

Lawrence Berkeley National Laboratory

Recent Work

Title

REAL-TIME PORTABLE ORGANIC VAPOR SAMPLING SYSTEMS: STATUS AND NEEDS

Permalink

<https://escholarship.org/uc/item/4xb1886x>

Author

Daisey, J.M.

Publication Date

1987-03-01



Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE DIVISION

LAWRENCE
BERKELEY LABORATORY

NOV 30 1988

LIBRARY AND
DOCUMENTS SECTION

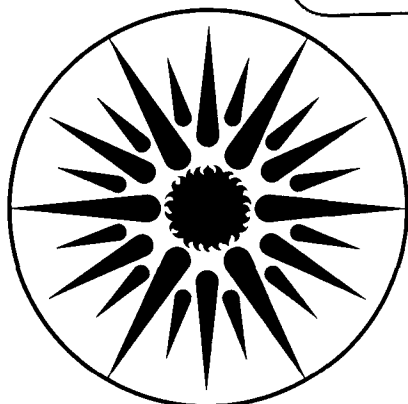
Presented at the American Conference of Governmental
Industrial Hygienists, Pacific Grove, CA, February 16-18, 1987,
and to be published in **Advances in Air Sampling**,
Lewis Publishers, Chelsea, MI (1988)

Real-Time Portable Organic Vapor Sampling Systems: Status and Needs

J.M. Daisey

March 1987

TWO-WEEK LOAN COPY
*This is a Library Circulating Copy
which may be borrowed for two weeks.*



**APPLIED SCIENCE
DIVISION**

LBL-25808
c.2

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

Published by Lewis Publishers, Inc.
for the American Conference
of Governmental Industrial Hygienists

REAL-TIME PORTABLE ORGANIC VAPOR SAMPLING SYSTEMS: STATUS AND NEEDS

Joan M. Daisey

Indoor Environment Program
Applied Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

March 1987

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building and Community Systems, Building Systems Division, of the U.S. Department of Energy under Contract NO. DE-AC03-76SF00098.

Real-time portable organic vapor sampling systems: status and needs

JOAN M. DAISEY, Ph.D.

Indoor Environment Program, Applied Science Division

90-3058

Lawrence Berkeley Laboratory

Berkeley, CA 94720

INTRODUCTION

The term volatile organic compounds (VOC) is used to designate a wide variety of organic compounds which can exist in the gaseous phase at significant concentrations at ambient temperatures. It includes aliphatic and aromatic hydrocarbons, such as hexane and benzene, chlorinated hydrocarbons, such as vinyl chloride, oxidized hydrocarbons such as alcohols, ethers, ketones, aldehydes and esters and nitrogen-containing compounds, such as amines and diisocyanates. The compounds in this class include toxic agents which are irritants, neurotoxins, allergens, carcinogens and teratogens.

The VOC have uses as industrial solvents, as raw materials for the manufacture of synthetic materials and as components of consumer products. Widespread use of these compounds has resulted in exposure to industrial workers, to workers involved in clean-up of sites where these materials have been dumped, to office workers in buildings which are constructed of synthetic building materials, and to occupants of homes and schools. The nature of the VOC exposures to these diverse populations varies considerably. In industrial situations, workers are typically exposed to high concentrations of one or two known compounds. At toxic waste sites, a wider range of VOC at varying concentrations is encountered and the identities of the VOC are not always known *a priori*. In contrast to these exposures, workers in office buildings may be exposed to complex mixtures of than 20 or more VOC, each at a low concentration, but which taken in sum may be in the mg/m³ range. Because of the potential health effects of these exposures, there is a need for instrumentation to measure the concentrations, and sometimes the identities, of VOC in a range of environments.

Real-time portable sampling systems for volatile organic compounds sample, measure and directly read out or record the atmospheric concentrations of these compounds in the field, often continuously. The term portable is used here to describe an instrument that can be carried or moved by one person. Portable, real-time VOC instruments currently available range from small hand-held, relatively inexpensive (\$3-5K) devices that provide a generic measure of VOC or measure a single compound to infrared monitors which measure one or a few compounds and brief-case size portable gas chromatographs with a variety of detectors. The latter can separate and measure more individual VOC. Prices are generally in the \$12-15K range. Mobile gas chromatograph/mass spectrometer (GC/MS) systems have been included in this review though they are not portable as defined above. A number of these instruments are now available for field work and they provide compound identifications as well as concentrations. These instruments must be moved in a van or trailer. Prices range from \$50-400K.

