be two to five times greater than median outdoor levels for the 11 volatile organic chemicals. At the highest exposures, indoor levels exceeded outdoor levels up to 70 times. Precise indoor sources of these pollutants are not known. The scientists, however, suspect building materials and consumer products.

The study's principal investigator Lance A. Wallace, a physicist in EPA's Office of Research & Development, says he "doesn't know whether the levels detected indoors cause cancer." However, he adds, one of the 11 chemicals, benzene, is a known human carcinogen, and five others are suspected cancer-causing agents. He suspects that the 11 may be contributing to the "sick-building syndrome" phenomenon. As buildings have become more airtight, complaints of sleepiness and general malaise have increased.

Wallace says that the National Aeronautics & Space Administration is an untapped repository for information on the contribution of materials to indoor air pollution. The agency has tested 10,000 materials used in the shuttle for their "off-gassing" characteristics. Because astronauts were experiencing the sick-building syndrome, NASA needed to know which materials were releasing volatile organic chemicals. Xylene, a toxic chemical at high concentrations and one of the 11 most often measured chemicals indoors, was detected by NASA in nearly 800 of the 10,000 materials tested. NASA found that marking pens released the highest levels of xylene, Wallace says.

In the EPA study, another of the

### Many toxic chemicals are prevalent indoors

**1,1,1-Trichloroethane,** solvent
**Tetrachloroethylene,** solvent
**Benzene,** paint, tobacco, gasoline
***o*-Xylene,** paint, gasoline
***m,p*-Xylene,** paint, gasoline
**Ethylbenzene,** paint, gasoline
**Carbon tetrachloride,** solvent
**Trichloroethylene,** solvent
**Chloroform,** tap water
**Styrene,** insulation, plastics
***p*-Dichlorobenzene,** moth crystals, deodorants

11 chemicals, benzene, was found to be 30 to 50% higher in the air of homes of smokers than in the homes of nonsmokers. Using a breath analysis technique developed for this study, smokers' breath was found to contain twice the concentration of benzene than did the breath of nonsmokers.

Wallace says one of the most significant findings of the EPA study is that "breath values are reflective of personal exposure" to toxic volatile organic chemicals. The test is simple, sensitive, noninvasive, but expensive—about $500 per sample. It would be most useful in monitoring the exposure of people to a chemical spill or release, especially when air monitors could not be used in a timely fashion.

The findings of the EPA study, known as the TEAM (total exposure assessment monitoring) study, have been replicated by European scientists using different methodology. Phillip J. Walsh, an environmental health scientist at Oak Ridge National Laboratory, reviewed the TEAM study protocols. He says TEAM "is a competent study, conducted by a competent team, so the results are probably valid results." A special review panel of EPA's Science Advisory Board (SAB) was even more positive.

After reviewing the TEAM study, the SAB panel wrote: "This series of studies, more than any other, provides compelling evidence of the necessity of evaluating total human exposure and of not basing exposure estimates on pollutant concentrations measured only by fixed-station monitors." At present, under the Clean Air Act and other relevant laws, epidemiological studies are designed, and regulations are set based on measurements from fixed-station monitors.

EPA staff director for SAB Terry F. Yosie says that Wallace and his TEAM collaborators "identified specific microenvironments and correlated human activity patterns with pollutant exposures." Since people spend up to 95% of their time indoors, and indoor air contains higher levels of 11 toxic chemicals than outdoor air, scientists are beginning to think that legislation ought to be drafted to reflect these realities.

*Lois Ember, Washington*