There are a variety of applications for real-time portable and mobile sampling instruments. Portable monitors can be used to warn workers of dangerously high levels of toxic VOC in industrial settings and at toxic waste sites or to monitor for compliance with regulations or commonly accepted standards. They can be used in surveys of toxic waste sites, to locate leaks in an industrial plant, to trace pollutant plumes and to define safe zones in an accidental release of VOC. These applications generally involve monitoring for a limited number of known compounds present at relatively high concentrations.

More recently, a demand had developed for instruments with greater specificity and sensitivity. Such instruments are required in situations in which the identities, as well as concentrations, of the toxic compounds must be determined or in which there are exposures to more complex mixtures of VOC, such as at toxic waste sites. Instruments with greater specificity and sensitivity are also needed for research.

Applications in research include more long-term investigations of the nature, sources and transport of VOC at toxic waste sites and investigations of indoor air pollution.(1) Real-time instruments may be useful in efforts to determine the causes of "sick-building syndrome" in which workers in newly constructed or renovated buildings experience a variety of symptoms, including headache, nausea, and mucous membrane irritation.(2) Breath analysis for biological monitoring in the field is yet another potential research application of more specific and sensitive VOC analyzers.

This paper reviews portable and mobile instruments that are commercially available for real-time VOC monitoring in field situations. Portable instruments for detecting explosive gases, such as methane, ethane, butane, etc., are not reviewed here but have been discussed by Nader et al.(3) A wide variety of detection systems have been used in portable VOC monitors including electrochemical and colorimetric detectors, thermal conductivity, flame ionization, photoionization and electron capture detectors, infrared and ultraviolet light spectrometers and quadrupole and ion-trap mass spectrometers. The instruments reviewed here have been grouped by the type of detection system used.

SAMPLERS WITH FLAME IONIZATION DETECTORS

The flame ionization detector (FID) is an almost universal detector for organic compounds with a sensitivity in the ppm range. In the FID, VOC with air is mixed with hydrogen and combusted to produce ions. A potential is applied across two electrodes and a current is produced which is then amplified. The current is proportional to the concentration of the VOC and the number of carbon atoms in the compound. The response is depressed by electronegative atoms such as O, S and Cl. The detector is insensitive to water, CO, CO₂ and NO_x but responds to most organic compounds and gives a linear response over orders of magnitude of concentration.

Flame ionization detectors are used in survey meters, primarily to locate areas of high concentrations or leaks, and in portable gas chromatographs. Table 1 presents examples of the instruments that are available. The AID Total Hydrocarbon Analyzer is a hand-held instrument which is used as a survey meter. This instrument detects VOC and low molecular weight hydrocarbons such as methane and ethane which are not generally included in

the VOC designation. Similar units are available from Foxboro; a gas chromatograph option available for Model OVA-128 provides greater specificity by separating the VOC. These instruments all have internal H₂ supplies which are required for FID.

Barsky and co-workers have evaluated the effects of 0 and 90% relative humidity on the detection of selected and aliphatic hydrocarbons and chlorinated hydrocarbons with the Century Model OVA-128 Portable Organic Analyzer (Foxboro Analytical) and found that the linear dynamic range extended to at least 100 ppm at both 0 and 90% RH for most of the compounds investigated.(4)

SAMPLERS WITH PHOTOIONIZATION DETECTORS

In a photoionization detector (PID), a high energy ultraviolet lamp is used to ionize VOC in the air sample:



where $h\nu \geq$ the ionization potential of the molecule(s) of interest. The ionized sample produces an ion current proportional to mass. The lamps used in these devices ($h\nu \approx 10 - 11$ eV) do not ionize major components of air such as O₂, N₂, CO, CO₂ and H₂O but are energetic enough to ionize many VOC. Interferences from more abundant hydrocarbons such as methane and ethane are minimized by selecting a lamp which does not emit photons of a high enough energy to ionize these compounds. By utilizing lamps with different photon energies, the detector can be modified for almost universal or more selective detection. In contrast to instruments with FIDs, an internal H₂ supply is not required for the PID detector. Barsky and co-workers have reported that 90% RH appears to decrease the response of the 10.2 eV lamp PID by a factor of two for most compounds tested, relative to the response under dry conditions.(4)

The sensitivity of the PID ranges from less than a ppb to ppm levels and varies with compound. Table II presents the ranges of molar responses for different classes of VOC, relative to benzene, which have been reported for the HNU 10.2 eV lamp.(5) Molar responses for the low molecular weight alkanes and alkenes and for aldehydes, ketones and esters tend to be lower than that of benzene. Classes of compounds containing aromatic rings, in general, give relative molar responses greater than one, sometimes as high as three. Within a class, lower molecular weight compounds tend to give lower responses than higher molecular weight compounds.

Table III presents examples of the many portable real-time VOC samplers which utilize PIDs. The simplest instruments are hand-held, battery operated samplers with a direct-read out of concentration on a dial or LCD display. Recorders can be attached to some of these instruments and some instruments incorporate audible alarms.

A number of portable GC instruments with PIDs are also available. These are generally the size of a brief-case or small suitcase and incorporate microprocessors for instrument control and for data handling. For most of these instruments, the GC is operated at ambient temperatures. Since this can result in variable retention times for the compounds under different conditions, the instrument should be calibrated in the field. Internal

calibrant gas is included in some instruments; e.g., the Photovac and Sentor. The Sentor GC has a temperature-controlled column that can be heated to 150°C and is available with electron-capture and argon ionization detectors as well as a PID.

PORTABLE GAS CHROMATOGRAPHS WITH OTHER DETECTORS

Portable GCs with other types of detectors are also available. The Sentor instrument is available with both an electron capture detector (ECD) and an argon ionization detector (Table III). The ECD detector is particularly sensitive to chlorinated compounds with a lower limit of detection of 0.01 ppb. XonTech, Inc. also makes a portable GC with a preconcentrator and an ECD or argon ionization detector. This instrument operates on a 12 volt battery or 120/220 VAC and has both audible and visual alarms. The operating range is reported to be 10 ppb to 100 ppm.

Portable GCs with thermal conductivity detectors (TCD) are available from Bendix Corporation and Microsensor Technology, Inc., as shown in Table V. The Micromonitor instrument is a modular instrument with up to 5 micro GC modules with TCDs.(6) The individual modules consist of a carrier gas regulation system, a sample injection system, reference and sample columns, thermal conductivity detectors, and electronics. The columns, capillary or packed, are etched on a silicon wafer and then sealed with a flat Pyrex glass plate. Sample volumes of 80 nL can be analyzed in about 45 sec. with the capillary column. The detector is an integrated TCD on a thermally isolated Pyrex glass membrane with a thermal time constant of 200 sec, reportedly capable of detecting 15 femtograms of pentane eluting from a capillary column. In order to minimize interferences due to co-eluting compounds, two separate columns are used and retention times on those columns are correlated using the microprocessor. If the peaks for a given compound are found at appropriate retention times on the two columns, the compound is considered to have been identified. Because of a number of technical difficulties with this system, Microsensor Technology, Inc. has temporarily halted production. They claim that the problems have been solved and that they expect to be back in production this year. (Personal communication)

Gas chromatographic instruments with FIDs, PIDs or other detectors have been developed to work best with specific analytes and must be calibrated accordingly. Although they can indicate the presence of high levels of unknown VOC, they cannot be used to identify the compounds present nor to give more than semi-quantitative information on the levels present in such instances. Nonetheless, these instruments are very useful in many field monitoring situations.

INFRARED VOC ANALYZERS

Infrared (IR) VOC analyzers detect and quantitate gases which absorb radiation in the spectral range of 2.5 to 15 μm . These instruments are based on the principle that the IR spectrum of each organic compound is unique. The IR spectrum of a compound is due to the absorption of infrared radiation to give energy transitions between vibrational and rotational energy levels of molecules in their ground electronic state. Many of the vibrational energy transitions observed in IR spectra are characteristic of certain functional groups. For example, the carbonyl functional group (C=O)

typically absorbs IR radiation of about 1700 cm^{-1} . The exact frequency will depend upon the particular compound as well as its state (gas, liquid, solid). Thus, IR spectra can provide structural information for unknown compounds or can be used to identify a compound if a spectrum has been reported for that compound.

Foxboro is the major manufacturer of portable instruments (Table IV). These instruments consist of a source, a circular variable filter to select IR radiation in different frequency intervals and a detector. Resolution with filters is typically about 10 cm^{-1} .

Detection limits depend upon the absorption coefficient of the compound at a given wavelength or frequency. IR absorption coefficients are typically several orders of magnitude lower than those for visible or ultraviolet absorption. In order to compensate for low IR absorption coefficients, portable instruments incorporate long (often variable) pathlength cells, typically about 1 to 20m. The long pathlength is achieved by multiple reflections between two mirrors. Sensitivities in the ppb to ppm range can be achieved in this way. A single wavelength is selected for monitoring a given compound. The wavelength selected for monitoring should ideally be one at which no other compound absorbs, although an instrument which has a microprocessor could correct for interferences from other compounds. Table VI presents the monitoring wavelengths, pathlengths and minimum detectable concentrations for several VOC for the Miran 1B portable Ambient Analyzer. The minimum detectable concentrations are typically well below the OSHA maximum allowable exposure (8 hour weighted average). Foxboro provides similar data for over two hundred compounds.

The simplest instruments, Models 101 and 103, use a fixed cell pathlength and are calibrated by the manufacturer for one (101) or a few (103) pre-selected compounds. The more complex instruments (Models 1A, 1B) provide variable pathlengths and variable wavelengths. These instruments can be used to scan the entire infrared spectrum of the air in a given location to provide a general picture of the contaminants present or can be used for quantitative monitoring at a one wavelength at a time. Model 1B incorporates a microprocessor which controls instrument parameters for sequential analysis of more than one compound.

The Miran IR portable monitors have been widely used in a variety of applications, ranging from industrial hygiene and toxic waste site monitoring to research in industrial hygiene and inhalation toxicology.

Their applicability for monitoring complex mixtures is limited. The infrared spectrum of a complex mixture of VOC is the sum of the spectra of the individual compounds (assuming there are no interactions among compounds, which is generally true for gaseous mixtures). For some simple mixtures, with a limited number of compounds, wavelengths can be found for each component at which there is little or no interference, for example, benzene and toluene (Table VI). For highly complex mixtures such as those which might be found in a "sick building" the interferences will be overwhelming and this type of instrumentation will not be applicable. Since conventional IR detectors are not as sensitive as FID and PID detectors, it is not practical to use these as gas chromatograph detectors to provide greater specificity.

MASS SPECTROMETERS

Mass spectrometers, in general, are very useful for the analysis of complex mixtures and provide great specificity and sensitivity. They are, however, very expensive instruments. In an electron impact (EI) mass spectrometer (MS), gas phase molecules at very low pressure are ionized by bombardment with accelerated electrons. The ions thus produced are accelerated by an electric field and passed through a magnetic field where they are separated according to their mass-to-charge ratio. Most commercial mobile instruments use a quadrupolar magnetic field to separate ions of different masses. The ion current at the collector is then amplified and a mass spectrum of ion current versus mass-to-charge ratio is obtained. These spectra are different for different compounds and can be used for identification and quantitation.

In chemical ionization mass spectrometry, a large excess of a second gas, such as methane or butane, is added to the ionization chamber. Most of the ions are produced from this secondary gas. These ions react with the analyte to produce secondary ions which are then separated and detected as in EI/MS. The chemical ionization (CI) mass spectrum differs from that produced in EI mode.

Several mass spectrometers have been developed for field studies and are described in Table VII. These instruments are mobile rather than portable, that is, they are designed to be moved and operated in a van or mobile laboratory. It should be noted that there are many instruments designed for laboratory use which also can be mounted in a mobile laboratory but the emphasis in the review is on instruments specifically designed for field use or instruments that are now being used in the field. The Bruker and VG Petra are rugged field instruments which do not include chromatographic columns. These instruments use membranes which are selectively permeable to organic compounds to provide the interface between the VOC at atmospheric pressure and the low pressure ionization chamber. Compounds are usually identified by monitoring selected peaks which are characteristic of the compounds of interest. These instruments are highly sensitive and can be used to detect picograms to micrograms of compounds (ppb to ppm range).

The Finnegan MAT 700 ITD is an ion trap MS detector coupled to a capillary GC. The ion trap detector is a three dimensional quadrupole which utilizes electrodes with hyperbolic inner surfaces. In conventional mass spectrometers, ions are formed in a source region and then injected into the mass analyzer. In the ion trap, ionization and mass analyses occur in the same place. Thus, no tuning is required and the instrument is simpler, in principle, to operate. This instrument is finding use in mobile laboratories.

The Sciex Trace Atmospheric Gas Analyzer (TAGA) can analyze gases at atmospheric pressure in real time, is highly sensitive and is designed to be used in the field. The TAGA is a tandem triple quadrupole mass spectrometer that uses sampled air as a chemical ionization reagent gas and measures either positive or negative ions. (7) In positive mode, nitrogen in air is ionized, which in turn transfers its charge to O_2 . The O_2^+ ion clusters with water vapor in the air and ultimately forms the hydrated proton H_3O^+ $(H_2O)_n$ which then ionizes the VOC in the sample with little or no fragmentation. The VOC parent ions thus produced are isolated by the first

filtering quadrupole and focused into a collision chamber with argon gas. Collisions between the parent ions and the argon cause fragmentation into daughter ions which are then separated by a second filtering quadrupole. The filtering quadrupoles are set to isolate the parent and daughter ions characteristic of a given compound. By sequentially monitoring for selected ion pairs, it is possible to analyze the air for several compounds in a semi-continuous mode while also reducing the risk of false positives. A full set of measurements of multiple VOC can be obtained every few seconds. Certain isomers which give the same parent and daughter ions cannot be distinguished since there is no GC separation. Since ambient air is used in this instrument, the response factors for VOC vary with changes in humidity and must be redetermined at regular intervals throughout the sampling period.

OTHER PORTABLE VOC MONITORING INSTRUMENTS

There are a number of inexpensive portable instruments which can be used to monitor specific compounds in situations in which there are no significant interferences from other VOC. Some examples are given in Table VIII. MDA Scientific, Inc. markets a pocket-size monitor for formaldehyde which uses an electrochemical fuel cell with two platinum electrodes. Formaldehyde is oxidized at one electrode and an electrical current is produced. The current charges the cell to a voltage which is proportional to concentration. This instrument has been reported to be linear over the range of 0.4 to 8ppm formaldehyde with an accuracy of $99 \pm 20\%$ over this range. (8) The lower limit of detection is 0.3 ppm. Positive interferences have been reported from methanol, styrene, 1,3-butadiene and SO_2 . (8) Interferences from phenol, resorcinol, formic acid and furfuryl alcohol were reported for an earlier model. (3) A special filter is now available to minimize phenol interferences.

Sunshine Scientific Instruments markets a portable monitor which can be used for certain VOC, such as benzene, acetone and toluene, that absorb ultraviolet light of wavelength 253.7 nm. The VOC being monitored must be known and the atmosphere must be free of any other species which absorb or scatter (e.g., particles) ultraviolet radiation at this wavelength. The limit of detection depends upon the absorbency index of the compound at 253.7 nm.

CEA Instruments, Inc. manufactures a portable instrument for continuously monitoring formaldehyde, which can also be converted for other VOC such as ethylene oxide and phenol. The TGM 555 is an automated wet chemical, colorimetric analyzer which uses the pararosaniline procedure for formaldehyde. Air is continuously drawn through a sodium tetrachloromercurate solution with sodium sulfite. Acid bleached pararosaniline is mixed with this solution using a peristaltic pump and the intensity of the resultant color is measured at 550 nm and displayed on a digital readout. A recorder output is also provided. Matthews has reported that with a series of minor modifications to the operational protocol and experimental design, the Model 555 analyzer can be used for formaldehyde monitoring at the sub - 0.15ppm levels typically found in homes. (9) Phenol can be monitored using 4-aminoantipyrine method (0-0.1ppm, adjustable to 0-10ppm) and ethylene oxide with the periodate/PRA procedure (0-1.0 ppm, adjustable to 0-25ppm).

FUTURE NEEDS

A range of portable and mobile instruments are currently available on the market for real-time monitoring of VOC. In selecting an instrument for a particular application, the needs for specificity, accuracy and sensitivity as well as response time must be kept in mind. The field conditions under which the instrument will be used must also be considered, such as, humidity and temperature extremes, and accessibility of the sampling area. Instruments which provide greater portability and reliability and reduce or eliminate the influences of temperature and humidity would clearly be welcome.

There is a need to develop personal monitors which can be used to monitor one or more VOC in industrial settings and can provide information on the time variation in concentrations as well as integrated measures of exposure. These would be useful for monitoring highly toxic VOC and in identifying work activities that lead to high exposures. Such instruments would also have many research applications.

There is increasing recognition of situations in which VOC exposure involves complex mixtures of many compounds. In some such instances, a semi-quantitative measure of total VOC is sufficient. However, there is often a need to identify as well as quantify the individual VOC in the mixture. At present, mass spectrometers are the only instruments which can provide identification. Truly portable GC/MS would be useful in such instances.

Gas chromatography - Fourier-transform infrared spectrometry (GC-FTIR) is being used increasingly in the laboratory for analysis of complex mixtures. (10,11) The FTIR spectrometer is based on interferometry rather than dispersion of infrared radiation. A computer is then used to transform the interferogram into an infrared spectrum. These instruments are much more sensitive than dispersion instruments and IR spectra can be obtained from nanograms to microgram quantities. Structural information can be obtained for unknown compounds. Infrared spectra can be used for compound identification, as are mass spectra, provided the spectrum of a given compound in the library. One advantage of such instrumentation is that a high vacuum is not required. At present, the instrumentation is not portable, although such instruments can be moved on carts and possibly portable instruments will be developed.

Existing instruments for real-time monitoring of VOC are gaining use in a variety of situations and it is likely that the need for such instruments will increase in the future. Despite their increasing use, there have been few instances in which the performance of these instruments has been critically evaluated. There is a need to systematically evaluate instrument performance and to provide guidance for appropriate applications. This is an area in which ACGIH can play a role.

ACKNOWLEDGMENT

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building and Community Systems, Division of the U.S. Department of Energy under contract No. DE-AC03-76SF00098. The use of trade and product names does not imply endorsement. The comments and suggestions of A.T. Hodgson, D.T. Grimsrud and J.R. Girman on this manuscript are gratefully acknowledged.

REFERENCES

1. Blanchard, R.D. and J.K. Hardy: Continuous Monitoring Device for the Collection of 23 Volatile Organic Priority Pollutants. Anal. Chem. 58: 1529-1532 (1986).
2. World Health Organization: Indoor Air Pollutants, Exposure and Health Effects Assessments. Euro Reports and Studies, No. 78, Working Group Report, Nordlinger, Copenhagen (1982).
3. Nader, J.S., J.F. Lauderdale and C.S. McCammon: Direct Reading Instruments for Analyzing Airborne Gases and Vapors. Chapter V In: Air Sampling Instruments for Evaluation of Atmospheric Contaminants, 6th ed., P.J. Liroy and M.J.Y. Liroy, Eds., pp. VI - VII8, American Conference of Governmental Industrial Hygienists, Cincinnati, OH (1983).
4. Barsky, J.B., S.S. Queltee and C.S. Clark: An Evaluation of the Response of Some Portable, Direct-Reading 10.2 eV and 11.8 eV Photoionization Detectors and a Flame Ionization Gas Chromatograph for Organic Vapors in High Humidity Atmospheres. Am. Ind. Hyg. Assoc. J. 46: 9-14 (1985).
5. Langhorst, M.L. Photoionization Detector Sensitivity of Organic Compounds. J. Chromatog. Sci. 19:98-103 (1981).
6. Saadat, S. and S.C. Terry: A High-speed Chromatographic Gas Analyzer. Am. Lab. (May): (1984).
7. Lane, D.A., T. Sakuma and E.S.K. Quan: Real-time Analysis of Gas Phase Polycyclic Aromatic Hydrocarbons Using a Mobile Atmospheric Pressure Chemical Ionization Mass Spectrometer System, In: Polynuclear Aromatic Hydrocarbons: Chemistry and Biological Effects, A. Bjorseth and A.J. Dennis, eds., pp. 199-215, Battelle Press, Columbus, OH (1980).
8. Coyne, L.B., R.E. Cook, J.R. Mann, S. Bouyuocos, O.F. McDonald and C.L. Baldwin: Formaldehyde: A Comparative Evaluation of Four Monitoring Methods. Am. Ind. Hyg. Assoc. J. 46:609-619 (1985).
9. Matthews, T.G.: Evaluation of a Modified CEA Instruments, Inc. Model 555 Analyzer for the Monitoring of Formaldehyde Vapor in Domestic Environments. Am. Ind. Hyg. Assoc. J. 43:542-552 (1982).
10. Griffiths, P.R.: Fourier - Transform Infrared Spectrometry. Science 222:297-302 (1983).
11. Griffiths, P.R., S.L. Pentoney, Jr., A. Giorgetti and K.H. Shafer: The Hyphenation of Chromatography and FT-IR Spectrometry - Anal. Chem. 58: 1349A - 1364A (1986).

Table I. Examples of Portable Real-Time VOC Samplers with Flame Ionization Detectors.

Instrument	Description	Detection Range, ppm (as CH ₄)
AID Portable Total Hydrocarbon Analyzer	Survey instrument, 2 units 10 x 21 x 25 cm, 15 x 16 x 10 cm 6.4 kg, rechargeable internal H ₂ supply, operates 8 hr on a battery; alarm; recorder may be connected	Model #710: 0.1-2,000 Model #712: 1.0-20,000
Foxboro Century Organic Vapor Analyzers	Survey instrument, 22 x 30 x 11 cm, 4.1 kg. plus probe/readout assembly, 0.9kg, rechargeable internal H ₂ supply, audible alarm; operates 8 hr. on battery; gas chromatograph option (OVA 108 and 128)	Model OVA 88: 1-100,000 Model OVA 108: 1-10,000 Model OVA 128: 0-10, 0-100, 0-1,000

Table II. Molar Response of the Photoionization Detector to Various Classes of Organic Compounds Relative to Benzene^a.

Organic Compound Class (n) ^b	Relative Molar Sensitivity
C ₆ - C ₂₂ Alkanes (straight, branched and cyclic) (31)	0.011 - 1.13
C ₇ - C ₁₉ Alkenes (16)	0.51 - 1.17
C ₄ - C ₉ Aldehydes (6)	0.30 - 0.53
C ₃ - C ₉ Ketones (28)	0.35 - 0.82
C ₄ - C ₁₂ Alcohols (10)	0.023 - 0.36
C ₄ - C ₁₄ Esters (20)	0.01 - 0.82
C ₇ - C ₁₆ Aromatic Hydrocarbons (13)	1.09 - 1.69
Chlorobenzenes (Cl ₂ - Cl ₈) (10)	1.20 - 1.44
Chlorophenols (Cl - Cl ₅) (19)	1.14 - 1.47
Polychlorinated Biphenyls (10)	2.18 - 2.96
Phthalates (5)	0.56 - 1.78
Polycyclic Aromatic Hydrocarbons (2-4 rings) (12)	1.88 - 3.08

a. From Langhorst (1981), using HNU PID (10.2 eV lamp)

b. Number of compounds tested.

Table III. Portable Real-Time VOC Samplers using Photoionization Detectors.

Instrument	Description	Detection Range, as benzene
HNU Systems Photoionization Analyzer	28 x 13 x 21 cm, 3.6 kg, with sensor (25 x 6 cm); battery operated (8hr); meter readout; 0-10 mV recorder jacks available	LLD:* 0.2ppm Ranges: 0-20, 0-200, 0-2000 ppm
AID Portable Organic Vapor Analyzer	7.6 x 22.8 x 25.4 cm, 3.75kg; battery operated (8hr), alarm, liquid crystal display, optional strip chart recorder Limited specificity; precision/accuracy ± 0.1 ppm, 2 sec. and 5 sec response times	Model #580 (500 ml/min): 0.1 - 2000 (ppm) Model #585 (50 ml/min): 0.1 - 10,000 ppm
AID Organic Vapor Meter Model 910	23 x 43 x 46 cm, 11.8 kg, sampling rate variable up to 4 l-min ⁻¹ ; for stationary use, strip chart recorder, LED display; low and high level alarms	10eV lamp - 0.1 - 2000, accuracy/precision ± 0.1 ppm; response time depends on flow rate
Photovac 10S Portable Air Analyzer	46 x 33 x 15 cm 11.8 kg; includes a GC column operating at ambient temperature and a computer programmable for continuous monitoring, TWA, peak levels; strip chart recorder, printer/plotter and digital data displays; battery operated; internal gas cylinder for calibration; optional alarm	0.1 ppb to ppm range
Sentex Sentor	14 x 46 x 46 cm, 13.6 kg; includes a GC column (4' x 6') that can be heated to 150°C, a sampling loop, microprocessor controlled; monitoring for up to 16 compounds; hard-copy print out of concentration and R.T. for 4 compounds per request; LCD display of chromatogram; automatic calibration at requested frequency.	LLD:* 0.1 ppb
HNU Systems Model 301P	27 x 34 x 28 cm, 9.8 kg compact GC with 301P field pack, 12VDC power source (8 hr); isothermal operation, packed or capillary column; with line power, optional microprocessor available with printer and temperature programming upgrade.	LLD:* 0.1 ppb

*Lower limit of detection

Table IV Portable Gas Chromatographs with Thermal Conductivity Detectors

Instrument	Description
Micromonitor (Microsensor Technology Inc.)	Up to 5 micro GCs with thermal conductivity detectors. Individual modules are 5 x 10 x 11.4 cm and consist of sample injection system, sample and reference capillary columns, carrier gas regulators, detectors etched on a silicon wafer; LLD* = 15 fg pentane from capillary column; microcomputer; correlation chromatography confirms presence of gases simultaneously detected on different columns; LCD and printer.
Unico Portable GC (Bendix Corp.)	41 x 56 x 18 cm, 22 kg, internal He carrier detector (thermistors) gas supply heated columns and detector, (Corp.) recorder, 115 VAC, microvolume sampling valve; LLD* for benzene -89 ppm/ml, for perchloroethylene - 25 ppm/ml.

* Lower limit of detection

Table V. Miran Infrared Analyzers (Foxboro) for Volatile Organic Compounds

Instrument	Description	Application
Model 101 Specific Vapor Analyzer	47 x 14 x 15 cm, 8.2 kg; fixed cell path-length and wavelength; factory calibrated; meter read-out in ppm and percent; AC or battery operated	Measurement of a fixed single compound
Model 103 Specific Vapor Analyzer	10.4 kg; 13.5 m fixed cell pathlength; change of filter and meter scale set permits change in monitored gas; meter read-out in ppm/percent; factory calibrated; 3m sample hose; operated from power outlet; battery-inverted package available.	Measurement of one or more pre-selected compounds, one at a time
Model 1A General-Purpose Gas Analyzer	14 kg; 20 m gas cell with variable path-length; variable wavelengths; meter read-out in absorbance units; strip-chart recorder available; can be operated with battery or power supply; 30 m sample hose	Scan of IR range for a general picture of contaminants or monitoring of a single compound at a selected wavelength
Model 1B Portable Ambient Air Analyzer	12.7 kg; 20 m variable pathlength gas cell; LCD read-out of concentration or absorbance; microprocessor with keyboard used for automatic wavelength and path-length selection, storage of calibration and analysis data, table of >100 compounds for which analyzer is precalibrated; memory space for up to 10 user-selected compounds; audible alarm; internal battery (4 hrs.).	Scan of IR range for qualitative analysis or quantitation of one compound at a time at selected wavelengths.

Table VI Recommended Instrument Parameters and Detection Limits for Miran Infrared 1B Portable Ambient Air Analyzer for Several VOC

Compound	Wavelength μm	Pathlength m	Minimum Detectable Concentration, ppm	Maximum Allowable Exposure, weighted (8h)Av., ppm
Benzene	9.9	20.25	2.2	10
Ethylbenzene	9.8	20.25	3.0	100
Toluene	13.9	6.75	1.1	200
Xylene	13.1	20.25	1.9	100
Hexane	3.4	0.75	0.1	500
Octane	3.4	0.75	0.1	500
Formaldehyde	3.6	20.25	0.5	3
Acetaldehyde	9.3	20.25	1.1	200
Carbon Tetrachloride	12.7	20.25	0.08	10
Chloroform	13.0	6.75	0.10	50
Vinyl Chloride	11.3	20.25	0.8	1

Table VII Mobile Mass Spectrometers

Instrument	Description
Bruker Mobile Environmental Monitor	Electron-impact quadrupole MS with a 3.5 m capillary GC, programmable from 70-190°C; 70 x 70 x 60 cm (electronics unit) and 50 x 50 x 24 cm (control unit), 145 kg; battery or generator-powered; VOC sampled through a selectively permeable membrane; can monitor 20 compounds simultaneously, up to 8 ions per compound; series of full spectra or time curves of selected ion can be determined; video screen and printer; alarm; ppb to percent; can be remotely controlled and can transmit measurements.
VG PETRA Models SS, SM and SA	Electron-impact quadrupole MS; 80 x 72 x 57 cm (2 stacked units), 58 kg (SS), 64 kg (SM), 72 kg (SN); VOC sampled through a selectively permeable membrane; 200 amu scan; model SS - scan and single channel monitoring; model SM - scan and multi-peak monitoring, oscilloscope output; model SA - scan and multiple peak monitoring, Apple II microcomputer, video printer output and visual display.
Sciex TAGA 6000 E	Atmospheric pressure chemical ionization triple quadrupole MS/MS mounted in a large, air-conditioned/heated mobile laboratory; 10-1200 amu; data acquisition modes include scan-scan, parent ion scan, daughter ion scan, multiple reaction monitoring, synchronous (neutral loss/gain) scan, conventional ms scan, and multiple ion monitoring; DEC RSX-11M operating system, interactive graphics terminal and hard copy unit; can be interfaced with a G.C.

Table VIII Other Portable VOC Monitoring Instruments

Instrument	Description
Formaldehyde Mark II (MDA Scientific, Inc)	Pocket-size monitor with electrochemical fuel cell detector, battery operated, LCD digital read-out, 0.3 to 99.9 ppm, 20 sec response, $\pm 15\%$ accuracy and precision, special filters used to eliminate interferences from phenol; interferences methanol, ethanol, formic acid, acrolein from cigarette smoke
Instantaneous Vapor Detector (Sunshine Scientific Instruments)	Portable monitor (13 x 10 x 43 cm, 3.6 kg) detects aniline, benzene, alcohol, acetone, pyridine, toluene, etc by absorption of ultraviolet light; meter read-out, range is about 0.01 mg/m ³ ; battery operated
Toxic Gas Monitors TGM-555 (CEA Instru- ments)	Portable colorimeters in which a selected VOC (formaldehyde, ethylene oxide, or phenol) is absorbed in a liquid which is then mixed with a specific chemical reagent to yield a colored product; 51 x 41 x 18 cm, 13.6 kg, with rechargeable battery (12 hrs) and constant volume adjustable air pump; digital readout, optional recorder; 0.002 to 10 ppm (formaldehyde) $\pm 1\%$ reproducibility.

*LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720*